SHOE MODIFICATIONS IN LOWER-EXTREMITY ORTHOTICS*

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INTRODUCTION

The art and science of correcting foot deformities is still a mixture of tradition, artisan skill, clinical experience, and the prescribing doctor's professional convictions. Although it is the orthotist's duty to discuss with the orthopedist any questionable aspects of a prescription, it is obviously not his privilege to countermand the doctor's judgment in the matter.

It must also be understood that a foot deformity is not to be taken as an unalterable fact until all methods of relief, such as physiotherapy and surgery, have been fully explored. The orthotist must also appreciate the fact that the basic principles of foot correction have yet to be agreed upon by anatomists and orthopedists. Some specialists even dispute the location of the arches. In spite of controversy, however, the orthotist must properly implement the prescription as given him by the orthopedic surgeon, otherwise, his knowledge of shoe modifications will be of little value to the patient.

Not included in this presentation are the foot problems of the infant, the adolescent, and adult females. Based upon an intra-VA lecture, the material presented here quite naturally applies primarily to the adult male.

PURPOSE OF SHOES AND MODIFICATIONS

Originally shoes were a simple covering used to protect the foot from sharp stones and thorns and from the uncomfortable vagaries of the weather. As with other forms of body covering, it was not long before footwear became embellished with decorative effects and acquired a function in overall cosmesis and social acceptability. In terms of locomotion, however, the shoe is basically a means of weight transfer to the ground. Today's shoe, with its relatively light upper part, a stiff or thick sole and heel, and an almost flat insole and outsole, provides the normal foot with adequate support and purchase upon the ground.

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*Based principally on lecture presented at VA-training courses, New York University Prosthetics Courses, and other seminars.

With proper modifications, shoes can also be made to afford the *deformed foot* protection, cosmesis, and better balance for standing and walking. Indeed, the main purpose of all shoe modifications is the restoration of as normal a gait and weight-bearing pattern as is possible for the patient.

Shoe modifications are even more important when fitting the person who must wear a leg brace. A brace can be made to fit the patient beautifully and to function perfectly, but its effectiveness will be lost if the orthotist has overlooked the correct construction of the shoe or the factors necessary for functional weight-bearing. With a poor shoe foundation, the brace cannot be held in true alignment, and a leaning-tower-of-Pisa effect will result from the tendency of the foot and leg to tilt the brace in the direction favored by the residual pathology.

By redistributing body weight away from the sensitive areas of the foot to the nontender parts, the orthotist strives not only to relieve his patient of pain but also to achieve a well balanced weight-bearing pattern for him.

Ideally, weight bearing is distributed over the sole in a three-point pattern, i.e., upon the apex of the plantar surface of the calcaneus, upon the first metatarsal head, and upon the fifth metatarsal head (Fig. 1). For most of his orthopedic patients, however, the orthotist must resort to the judicious use of shoe modifications to achieve a three-point pressure pattern on the sole of the foot.

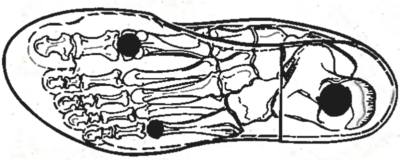

FIGURE 1. Three-point weight-bearing pattern of the normal foot (right foot, plantar view). Body weight is distributed evenly between the apex of the calcaneus and the first and fifth metatarsal heads.

The location, shape, and size of the modifications can be determined by temporarily taping or gluing components to an unmodified stock shoe. Observation of the gait pattern and examination of the shoe bottom for proper tread will indicate to the orthotist the need for any further changes. If extensive changes are necessary, orthopedic shoes should be recommended. Our concern here, however, is mainly with modifications that can be made with stock shoes that are available at almost any store.

SHOE CHECKOUT

Before applying any modifications, however, the orthotist should first check out the stock shoe (Fig. 2).

The stock shoe last should afford ample width from the metatarsophalangeal joints anteriorly to the ends of the distal phalanges to allow the greatest amount of toe prehension possible at pushoff. A comfortable but snug fit from the waist of the shoe to its heel is necessary for support and to prevent motion at the quarters during dorsiflexion. The straight inner border, or as it is sometimes referred to, the straight innerline combination last, affords these desired features. The term combination indicates that a wide or narrow heel width may be used with the appropriate ball width in order to achieve proper heel-to-ball conformity, e.g., many patients require a very narrow heel with a normal ball width, or vice versa. To allow foot elongation during ambulation, the distal end of the insole should extend ⅝ in. beyond the tip of the hallux.

Where there is a clawfoot or hammertoe condition, the last should be built up to provide pressure relief.

The outsole should be made of prime leather, about ¼ in. thick, and the heel should be about ¾ in. high and broad enough for stability.

The shoe should also include a steel shank that extends from midheel to the ball of the foot (Fig. 3). Proper placement and rigidity of the

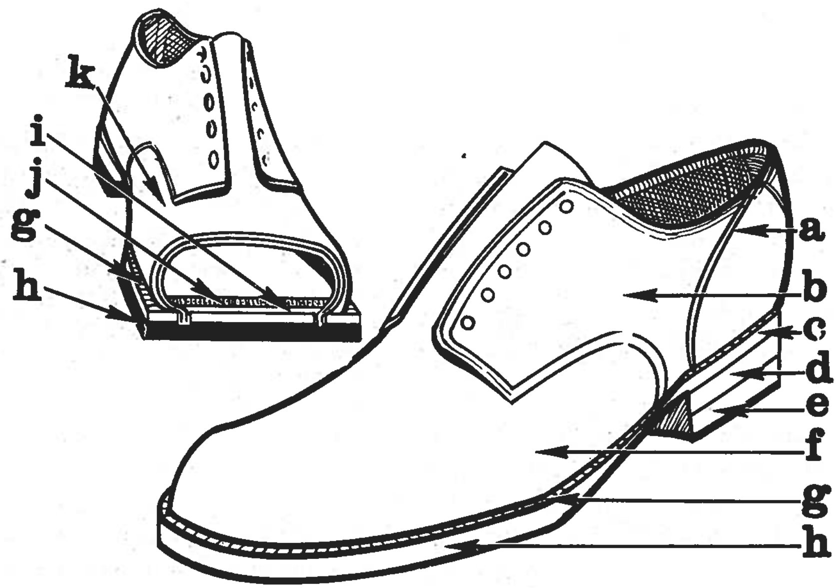

FIGURE 2. Parts of a shoe. (a) Foxing; (b) quarter; (c) heel seat; (d) heelbase; (e) heel; (f) vamp; (g) welt; (h) outsole; (i) filler; (j) insole; and (k) waist.

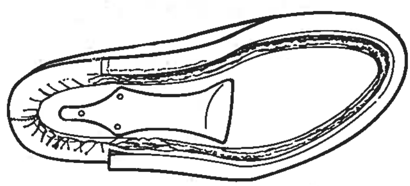

FIGURE 3. Steel shank placement.

shoe shank can be determined by holding the shoe in one hand and trying to dorsiflex it with the other. If the shoe bends at the break without too much depression behind that point, then the steel shank is correctly placed. With the shoe shank properly placed (¼–⅜ in. posterior to the break of the shoe), dorsiflexion of the shoe on the foot will be congruent to that of the metatarsophalangeal joints at rollover. If, however, the shoe shank is placed anteriorly to the break of a low-quarter shoe, dorsiflexion will force the quarters distally away from the foot, incurring a great degree of undesirable piston motion in gait; with the more extensive instep and ankle coverage of the chukka or high-quarter shoe, great pressure would be borne at the instep of the foot. If, however, the shoe shank is placed too far posteriorly from the break, dorsiflexion will force the longitudinal arch of the shoe to depress and the weight-bearing heel surface to shift toward the heel breastline. A footslap-type of gait in midstance, with possible depression of the medial and lateral longitudinal arches of the foot and ensuing pain, may result from those conditions. Placing the steel shank at the breakline would greatly shorten the life of the shoe since repeated dorsiflexion during ambulation would force the anterior edge of the shank to perforate the outsole.

For brace wearers, it is absolutely essential that a solid sole material be used. If crepe or composition rubber were used, the sole would compress under vertical load, introducing undesirable pseudo plantar flexion-dorsiflexion and varus-valgus motions. The shoe should also include a steel shank that extends from approximately midheel to the ball of the foot.

SHOE STYLES

The stock shoe comes in several styles, including the blucher, the bal, the chukka, and the convalescent or postsurgical-type shoe (Fig. 4). An understanding of the makeup of these various styles will help the orthotist in selecting the shoe that will be best for his patient's particular foot problems.

Blucher

The style of shoe that the orthotist most generally prefers his patient to wear is almost invariably the laced blucher with plain toe (Fig. 4a). The quarters of this shoe extend forward over the throat of the vamp, are loose at the inner edge, and lace across the tongue, affording easy access for the foot into the shoe. Whether the patient has a free or limited ankle joint, he should have the easy access which the blucher-style upper affords.

Bal

Although it has front lacing, the bal (Fig. 4b) does not afford easy access of the foot because the vamp is sewn over the quarters at the front of the throat. The bal is usually prescribed only when there is no foot pathology involved, as for example, in heel elevation, where leg shortening exists without foot or ankle deformity.

Convalescent Shoe

A special variation of the blucher, called the convalescent or surgical shoe (Fig. 4c), may be advisable after foot surgery or for the ankylosed foot. The convalescent shoe has lacing to the toes, and the toecap is formed by the extension of the tongue to the front of the outsole. Such a design provides easy entry for the foot that is spastic or that cannot be plantar flexed.

Since the patient with a stiff ankle joint or a completely ankylosed foot cannot plantar flex without pain, he must don his shoe almost vertically, with no moments toward plantar flexion. For such a patient, the convalescent high quarter with posterior closing is beneficial (Fig. 4d).

Shoe Uppers

The blucher and bal styles are available in both the low-quarter upper (1½ in. below the malleoli) and the high-quarter upper (about 2 in. above the malleoli). A shoe with a three-quarter upper that goes to the apices of the malleoli is called a chukka (Fig. 5). The broad coverage of the foot provided by both the chukka and high-quarter uppers helps to prevent piston motion during walking and so is excellent for limited or stiff joints. (Piston motion is the term used to describe the upward movement of the leg and foot working against the downward pressure of the brace and shoe during the swing phase of gait. This action can produce a very painful chafing of the calf.)

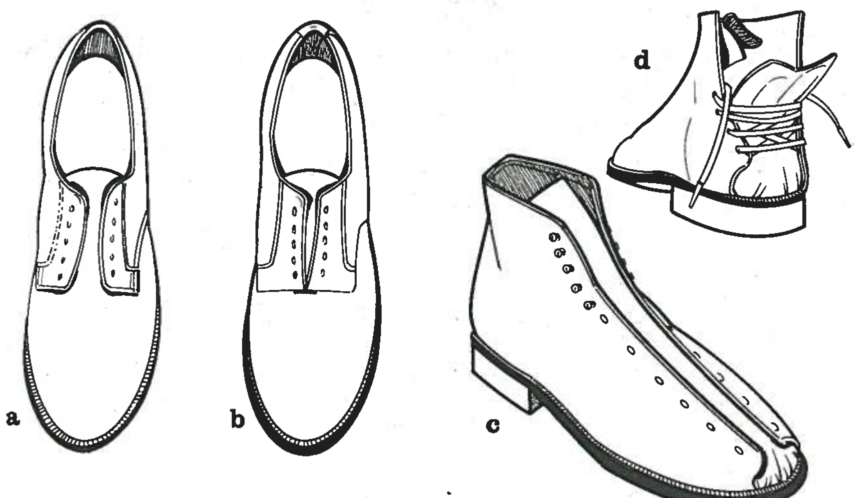

FIGURE 4. Shoe styles. (a) Blucher, (b) bal, (c) convalescent, and (d) convalescent with posterior closure.

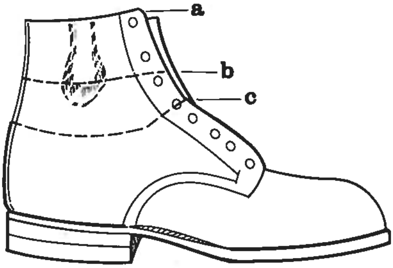

FIGURE 5. Shoe uppers. (a) High quarter, about 2 in. above malleoli; (b) chukka (three-quarter upper), at the apices of the malleoli; and (c) the low quarter, about 1½ in. below the malleoli.

The chukka with lacing (Fig. 6a) is particularly effective for a foot with scars that might be abraded by the top edge of a low-quarter shoe. The chukka with strap and buckle (Fig. 6b) is often recommended for patients with poor finger dexterity. A variation that further facilitates donning is the low quarter with a clip fastener tongue (Fig. 6c). When the tongue is pushed forward, the patient can don his shoe by using a long shoe horn or by pushing the toe tip against a wall. With his foot in the shoe, he need then only tap the clip tongue closed, where it will remain secure until pushed forward again for removal. Another variation that facilitates donning is the low quarter with elastic goring on the medial and lateral sides of the quarters. The use of elastic laces on the blucher-type low-quarter uppers with a long shoe horn will also help the patient with poor finger dexterity, or lack of hip flexion power, to don his shoes more easily.

Toe Design

The forepart of the shoe is designed in one of five variations: plain toe, moccasin, straight tip, wing tip, or **U**-tip (Fig. 7). The blucher and bal are available in all five styles, but the chukka is made in only three: the plain toe, straight tip, or the wing tip. The plain toe is the most practical type

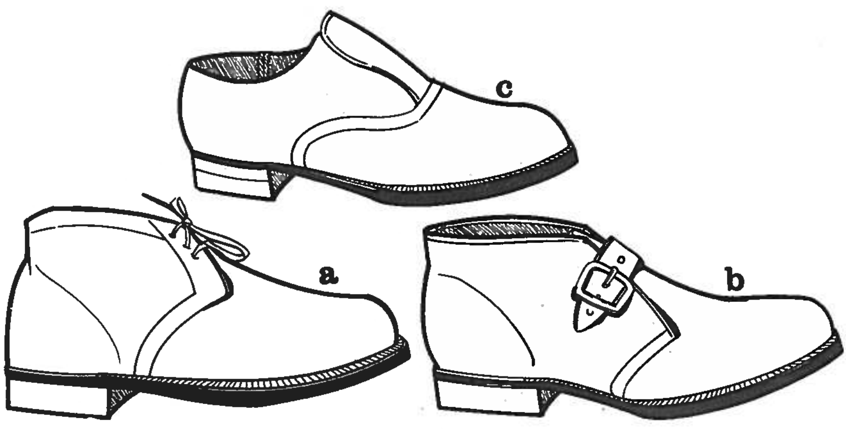

FIGURE 6. Fasteners. (a) Lacing, (b) strap and buckle, and (c) clip fastener tongue.

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for all orthopedic shoes since the absence of excessive stitching and overlays allows a smooth inner shoe surface, which reduces the possibility of foot abrasions. The other toe types are not generally recommended.

Although the plain toe and moccasin foreparts have no special decoration, the straight, wing, and U-tips may have pinking, medallions, perforations, or imitation foxing at the quarters. These designs are purely ornamental in function.

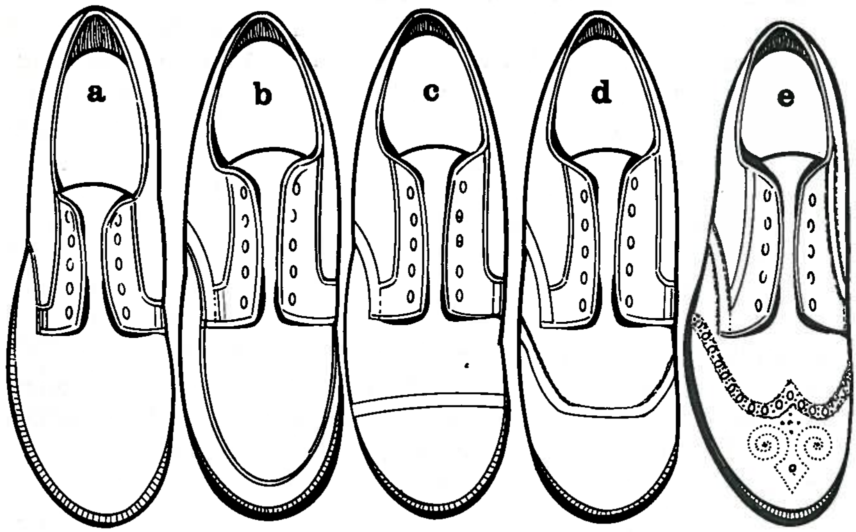

FIGURE 7. Toe designs. (a) Plain toe, (b) moccasin, (c) straight tip, (d) U-tip, and (e) wing tip.

ORTHOTIC DEVICE ATTACHMENT

In discussing orthotic device attachments, we refer to the orthotic device as a brace and the distal portion joining the shoe as the brace attachment. The choice of brace attachment is greatly affected by the type of outsole materials used on the shoe since the attachment and the shoe should be rigidly joined to each other. As previously mentioned, the shoe should have at least a 12-iron prime-leather sole to afford a sufficiently solid foundation for brace attachments. If rubber, Neolite, Neoprene, or crepe rubber soles are used, the joint of the components cannot be rigid since such resilient materials allow the brace attachment to move mediolaterally and anterioposteriorly, thus simulating inversion-eversion and plantar flexion and dorsiflexion. Even for the simplest leg, ankle, or foot pathologies, these characteristics are most undesirable.

The types of brace attachments most commonly used are the stirrup, caliper box, or footplates. These may be used as stiff-ankle joints with no motion, with limited motion, with solid or spring-loaded stops, or with free-motion ankle joints.

The stresses applied to the shoe through the brace attachment tend to distort the shoe, particularly in the longitudinal arch area. Since the stock shoes purchased by most patients usually contain inferior sole materials and either no shank, a wood shank, or a poor quality steel shank, proper reinforcement is necessary to prevent depression of the longitudinal arch.

Another cause for failure of the longitudinal arch of the shoe is the fact that many prefabricated shoe attachments have narrow tongues with insufficient area for selecting rivet locations (Fig. 8a). The orthotist is forced to rivet through the center of the steel shank causing a cross-sectional failure in a short time.

If the orthotist cannot prevail upon the manufacturer of prefabricated brace attachments to provide broadened tongue areas for these attachments, he can weld or braze a reinforcement plate over the tongue and heel of the regular attachment, shaping the tongue of the plate broadly (Fig. 8b). The broadened tongue affords sufficient area for the selection of rivet locations which will bypass the steel shank lying beneath, thereby eliminating possible perforation and failure of the steel shank.

The effects of shoe distortion caused by poor material or shank failure are obvious. When the longitudinal arch of the shoe depresses sufficiently, the patient may feel pain or discomfort in any or all of the tarsometatarsal and talocalcanealcuboid joints; the subtalar and tibiotalar joints may also be highly affected. To relieve this discomfort, the patient tends to flex his knee, reducing the stress on the brace and shoe but producing an undesirable gait characteristic.

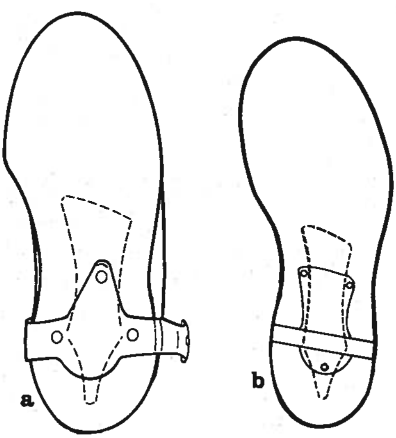

FIGURE 8. Brace attachment and its relationship to steel shank. (a) Prefabricated stirrup riveted to shoe; shank perforation. (b) Orthotist-modified caliper box riveted to shoe (shank unperforated at midportion).

It must also not be overlooked that in joining the heelbase and heel to the exposed outsole and brace attachment, the orthotist shoemaker generally drills holes into the attachment to assist in nailing. The holes are drilled close to the edges of the anterior radii formed by the stirrup uprights and that part of the stirrup in contact with the outsole. These points are normally vulnerable to vertical load and are drastically weakened by the holes. With limited-motion or rigid-stop ankle joints, a cross-sectional failure may be expected to occur at those points after a comparatively short period of wear.

To prevent such failures, epoxy cement or 4110 Laminac Resin may be used to join the heel and heelbase to the outsole and brace attachment without drilling holes through the latter. These two plastic resin cements are easy to apply with brush or dauber, and they hold the components securely to one another.

SHOE MODIFICATIONS

Let us now turn to shoe modifications. The purpose of shoe modifications is to restore, in so far as possible, foot balance in standing and walking. The goal is to achieve a pressure pattern on the sole of the foot in which the weight is distributed between the first and fifth metatarsal heads and the apex of the plantar surface of the heel.

If the foot has a normal calcaneus (not tilted anteriorly or posteriorly), its position in the shoe can generally be used as a reference point in placing modifications within the shoe. For the average person, this reference point is usually located at the midpoint of the heel.

The location and size of the shoe modifications required to achieve the optimum foot-pressure pattern can be determined by the temporary addition of components to the shoe. By observing the patient's gait pattern, with the temporary modifications in place, and then examining the bottom of the shoe, the orthotist can determine whether the modifications are satisfactory.

Internal and External Modifications

Insert and sandwich modifications are generally classified as internal components, and overlays are classified as external components (Fig. 9). An insert is placed over the surface of the insole and may be removable or permanently mounted. A sandwich is a component that is placed between the insole and outsole of the shoe; it may be sandwiched between the heelseat and the heelbase or between the heelbase and the heel. In either area, the sandwich is usually cemented or nailed into place. The solid steel shank is an example of sandwiching. An overlay is a component that is nailed or cemented to the bottom surface of the outsole.

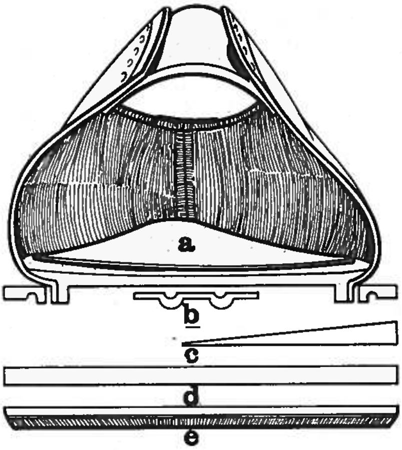

FIGURE 9. Metatarsal cross-sectional view of shoe and modifications. (a) Metatarsal pad insert; (b) steel shank, sandwich; (c) lateral sole wedge, sandwich; (d) outsole; (e) overlay, rocker bar.

MEDIAL LONGITUDINAL ARCH SUPPORT AND/OR LATERAL WEIGHT SHIFT

The following components are listed in the order of the amount of support they provide to effect medial longitudinal arch support and/or lateral weight shift:

Internal

1. Steel shank in shoe
2. Cookie insole and insert
3. Navicular (scaphoid) pad
4. Longitudinal arch support
5. Long counter on medial side

External

6. Orthopedic heel (Thomas)
7. Thomas heel wedge
8. Medial sole and/or heel wedge
9. Medial shank filler
10. Valgus strap

Foot Disabilities

Foot disabilities for which these components are used include medial pes planus, pes cavus, and valgus.

In *medial pes planus,* the medial longitudinal arch is depressed, causing the navicular bone to become prominent and the forefoot to abduct. In one type of pes planus, the foot is spastic with contracted tendons and ligaments. The characteristics of another type, flaccid pes planus, are a long slender foot with relaxed tendons and hypermobility of the articular surfaces of all the joints. For the relief of pes planus, support and/or elevation is necessary.

Pes cavus is characterized by medial and lateral longitudinal arches that are high or "hollow" because of shortened extensor tendons of the dorsum; the metatarsal arch, however, is depressed. This condition is often of congenital origin but may also be residual from poliomyelitis, multiple sclerosis, or cerebral palsy. Pes cavus requires support to prevent pain in moments toward depression of the longitudinal arches.

In *valgus* (eversion, Fig. 10a), the lateral aspect of the plantar surface of the foot is elevated with the medial longitudinal arch depressed; the subtalar and tibiotalar ankle joints lean and stretch at their medial ligamentous connections, causing the medial malleolus to protrude. This condition may be either spastic or flaccid and often requires both support and weight shift. Figure 10 illustrates the position of the ankle and heel when the foot is in valgus, normal, and varus positions.

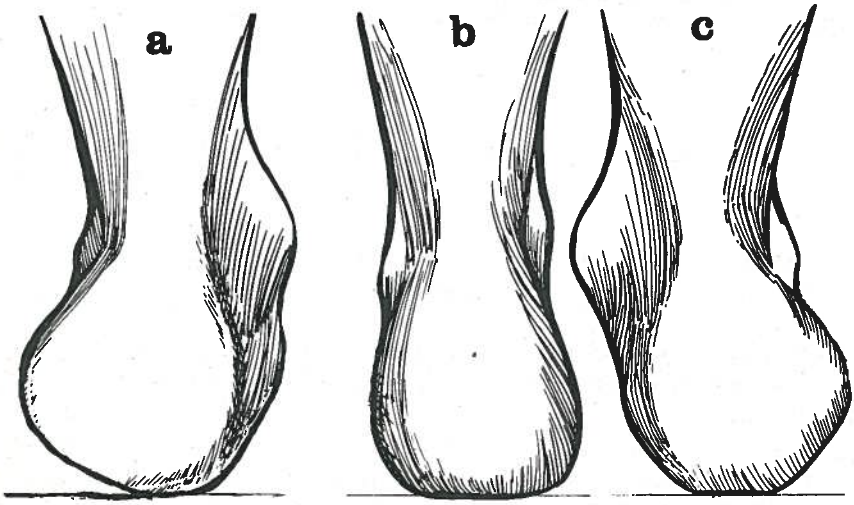

FIGURE 10. Left foot in (a) valgus, (b) normal position, and (c) varus.

Shoe Modifications

1. Steel Shank in Shoe. Most custom and stock orthopedic or high-quality stock shoes contain a steel shank. If the shank is not positioned as explained in the section on shoe checkout (Fig. 3), it will not function properly. If the steel is poor in quality it will cause the depression of the longitudinal arch of the shoe under weight bearing. The posterior terminus of the steel shank should be at least ½ in. posterior to the plantar apex of the calcaneus, and extend anteriorly to a point ¼ or ⅜ in. posterior to the break of the shoe. The steel shank is often referred to as "the backbone of the shoe." Its width is determined by the width of the shoe, weight of the patient, type of brace and vocation of the patient. The average low- or medium-priced stock shoe, rarely includes an adequate steel shank. It is therefore often necessary to remove the original shank and install a more adequate support.

2. Cookie Insert or Insole. If a steel shank alone does not provide sufficient support for the longitudinal arch of the shoe sole or foot, a cookie *insert* may be indicated. The cookie is generally made of shoulder leather for rigidity, and is shaped to conform to the longitudinal arch of the foot with the highest point of support in the area of the talonavicular joint (Fig. 11). It should extend from a point approximately 1¼ in. posterior to the heel breastline to approximately ½ in. posterior to the first metatarsal head. The medial edge, which is feathered, should lie against the quarter lining on the medial side of the longitudinal arch. The distal surface of the cookie lies against the insole of the shoe. It provides a more rigid support when used with a long counter on the medial side. In the custom shoe or the stock shoe with orthopedic features, the cookie *insole* is an integral part of the shoe, being a modification of the insole.

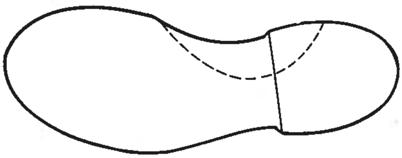

FIGURE 11. Placement of cookie insert or navicular pad.

A cookie insert may be applied at any time to any type of shoe. Available commercially in various sizes, the cookie may be glued in permanently or inserted as a removable component.

3. *Navicular Pad (Scaphoid).* Like the cookie, the navicular pad is also designed to provide additional support for the longitudinal arch on the medial side (Fig. 11). It is installed in the same place in the shoe as the cookie insert and, in general, has the same contour. It also provides better support if used with a long counter on the medial side. There are, however, specific differences. To provide a resilient support, the navicular pad is made of compressible materials such as sponge rubber of various durometers, and the rubber surfaces are covered with leather for comfort. The navicular pad is generally prescribed in cases where the patient cannot tolerate the rigid support of a cookie.

4. *Longitudinal Arch Support.* This modification may be prescribed in cases where broader areas of support are required, including the entire plantar surface of the foot. In providing support for the medial longitudinal arch, the broad extent of the arch support tends to shift the body weight laterally and in some cases may preclude the use of a valgus strap.

Longitudinal arch support inserts may be procured commercially in a variety of materials such as metal, plastic, and leather. If necessary they may be reshaped for final fitting by hammering, heating, and bending.

5. *Long Counter on the Medial Side.* The medial counter on the stock shoe usually extends approximately ⅜ to ½ in. forward of the breast of the heel (Fig. 12). In the stock shoe with orthopedic features, it extends approximately midway between the heelbreast and the break of the shoe,

thus providing additional support for the longitudinal arch. Regardless of the shoe type, the counter is usually made of shoulder leather since its function is to provide a rigid wall to retain the foot in the desired alignment. The entire counter is sandwiched between the quarter lining and the quarter of the upper during the lasting step of shoe fabrication.

Even with a long medial counter in the stock shoe with orthopedic features, it is sometimes necessary to use a cookie or a navicular pad as well. The counter in the custom orthopedic shoe will provide more effective support due to the closer conformity of the longitudinal arches of the foot and shoe.

6. *Orthopedic Heel* (*Thomas*). This modification is similar in appearance and material to a standard rubber heel. The difference lies in an extension of the medial heel breastline (Fig. 13). In the stock shoe with orthopedic features, the anterior projection of the medial breast of the Thomas heel extends approximately ½ in. anterior to the normal heel breastline, at which point it is directly beneath the navicular bone. In the custom orthopedic shoe it may extend to any desired length, giving more extensive support to the medial longitudinal arch. It is prescribed to provide additional support and/or stability for the medial longitudinal arch.

Thomas heels are also sometimes referred to as "S-shaped" or "keystone" heels. They are commercially available as half heels in a variety of sizes, but they can also be made in the shop from Neoprene, crepe rubber, or from a standard rubber heel of a length equal to the Thomas heel projection. The material is then cut according to the Thomas heel pattern by shortening the lateral side.

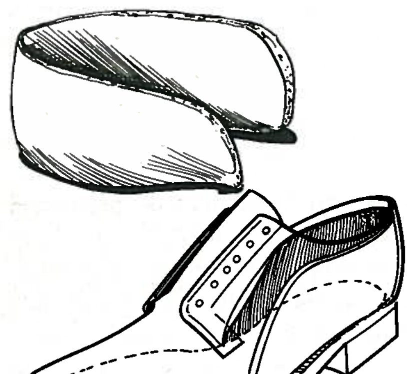

Figure 12. Long counter on the medial side.

Figure 13. Orthopedic heel (also known as the Thomas heel).

7. *Orthopedic Heel (Thomas) Wedge.* If it is necessary to increase the amount of medial longitudinal support above that provided by the Thomas heel alone, a medial wedge for the heel may be prescribed. The wedge is made of shoulder leather from $\frac{1}{16}$ to $\frac{5}{16}$ in. thick depending upon the weight of the patient and the desired amount of support. Since it is designed to augment the function of the orthopedic heel, the wedge is usually sandwiched between the heelbase and outsole over the area of the forward extension of the heel, though it may also be applied between the heel and the heelbase in this area.

8. *Medial Wedging.* Medial wedging may be prescribed if there is a greater need for shifting the body weight laterally than for support of the medial longitudinal arch alone. Wedges for this purpose may be applied to the sole, the heel, or over the full length of the sole and heel. Medial wedges are generally made of shoulder leather although other suitable materials may also be used; they provide a wide range of correction.

a. Sole wedge. This modification is intended to shift the body weight from the medial to the lateral side of the tarsal and metatarsal aspect of the foot. At the same time, the sole wedge provides a certain amount of support for the medial longitudinal arch.

The most desirable type of sole wedge is placed over the outsole (the overlay), starting midway between the medial heel breastline and the break of the shoe and extending to the anterior end of the sole. Laterally, the sole wedge extends approximately to the longitudinal midline of the sole. Its lateral extension depends, however, upon the total elevation of the wedge, since the most gradual feathering is desired to avoid creating "pockets" on the sole which do not contact the ground. As an overlay, rather than being sandwiched between the insole and the outsole of the shoe, the thinner insole is not distorted, and there is less likelihood of significant pressures being transmitted to the plantar surface of the foot. Another advantage of a wedge applied as an overlay is that it is easily adjusted or replaced without damage to the outsole and welt of the shoe. Walking on the replaceable wedge rather than on the sole of the shoe also prolongs shoe life.

b. Heel wedge. Wedges are applied to the heel in order to effect a lateral shift of the weight in the area of the talocalcaneal and talonavicular joints. A heel wedge may also be applied to counteract the effect of a lateral sole wedge and prevent an uneven tread pattern (cross wedging). The heel wedge should be sandwiched between the outsole and the brace attachment; however, if it is placed between the brace attachment and the heel, the effect of the lateral weight shift would cause tilting of the limb and brace. The effect on the gait pattern would be quite undesirable since a tendency toward adduction of the limb would occur.

c. Sole-and-heel wedge. Sole-and-heel wedges are prescribed in cases where the medial aspect of the foot bears too much weight, as in valgus or in depression of the medial longitudinal arch. The wedges are often used in conjunction with a longitudinal arch support insert to augment the effect of a lateral weight shift along the entire length of the foot. This type of wedge may be applied as a unit which extends the full length of the sole and heel, or it may be applied in two sections, the sole section and the heel section (Fig. 14).

As a unit, the heel-and-sole wedge offers more longitudinal support than the separate sections. Their effectiveness in shifting the body weight laterally is approximately the same. In separate sections they are installed exactly as indicated above for either one, but as a unit the wedge is an overlay of the outsole and laid *under* the heelbase in the conventional manner. The portion extending over the medial longitudinal area affords longitudinal support by its added substance, which reinforces the outsole and shoe shank somewhat.

9. *Medial Shank Filler.* The medial shank filler is prescribed in cases where the patient's weight tends to depress the longitudinal arch in the shoe. By its characteristic shape, the medial shank filler eliminates the void existing between the ground and the medial plantar surface of the longitudinal arch of the shoe (Fig. 15). By application of additional height, elevation and lateral weight shift can be provided for a depressed medial longitudinal arch and/or valgus condition, which includes the talonavicular, navicular first cuneiform, first cuneiform, and base of first metatarsal articular margins.

This component extends from the medial breastline anteriorly to the head of the first metatarsal, at which point the shank filler is feathered and blends into the level of the outsole at the break of the shoe. Laterally, the filler can extend at the breastline to a point deemed necessary to afford adequate longitudinal arch support, and this extent would be carried anteriorly to a point at the line of the metatarsal heads, where it too would feather and blend into the level of outsole at the break of the shoe.

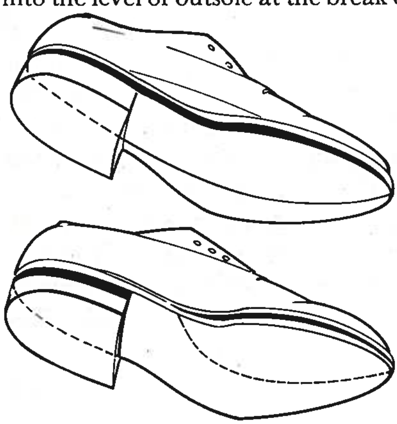

FIGURE 14. Medial sole-and-heel wedging. Bottom: sandwich, in two sections; top: as an overlay unit extending the full length of the sole and heel.

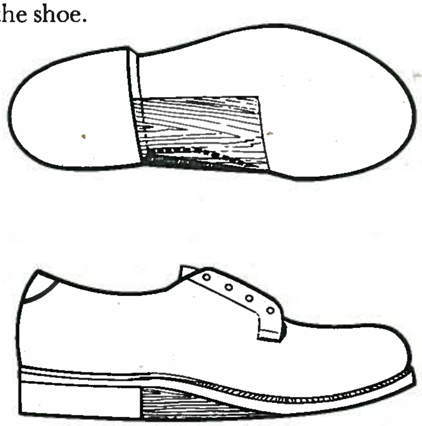

FIGURE 15. Medial shank filler. Top: plantar view; bottom, medial view.

10. Valgus Strap. The valgus strap applied medially is designed to prevent the foot and ankle from assuming a valgus attitude (Fig. 16). In spasticity or muscle contracture, where the foot, even when unweighted, intermittently or constantly assumes a valgus position, the strap functions to maintain correct mediolateral alignment. The strap prevents the foot from going into a valgus attitude by overcoming the action of the spastic or contracted muscles; it may also be used in cases of mild spasticity and contracture of flaccidity where the foot assumes a valgus attitude only when bearing weight.

FIGURE 16. Valgus corrective strap; dotted line indicates more effective placement. (Note hole in heel for caliper-box attachment.)

To be most effective the valgus strap should lift or help prevent depression in the following areas:

a. Medial anterior aspect of the talocalcaneal joint;
b. Talonavicular joint;
c. Navicular first cuneiform joint;
d. First cuneiform base of the first metatarsal joint.

Therefore, the area of attachment for the distal end of the strap should be from a point ½ in. posterior to the medial breastline (or ½ in. plus the length of the medial projection of a Thomas heel) to a point approximately 60 percent of the distance between the heel breast and the break of the shoe.

For cosmetic reasons, however, the distal attachment of the strap is frequently placed more posteriorly, extending anteriorly approximately to the breastline of the heel. The reason for this posterior attachment is to position equivalent amounts of material on either side of the brace uprights or shoe attachment. In this position, the force of the strap is applied primarily in the area of the calcaneous and talus, and the effect on the foot is reduced due to the relative motion between talus and navicular, navicular and first cuneiform, and first cuneiform and base of the first metatarsal.

From its distal attachment, the strap extends proximally to a point about 1½ in. above the apex of the medial malleolus, where it divides into an anterior and posterior strap encircling the leg and the lateral brace upright, and then buckles on the lateral side.

LATERAL LONGITUDINAL ARCH SUPPORT AND/OR MEDIAL WEIGHT SHIFT

The following components, listed according to the amount of support they provide, are used to effect lateral longitudinal arch support and/or medial weight shift.

Internal

1. Long counter on the lateral side
2. Lateral heel wedge insert

External

3. Lateral heel and/or sole wedge
4. Reverse orthopedic heel (Thomas)
5. Lateral shank filler
6. Lateral flaring of sole and/or heel
7. Varus strap

Foot Disabilities

Disabilities of the foot for which the above-listed components are used include lateral pes planus, varus, and ankylosis.

In *lateral pes planus,* the lateral longitudinal arch is depressed, which causes the base of the fifth metatarsal and the cuboid bones to protrude at their plantar surfaces. The forefoot will usually adduct. Here too, as for medial pes planus, provision for support and/or elevation must be made for relief.

In *varus* (inversion, Fig. 10c), the medial aspect of the plantar surface of the foot is elevated, and the lateral longitudinal arch is depressed; the subtalar and tibiotalar ankle joints lean and stretch at their lateral ligamentous connections, causing the lateral malleolus to protrude. Support and/or weight shift is often required for relief and restoration of foot-ankle alignment.

With *ankylosis,* fixation of the articular surfaces of margins of the joints of the lateral longitudinal arch allows only slight passive motion or none at all. Pain, experienced where moments toward varus or valgus occur, usually is relieved by the support of a lateral wall with an extended base (flare).

Shoe Modifications

1. Long Counter on the Lateral Side. This modification helps prevent depression of the lateral longitudinal arch by providing a rigid wall which effectively restricts the movement of the foot into an attitude of varus. To provide the maximum effective support, the anterior extent of the counter should terminate at a point just posterior to the fifth metatarsal head. The long counter can be simulated by gluing a prefabricated or preshaped half-counter into a stock shoe, but the shoe must be wide enough to allow for this modification. The extended counter can be covered with a thin leather skin for comfort.

2. Lateral Heel Wedge Insert. If the long counter does not provide sufficient lateral support, a lateral heel wedge insert may be indicated (Fig. 17). This modification raises the lateral longitudinal arch and shifts the body weight toward the medial side of the foot. It may, in some flaccid cases, obviate a varus strap.

The wedge is placed inside the shoe with the thickest section beneath the lateral weight-bearing point of the calcaneus. When properly fabricated and installed, the insert should provide additional support in the area of the base of the fifth metatarsal; by so doing, it will also afford slight support at the plantar protuberance of the cuboid bone. If it does not provide such support, some of its effectiveness is lost through the relative motion between the bones of the midfoot and the forefoot.

Although sponge rubber in varying durometers is frequently used, other materials such as leather and cork are also suitable. The basic material is usually covered with thin leather or plastic sheeting, and the insert may be permanently glued or left removable.

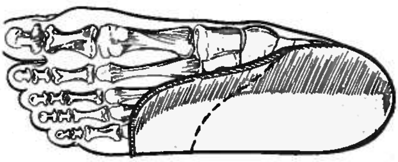

FIGURE 17. Lateral heel-wedge insert extended to fifth metatarsal head; dotted line indicates position of lateral heel-wedge insert to fifth metatarsal base.

3. Lateral Wedges (Sandwich). a. *Heel.* The external lateral heel wedge serves the same purpose as the internal insert. It affords, however, somewhat less support since it does not conform directly to the foot and extends only to the breast of the heel. If it is sandwiched between the brace attachment and the outsole, it will be somewhat effective in preventing a varus inclination of the talocalcaneal and tibiotalar joints. If, however, the lateral heel wedge is sandwiched between the brace attachment and the heelbase, then an undesirable effect may occur, i.e., the weight of the limb is shifted by the tilting of the brace, which causes pressure points on the thigh and leg. A lateral heel wedge properly applied, however, can be useful in relieving or correcting a flaccid genu varum, with or without a side-pulling kneecap. The angle of flaccid ankle joint in varus should, during the stance phase of gait, also be reduced and approach normal alignment.

b. *Sole.* The application of a medial longitudinal arch support or a medial heel wedge designed to shift the body weight laterally may require compensation in the form of a lateral sole wedge (cross wedging). This modification may also be indicated for depression of the lateral longitudinal arch in the area from the head of the fifth metatarsal to its base, including the anterior third of the cuboid.

As was mentioned with respect to the medial sole wedge, the lateral wedge is more effective as an overlay rather than as a sandwich. When properly installed, its lateral side extends from a point approximately 1½ in. posterior to the break of the shoe to the anterior tip of the sole, with its highest point slightly behind the head of the fifth metatarsal. Its medial extension is governed by the total elevation of the wedge and the need for very gradual feathering. As it slopes medially, however, it provides additional support for the heads of the fourth and third metatarsals.

c. *Sole-and-heel wedge.* Both sole and heel wedges are prescribed in cases where the lateral aspect of the foot bears too much weight and in cases of severe varus or depression of the lateral longitudinal arch. A sole-and-heel wedge is often used in conjunction with a long counter on the lateral side and/or a heel wedge insert to augment the desired medial weight shift effect. The lateral heel-and-sole wedge may be applied in the same manner as the medial sole-and-heel-wedge; it too offers more support when applied as a unit.

4. *Reverse Orthopedic Heel* (*Thomas*). As discussed earlier, orthopedic heels are obtained commercially as half heels in a variety of sizes. Their distinguishing feature is the anterior projection of the medial side of the heel breasting. When applied to the heel base, they provide support for the medial longitudinal arch. When used to support the *lateral* longitudinal arch, a "left" orthopedic heel is simply used on the right shoe and vice versa; for this reason they are called reverse orthopedic (Thomas) heels (Fig. 18).

The projection of the reverse orthopedic heel extends approximately ½ in. anterior to the normal heel breastline and is located beneath the lateral prominence of the base of the fifth metatarsal. It therefore provides support in the areas of the calcaneocuboid and cuboid-base of the fifth metatarsal joints.

5. *Lateral Shank Filler.* The lateral shank filler is prescribed in cases where the patient's weight requires additional support for the lateral longitudinal arches of the foot and shoe. With the characteristic shape of the medial shank filler, the lateral shank filler eliminates the void existing between the ground and the lateral plantar surface of the longitudinal arch of the shoe (Fig. 19). By the application of additional height, elevation and medial weight shift can be provided for a depressed lateral longitudinal arch and/or varus condition involving calcaneocuboid, cuboid-base of fifth metatarsal joints, and the subtalar and tibiotalar joints.

This shank filler extends from the lateral breastline anteriorly to the head of the fifth metatarsal, at which point it is feathered into the level of the outsole at the break of the shoe. Medially it can extend from the breastline to a point deemed necessary to afford adequate longitudinal arch support. This extent would be carried anteriorly to a point at the line of metatarsal heads, where it too would feather into the level of the outsole at the break of the shoe.

6. *Lateral Flaring of Sole and Heel.* In such conditions as painful ankylosis of unsuccessful arthrodesis of the tibiotalar, subtalar, talonavicular,

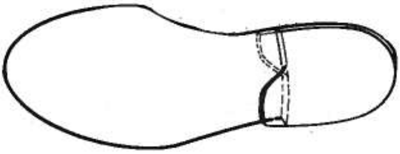

FIGURE 18. Reverse orthopedic heel. Dotted line indicates the position of the regular orthopedic heel.

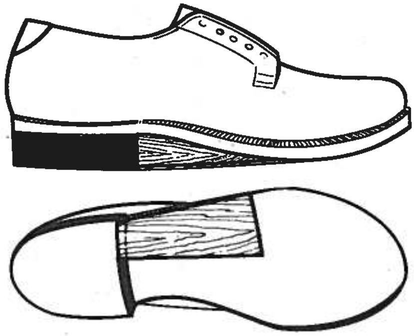

FIGURE 19. Lateral shank filler. Top: lateral views; bottom: plantar view.

calcaneocuboid or tarsometatarsal joints, tendency of the foot to move toward a varus attitude should be prevented. For this purpose the heel, sole, or both may be flared on the lateral side in order to provide greater resistance to any tendency toward varus. The extent of the flare depends upon the degree of restraint required and is usually determined by trial-and-error. The medial longitudinal arch should be adequately supported at the same time to prevent moments toward medial weight shift.

a. *Flaring the heel.* If it is necessary to prevent a tendency toward varus in the area of the tibiotalar, subtalar, and/or the calcaneocuboid joints, flaring the heel alone may suffice. The heel is removed, and the heelbase and outsole are cut on a bias with the feathered edge on the lateral side. A piece of heelbase and a piece of outsole leather are shaped with their lateral shoulders flared to replace the cutaway portions. A heel is attached to the base, and its lateral wall is flared to match the heelbase and to provide the desired degree of flaring at its plantar surface.

In the custom orthopedic shoe, the outsole can be initially prepared for sufficient flaring. At that point, however, it is important that the broadened plantar surface of the heel not include wedging to any degree since a moment toward valgus or medial longitudinal arch depression should be prevented. To augment the flare further, a thicker more rigid-than-usual long counter on the lateral side can be simulated as a glue-in over the lateral quarter lining.

If this kind of restraint is required over a broader area, extending into the tarsometatarsal region, a reverse orthopedic heel or lateral shank filler may be installed with a flare in the same way.

b. *Flaring the sole.* If additional support is required in the area extending from the cuboid to the distal end of the fifth toe, the sole can be flared. The area of the flare should be approximately 1 to 1½ in. posterior to the base of the fifth metatarsal and extending anteriorly to the toe end of the outsole. In the stock shoe, the outsole must be detached from the welt, and the welt removed from the insole and upper joint, extending from an area ½ in. anterior to the lateral heel breastline up to the lateral anterior end of the toe. Welting wide enough to afford an adequate flare, spliced at the terminals of the above-described areas, should be hand-stitched or McKay-machine stitched to the upper and insole. To apply this modification, the heel and heelbase must first be removed and then replaced. The void existing between the ground and the medial aspect of the sole, from toe to midshank, should be filled in to allow for the addition of the outsole so that with the proper flare on the lateral aspect of the outsole, a close-to-normal weight-bearing pattern is achieved. Here too, lateral wedging should be excluded to prevent a moment toward valgus, and the medial longitudinal arch should be adequately supported.

A long rigid counter on the lateral side, extending anteriorly to the fifth metatarsophalangeal joint, can be installed to afford a strong retaining wall. The lateral shank filler mentioned earlier can also be used with a flare.

c. *Flaring the sole and heel.* If it is necessary to prevent varus along the entire lateral aspect of the foot, both heel and sole may be flared (Fig. 20). This can be accomplished as described for each of the segments individually. If the required lateral flare is so extensive as to distort under weight bearing, another outsole may be applied over the first for added strength. In this case it is also necessary to add another sole to the sound side to maintain equal leg lengths.

d. *Varus strap.* The varus strap (Fig. 21) applied laterally is designed to prevent the foot from assuming a varus attitude. In spasticity or muscle

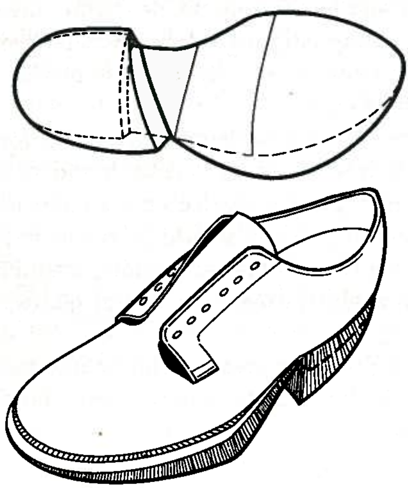

FIGURE 20. Lateral flaring of sole and heel. Top: plantar view; bottom; lateral view.

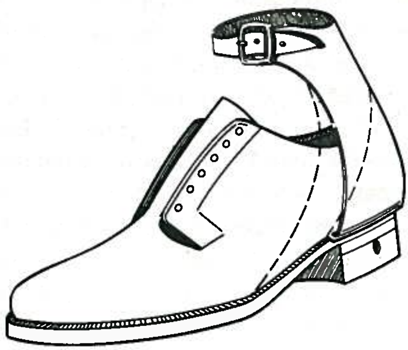

FIGURE 21. Varus corrective strap; dotted line indicates most effective placement.

contracture, where the foot, even when unweighted, intermittently or constantly assumes a varus position, the strap functions to maintain correct mediolateral alignment by overcoming the action of the spastic or contracted muscles. It may also be used in cases of mild spasticity and contracture or flaccidity where the foot assumes a varus attitude only when bearing weight.

To be most effective the varus strap should lift or help prevent depression in the following areas:

a. Lateral anterior aspect of the talocalcaneal joint;

b. Calcaneocuboid joint;

c. Cuboid base of the fifth metatarsal joint.

Therefore, the area of attachment for the distal end of the strap should be from a point ½ in. posterior to the lateral breastline to a point approximately 60 percent of the distance between the heelbreast and the break of the shoe.

As for the valgus strap, cosmetic reasons often dictate a design of lesser effect. In the varus strap the effect would be reduced primarily to lifting or preventing depression at the talocalcaneal joint and the talocuboid joint.

From its distal attachment, the strap extends proximally to a point approximately 1½ in. above the apex of the lateral malleolus, where it divides into an anterior and posterior strap encircling the leg and the medial brace upright, buckling on the medial side in a convenient position for the patient.

METATARSAL ARCH SUPPORT

There are two metatarsal arches, the anterior and the posterior. The anterior metatarsal arch is made up of the heads of the metatarsal bones, and the posterior metatarsal arch is formed by the bases of the metatarsal bones. A majority of foot disabilities affect one or both of these arches. Indeed, a list of possible deformities of the metatarsal arches is long, including such conditions as pes cavus, fractures, bursitis, hallux valgus, hallux rigidus, Morton's toe, splayfoot, plantar warts, and metatarsalgia.

To reduce the pain resulting from these disabilities and to assist in restoring a normal gait pattern, the following supporting components for the metatarsal arch are used:

Internal

1. Regular metatarsal pad, dancer pad, or metatarsal corset
2. Levy-type inlay—with or without hallux valgus pad
3. Morton's toe extension

External

4. Metatarsal bar
5. Rocker bar
6. Denver heel or bar
7. Long steel spring and rocker bar
8. SACH heel

Foot Disabilities

In *pes cavus,* the extensor tendons of the dorsum are shortened, causing the longitudinal arches to become high or "hollow" and also causing the proximal phalanges of each toe to dorsiflex while the middle and distal phalanges plantar flex. The dorsiflexion of the proximal phalanges

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forces the metatarsal arch to depress so that all the heads are in ground contact. Callosities usually develop on the plantar skin surfaces of these heads, and pain ensues.

Fractures of the metatarsal bones often result in the formation of callous tissue during healing. When weight is borne upon the plantar tissue that is sandwiched between the thickened bone and the tread area, pain ensues. If the periosteum is penetrated by the fracture, bone tissue may grow in irregular shapes and project beyond the surface of the remaining bone and periosteum. Such a bone projection, called exostosis, causes pain when pressed against plantar tissue. If securely held by fibrous tissue, a malunion in a metatarsal bone may be comfortably supported by a metatarsal arch support.

If *bursitis* (the inflammation of fluid-filled bursal sacs that develop at frictional areas between tissues) develops at the metatarsophalangeal joints, relief of tenderness is obtained by proper metatarsal support padding.

Morton's toe is a condition in which the first metatarsal bone is congenitally short. In comparison, the normal length of the second metatarsal seems excessive and upsets the proper three-point weight-distribution pattern. The weight-bearing area is reduced to the area between the second and fifth heads and the apex of the calcaneus. The head of the second metatarsal consequently becomes quite painful since it is not structured to bear so much weight, especially in rollover of the stance phase or toe spring at pushoff, which requires a great amount of plantar flexor strength. Support and elevation helps to relieve pain of this condition.

Plantar warts (calloused tissue appearing like small callosities when trimmed) expose a rather deep-rooted growth, resulting in a needle-sticking type of sensation. These warts seem to grow between and under the heads of the metatarsals; they are also found growing elsewhere on the plantar surface of the foot. It has been said that a virus infection is the causative factor in the growth of plantar warts. Proper padding will help to relieve this condition.

Hallux valgus occurs when the first metatarsal is abducted and the phalanges are adducted, producing a displacement of the great toe toward the other toes. This disability is often caused by the wearing of narrow or pointed-toed shoes. Where manipulation is painful and surgery is contraindicated for medical reasons, the deformity must be accommodated in an outflare-type of lasted shoe. Where manipulation is not painful, an innermold with padding to realign the hallux, placed in a straight inner-border last, will relieve the condition.

Hallux rigidus is a deformity characterized by a gait pattern with a heel strike that is more lateral than normal and with a weight shift to the lateral border of the foot and shoe during advance into midstance. At the midstance phase, the ankle is in slight voluntary varus with the midtarsal and forefoot in enough supination to relieve the first MP joint of weight bearing. The hallux rigidus deformity is caused by an overgrowth of bone (exostosis), resulting from congenital origins, trauma, or arthritic joint degeneration. The exostosis may develop at the base of the proximal phalanx of the hallux, or at the first metatarsal head. As the exostosis grows into a joint stop, movement of the first metatarsophalangeal joint becomes restricted and painful. To relieve the deformity, a medial longitudinal arch, a properly fitted metatarsal support for the first metatarsal head, and a long steel spring and rocker bar are needed.

Splayfoot is a deformity in which the metatarsal bones abduct from each other mediolaterally, at their head ends, and compress at the closely mated articular margins of the tarsometatarsal joints, depressing the anterior metatarsal arch. The degree of abduction and depression is dependent upon the laxity of the intrinsic muscles (plantar interossei and the adductor hallucis) of the foot. These muscles and their tendonous connectors normally truss the metatarsal bones so that they form a dome-shaped anterior arch and thus allow compressionless articulation to exist at the tarsometatarsal joints. Bandaging or corseting the foot from the waist level up to the tarsometatarsal joint level is the treatment generally administered this deformity. A metatarsal pad may be included for relief, if necessary.

Splayfoot is characterized by a flatfooted-type gait, in which the patient carries out heel strike and midstance, but then precludes rollover and toe-off by raising the foot horizontally from the ground. This type gait is a result of pain experienced while trying normal rollover and toe-off. The plantar flexors of the toes cannot be relied upon to perform normally in supplying spring forces. With the malalignment of the metatarsal bones, the spring forces necessary for toe-off would only further depress the anterior metatarsal arch, and pain would ensue. Another common problem with this deformity is that the patient wears a stock shoe that is much too wide at the ball of the foot, yet he will usually complain that his shoe is too tight; the fact is that with proper corseting there is a great amount of space in the shoe.

Shoe Modifications

1. Regular Metatarsal Pad. By elevating the inner sole posterior to the heads of the metatarsals, a metatarsal arch support helps to redistribute weight bearing in that area. Regular metatarsal pads are availble commercially in many sizes and are helpful in cases of moderate metatarsalgia (Fig. 22c).

Dancer Pad. For more serious metatarsalgia conditions, however, the broad shape and thickness of the dancer pad is more helpful since it provides more support than the regular metatarsal pad (Fig. 22a, b). Sometimes called "buttons" the dancer-type pad can be shaped to fit directly behind each of the metatarsal heads (Fig. 22a) so that its feathered edge comes under the surface of the metatarsal heads. This placement is particularly beneficial for the flexible foot. With the rigid foot or pes planus, however, the pad should be placed slightly more posterior to the metatarsal heads in order to relieve the pressure on the heads. The shaping of the dancer pad must conform to the soft tissues that cover the metatarsals, otherwise tissue stretch occurs, which counteracts the intended benefits of pressure relief. In fact, tissue stretch increases the sensitivity of prominent callosity areas even though the callosities are being relieved of body-weight pressures.

Metatarsal Corset. Figure 22d, e shows a metatarsal corset, which is an innovation that allows the patient to change footwear without removing the arch support, thereby reducing the necessity of repositioning the metatarsal pads several times a day. The corset utilizes either the regular metatarsal pad or dancer pads and may be fastened by elastic, strap, or buckle. The metatarsal corset can also be used for splayfoot since its trussing elements are lax enough to permit abduction of the metatarsal heads and depression of the anterior metatarsal arch.

Insole Pads. The metatarsal insole is another type of arch support that is generally used as a removable component. The pad is mounted on an insert which is shaped to conform to the insole of the shoe, from the heel to the area of midmetatarsal heads, where the insert feathers.

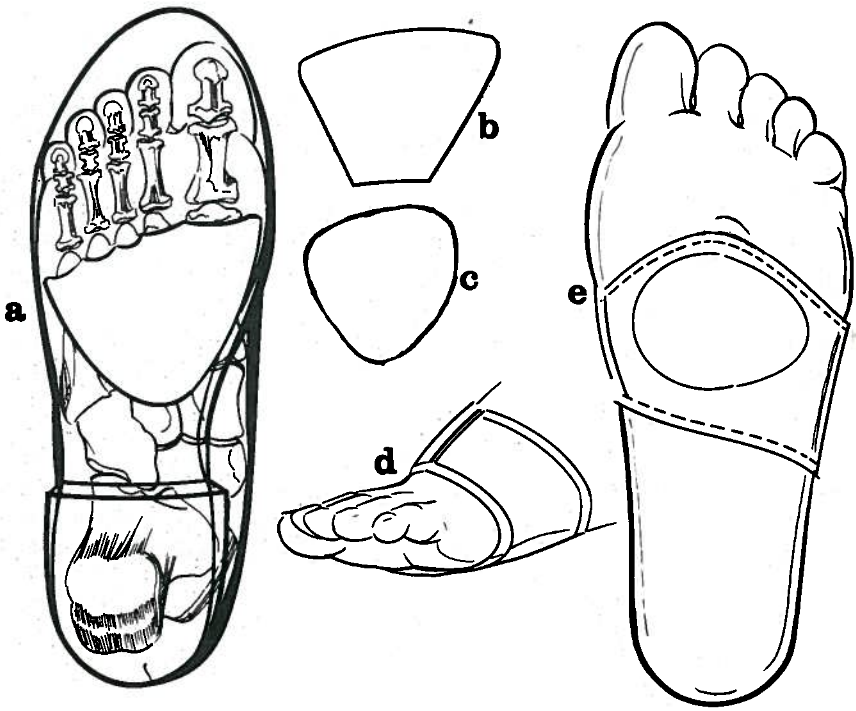

FIGURE 22. Metatarsal pads. (a) Contoured dancer pad; (b) noncontoured dancer pad; (c) regular metatarsal pad; (d) metatarsal corset, lateral view; and (e) metatarsal corset, plantar view.

2. *Levy Inlay.* The Levy-type inlay is often used when the plantar surface of the metatarsophalangeal or interphalangeal joints are hypersensitive to pressure. The Levy component is made by cementing a sponge or foam-rubber forefoot part to a combination arch support. Since the inlay is removable, it can easily be adjusted whenever necessary.

The full innermold coverage of the Levy inlay is also utilized to treat hallux valgus (bunion). A wedge-shaped pad made of resilient foam rubber should be placed between the hallux and the second toe in order to abduct the great toe and realign the first metatarsophalangeal joint toward a normal attitude (Fig. 23). A mittenlike sock with a separate section for the great toe helps to prevent wrinkles from forming between the pad and the toe.

3. *Morton's Toe Extension.* A toe extension is used to ease the painful condition often resulting from an abnormally short first metatarsal bone (Fig. 24). By raising the level of the first metatarsal bone and the phalanges of the hallux, the extension restores the proper three-point weight-distribution pattern, i.e., the weight is distributed between the plantar apex of the calcaneus and the first and fifth metatarsal heads.

For maximum effectiveness, Morton's toe insert should extend from the heel to the tip of the hallux, passing and supporting the medial portion of the longitudinal arch. The lateral extent of the insert should be feathered at the medial peripheral line of the second toe, forming a sharp radius between the first and second MP joints. At the lateral end of the radius, the insert should extend to the fifth MP joint. A properly fitted metatarsal support should be installed to relieve the second metatarsal head and any others requiring relief. The orthotist can fabricate this type of insert by using a semiprefabricated longitudinal arch support and adding the hallux

FIGURE 23. Foot fitted with hallux valgus support on Levy-type insole and mitten-like sock.

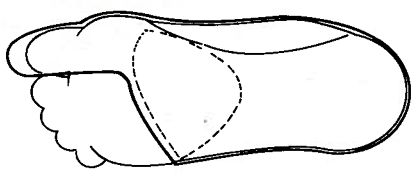

FIGURE 24. Morton's toe extension (plantar view). Dotted line indicates metatarsal support to relieve pressure on metatarsal heads.

extension. The choice of material depends upon the patient's weight and the sensitivity of the deformity.

4. *Metatarsal Bar.* Now we come to the first of the external types of metatarsal supports, the metatarsal bar, which is prescribed to relieve pressure from the metatarsal heads (Fig. 25 a, b). It may be used in place of insert components when foot sensitivity restricts their use, or it may simply be used to augment inserts for the nonsensitive foot. In a stock shoe, which has a thin insole susceptible to reshaping by perspiration or moisture, the metatarsal bar should be applied as an overlay; if the bar were applied as a sandwich, it would soon begin to rise within the shoe, reducing foot room and causing pressure against the sensitive postmetatarsal area.

The metatarsal bar should be placed on the outsole with its thickest point directly behind and parallel to the line between the first and fifth metatarsal heads so that after heel strike in rollover, the weight is borne at the area *behind* the metatarsal heads rather than *upon* the heads. The anterior extent of the metatarsal bar should taper about 1½ in.; its posterior taper may be shorter since it serves no function in pressure relief. As an overlay, the metatarsal bar has the added advantage of being easily adjusted or replaced without damage to the outsole and welt, thus prolonging shoe life.

5. *Rocker Bar.* The rocker bar (Fig. 25 c, d) is more extensively used than the metatarsal bar, particularly when improved gait function and a degree of immobilization are desired for the ankle, tarsal, transmetatarsal, metatarsophalangeal, or interphalangeal joints. Like the metatarsal bar, the rocker bar is prescribed to relieve pressure from the metatarsal heads.

In stock shoes, the rocker bar should be installed as an overlay, with its apex directly behind and in a line parallel to the first and fifth metatarsal heads. The anterior of the rocker bar extends farther to the toe end of the shoe than does the metatarsal bar. The exact extent is determined by the height of the apex and the feathering. The extension of the wearline of the sole toward the heel and the placement of the apex of the bar posteriorly, reduces the posterior and midfoot weight-bearing force appreciably during the period of rollover and pushoff. Without the rocker bar, the weight-bearing force would normally be applied to the metatarsal area during gait.

6. *Denver Bar.* The Denver bar (also called the Dutchman) is another type of metatarsal support, usually made of leather and applied as an overlay to the outsole by cementing or nailing (Fig. 25e, f). The posterior extent of the bar can be increased or decreased, depending upon the degree of pathology. Usually, the posterior face of the Denver bar is placed at the plantar surface of the instep, i.e., directly beneath the transverse arch of the foot at the tarsometatarsal joints. It is important that the orthotist achieve a balance between the shoe heelbreast and the Denver bar so that

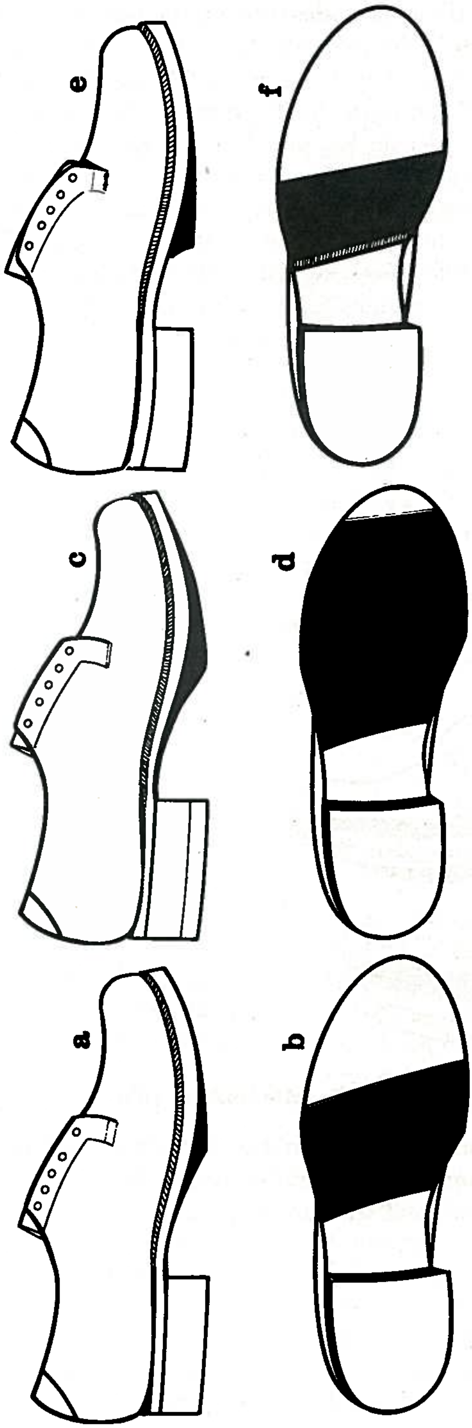

FIGURE 25. Metatarsal, rocker, and Denver bars. (a) Metatarsal bar, lateral view; (b) metatarsal bar, plantar view; (c) rocker bar, lateral view; (d) rocker bar, plantar view; (e) Denver bar, lateral view; and (f) Denver bar, plantar view.

during rollover in the stance phase of gait, the transverse arch is raised. As the transverse arch is elevated, the metatarsal bones are pulled posteriorly and the weight on the metatarsal heads is relieved. Should the orthotist wish to give support to the navicular bone or to effect a lateral weight shift, he may extend the Denver bar posteriorly or elevate the component.

7. *Long Steel Spring and Rocker Bar.* In conjunction with extended brace attachment tongues and/or long steel springs, the rocker bar provides firm support for the forefoot until late in the stance phase, thus reducing the support required of the toes (Fig. 26). When used with a stiff-ankle brace or a limiting plantar and dorsiflexion brace, the rocker bar also reduces motion in the tibiotalar and subtalar ankle joints, talonavicular, calcaneocuboid, and tarsometatarsal joints, making it helpful in relieving arthritic pains, ankylosis, and other ankle and foot disabilities.

8. *SACH Heel.* A soft heel simulating a SACH foot wedge used in conjunction with the rocker bar provides a more natural gait from heel contact to rollover to pushoff. The SACH foot wedge, which we refer to as a SACH heel in orthotics., is comprised of resilient materials, such as sponge, pedic, or crepe rubbers of adequate durometers with a thin rubber heel on top to provide cushioning at heel contact. The depression occurring at heel contact simulates plantar flexion, and in so doing causes earlier outsole contact with the ground.

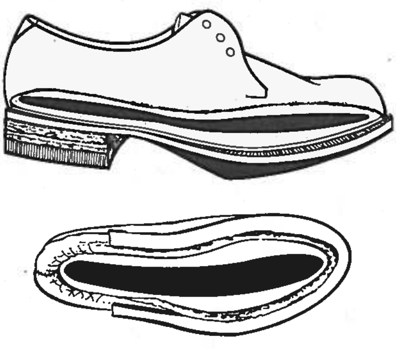

FIGURE 26. Long steel spring. Bottom: plantar view; top: in combination with SACH heel and rocker bar to facilitate rollover.

JOINT IMMOBILIZATION

In addition to support of the arches, many foot conditions require total immobilization of one or more joints of the foot, such as the interphalangeal, metatarsophalangeal, and the tarsometatarsal joints, or the talonavicular, calcaneocuboid, talocalcaneal, and tibiotalar joints. A patient may be suffering an arthritic condition or ankylosis, he may have had an unsuccessful arthrodesis, or his foot may be spastic. With any of these conditions, the patient needs maintenance of joint immobilization, yet he should have as normal a gait as possible. To achieve this, the orthotist immobilizes the affected joints by the judicious use of the following components:

Internal

1. Steel shoe shank
2. Long steel spring, if the metatarsal, phalangeal, and/or interphalangeal joints are involved
3. Steel-reinforcing plate on insole

External

4. Steel-reinforced tongue of brace attachment
5. Stiff or limited-motion ankle joints
6. SACH heel and rocker bar
7. Medial and/or lateral shank filler

Foot Disabilities

If the foot is deformed or amputated at the level of the interphalangeal, metatarsophalangeal, or the tarsometatarsal joints, ambulation is usually painful, causing a gait deviation. In order to avoid pain during rollover and pushoff of the stance phase, the patient pivots on his heel and abducts the midtarsal and forefoot by his voluntary outward rotation of the ankle and hip joints. This action eliminates rollover and pushoff entirely.

When ankylosis or arthritic deformities occur, the action of the affected joints and their ligamentous connectors is restricted, impeding flexion and extension. Unchecked moments of force at the affected joint levels will cause tissue stresses to develop. These stresses, if allowed to go unchecked, can cause a corresponding degree of tissue destruction and pain. Components must therefore be used that will prevent moments toward flexion or extension. The combinations of components for such foot disabilities are the same as those used for foot amputations at the various coincident skeletal levels.

Shoe Modifications

1. Steel Shank. A *Steel shoe shank* of at least 0.05-in. thickness with one or more corrugated ribs and length, width, placement, and function as described earlier, is the first prerequisite for proper shoe structure.

2. Long Steel Spring. Immobilization of the interphalangeal and metatarsophalangeal as well as the tarsometatarsal joints can be achieved by sandwiching a long steel spring into the shoe, which prevents dorsiflexion. Like the solid steel shank, the steel spring should be at least 0.05-in. thick and at least 1-in. wide. It should be made of spring steel and sandwiched between the insole and the outsole. The long steel spring should extend from a point ⅜ in. posterior to the insole rib at the toe end to a point approximately ½ in. anterior to the lasted upper edge at the heel. The heel-to-toe extension of the long steel spring prevents any dorsiflexion or plantar flexion from occurring at the break of the shoe. To increase the rocker action in rollover, the steel spring can be made slightly convex, and this internal curvature will lead to a more normal gait pattern.

The spring can most conveniently be installed when resoling of the outsole is necessary, otherwise, the shoemaker must open enough stitches between the welt and sole at the toe, or at the posterior quarter-to-sole joint where no welt usually exists, to afford adequate passage of the spring. At the time of resoling, a thin leather or cork separator should also be sandwiched in between the steel shank and the steel spring to prevent their making a metallic clicking noise when the patient walks. Adhesive tape might also be wrapped around the spring to dampen metallic clicking noises.

3. *Steel-reinforcing Plate.* This component is used to help stiffen the heel end. It should be set ¼ or ⅜ in. posterior to the break of the shoe; it can be made of spring steel or stainless steel of any desired thickness. This plate is placed on the shoe insole, sandwiching the insole and outsole between the brace attachment and itself.

4. *Steel Tongue.* The steel-reinforced tongue of the brace attachment to the shoe is made broad enough to bypass the steel shank in riveting, as described earlier. When welded or brazed to the tongue of the attachment, it strengthens and stiffens the longitudinal arch of the shoe. If the patient's weight warrants it, the insole plate is used in conjunction with the attachment.

5. *Stiff or Limited-motion Ankle Joints.* These types of joints prevent plantar flexion or dorsiflexion from occurring at the tibiotalar joint or at the metatarsophalangeal joints. Such joints permit dorsiflexion or plantar flexion to a limited degree, which is an asset during gait exercise.

6. *SACH Heel and Rocker Bar.* Clinical studies have shown that the SACH-heel-and-rocker-bar combination used for limited and stiff-ankle joints contributed greatly toward the comfortable restoration of a near-normal gait. As in the SACH heel of artificial legs, the SACH heel component is very resilient. At heel strike, it acts as a shock absorber, compressing and bringing the rocker bar into early contact with the ground. This compression of the SACH heel at heel strike affords the patient a pseudo-plantar flexion without forcing his ankle toward plantar flexion. Since early ground contact is made at the apex of the rocker bar, the shoe is ready for rollover and toe-off so rapidly that motion of the tarsometatarsal, talocrural, or subtalar joints is precluded.

The use of the SACH heel in immobilizing the tarsometatarsal joints gives the brace wearer other advantages. The resiliency of the SACH heel helps to relieve the pressures at the brace calfband and to prevent disturbance of the brace-to-leg alignment. The brace should have either a limited or a fused-solid ankle joint and also, for the heavy patient, a metal insole plate that rests on top of the leather insole. The stirrup, or other form of shoe attachment, should have a particularly broad tongue in order to bypass the steel shank.

7. *Medial and/or Lateral Shank Fillers.* These fillers can be used to prevent longitudinal arch depression and to maintain a rigid heel-to-ball section in cases of excessive obesity or in the case of a Chopart's or Lisfranc's amputation.

ARCH SUPPORTS—RELIEF OF TENDER TISSUE AND SUPPORT OF THE PLANTAR SURFACE OF THE FOOT

Functions of Arch Supports

The functions of arch supports as usually prescribed by physicians are as follows:

1. To relieve areas of pressure which are calloused or scarred.
2. To support weak, flat, or painful feet.
3. To align areas up to and including the pelvis, by elevating the medial or lateral aspects or by increasing the thickness of height of the supports, thus changing the direction, angle, and distribution of body weight to the foot or the affected side of the body.

Measurement and Fitting of Arch Supports

The measurement procedures used for arch-support fabrication include the use of prefabricated or semiprefabricated supports, paper impressions, and plaster-of-Paris casts.

Prefabricated Supports

Many prefabricated arch supports are measured by shoe size and width to the patient's feet.

Semiprefabricated Supports. Another accurate and simple procedure for measuring and fitting the foot is to purchase semiprefabricated arch supports, available by shoe size and patient's weight. The medial or lateral portion of the longitudinal arch support is shaped to conform to the patient's needs, a metatarsal pad is added as prescribed, and the entire unit covered with vinyl sheeting. This combination of fitting and modifying, along with a preliminary gait study can usually be completed during the patient's first visit. By such a procedure, substantial labor in casting and fabrication is saved, excellent fittings are obtained, and the patient's follow-up visits are kept to a minimum.

Paper Impressions. There are two types of commonly used paper impressions, the phenolphthalein and the ped-o-graph methods.

Phenolphthalein paper will activate and develop an impression of a foot sponged lightly with an aqueous solution of sodium bicarbonate.

Ped-o-graph impressions are made by the foot pressed on an inked pad, under which lies impression paper. The phenolphthalein and ped-o-graph paper impressions delineate the foot outline, within which darkened areas represent the pressure points. These impressions are limited, however, in the amount of detailed information often needed to fit severe foot disabilities.

Plaster-of-Paris Casts. In making a plaster-of-Paris cast impression, the orthotist places the patient's feet in a plaster-of-Paris solution so that the plantar surfaces of the feet are covered; the deepened contours of the resultant negative-cast impression indicate the pressure areas. Much more information on foot contouring is possible from the plaster-of-Paris casts than from the two-dimensional paper impressions.

The best reproductions of the patient's feet, however, are obtained with plaster-of-Paris *wraps*. The wrap cast, applied properly, covers the plantar, medial, and lateral aspects of the foot as well as portions of the dorsum up to an area just below the medial and lateral malleoli. The positive casts rendered from the negative wrap casts are excellent replicas of the patient's feet. Any indelible pencil markings over or around calloused, scarred, or sensitive areas are transferred from the foot to the negative, then once again to the positive cast. A maximum of information is obtained by this type of fitting impression.

Fitting Arch Support to Foot

In fitting an arch support to the foot, as distinguished from fitting the arch support to the shoe, a basic check for conformity, alignment, and provision for pressure relief at scarred and calloused areas must be made. With the use of metal arch supports, a further check must be made for the absence of sharp or rough edges which would injure the feet or mutilate the shoes.

To check for proper support length, place the conformed arch support against the patient's foot with the heel edge parallel to, and in a continuous line with, the posterior apex of the patient's heel, where a triangular space occurs because of the natural radial contour of the soft tissue of the heel. With the heel length properly positioned, the medial and lateral longitudinal arches of the foot should be checked. In a rigid pes planus, both longitudinal arches should have support; support and elevation medially will cause a lateral weight shift.

In a semirigid pes planus, support and/or elevation may be indicated without a shift of body weight. In a flaccid pes planus, both support and elevation are usually necessary to restore a normal longitudinal arch and reduce the effects incurred at the ankle joints.

In rigid pes cavus conditions, the longitudinal arches should be conformed to closely, leaving no voids which would allow moments toward depression and ensuing pain. In semirigid pes cavus, usually some degree of depression can be tolerated without discomfort; however, there are many cases that require as much support as rigid pes cavus. In the flaccid pes cavus, the foot should be supported at the height of a normal longitudinal arch.

With the arch support held in the proper position at the heel, its front end should be contiguous with the midline of the metatarsal heads (Fig. 27a). Since dorsiflexion of the toes causes a slight forward movement of all the metatarsal heads, the edge of the support, if measured for the proper length, will not be felt by the patient as he walks.

After the arch support is checked for proper length, the metatarsal pad is checked for proper positioning (see section on metatarsal pad).

Forefoot Extension. To provide an insole filler to prevent anterior shift of the arch support during wear, a forefoot extension piece can be made of a thinned or split-belly center leather or equivalent material for the purpose. If the metatarsophalangeal and interphalangeal joint plantar surfaces are calloused, scarred, or sensitive, then a soft foam or sponge rubber surface is indicated. Soft forefoot pieces should generally be about ⅛ in. thick and covered with thin skin leather or vinyl sheeting for smoothness and comfort.

Such forefoot pieces can be spliced and cemented to the commercially available prefabricated or semiprefabricated arch supports. If the orthotist makes a wrap cast or shoe last of the patient, the forefoot, midfoot, and "hindfoot" piece are in one unit, a type of inlay that provides truest conformity to the entire plantar surface of the foot; the inlay also includes the features that have been installed to relieve, support, or elevate specific areas.

Heel pads. Heel cushions or pads can be added to any type arch support to relieve sensitive plantar surfaces of the calcaneus or to relieve pressure from a calcaneal spur. The sensitive plantar surface usually can be relieved by a sponge-rubber pad shaped to fit the heel area of the shoe insole, with feathering toward the midfoot area. The calcaneal spur can be relieved with a similar pad that has a concavity cut to fit directly beneath the spur. To prevent tilting the calcaneus anteriorly, heel pads or cushions should be used with longitudinal arch supports.

Fitting Arch Support to Shoe

In fitting the arch support to the shoe, the orthotist must place the support in the shoe so that its heel edge rests against the distal posterior aspect of the quarter lining of the shoe (Fig. 27b). This position must be maintained to insure replication of the conformity achieved during the support-to-foot fitting phase; otherwise, even a slight anterior shift of the arch support may introduce pain.

There are fitting difficulties that result from poor last and upper styles. Many times a completed arch support has to be thinned out or lengthened to relieve pressure from a tight shoe or widened and thickened to fill up a loosely fitted shoe. Since a metatarsal pad causes some spread and abduction of the toes, a straight inner-border last rather than a pointed-toe shoe should be selected. A blucher-style upper should be used when a metatarsal arch support is necessary or the patient will find his shoe tight across the lower instep (Fig. 27c).

Fabrication Methods

Methods of fabricating arch supports include (1) molding, (2) pressing, and (3) hammering.

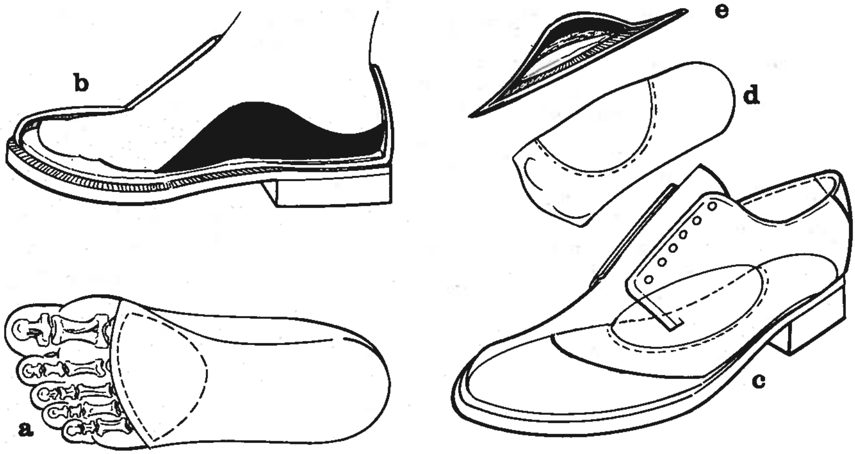

FIGURE 27. Arch supports. (a) Fitting of arch support to foot; dotted line indicates metatarsal pad placement; (b) fitting of arch support to foot in shoe; (c) wafer-type medial longitudinal arch support in shoe; (d) dorsal view of wafer support; (e) medial cutaway of wafer support showing wafer inserts.

1. The molding method can be applied to leather, laminated or sheet plastics, and Celastic. In this method, either the positive foot casts of the patient or shoe-last type forms are used as the base over which the materials are molded. The arch shells can be reinforced with steel shanks in the longitudinal area.

2. The pressing method is applied to aluminum or stainless steel, which is shaped by a power press over a shoe-last type of metallic form.

3. The hammering method can also be applied to aluminum or stainless steel for fabricating arch supports. In this method, the patient's foot cast is used as a guide, and the materials are hammered against a lead block until they conform to the positive casts.

Types of Metatarsal Arch Supports

The types of mettarsal arch supports most generally prescribed include:

1. The *Mayer,* for metatarsal conditions;
2. A *combination Schaeffer* for metatarsal and longitudinal support;
3. The *combination Whitman* for metatarsal, longitudinal, and lateral heel support.

Each of these supports can be made of leather, laminated plastics, or metal. The combination insole types are not usually permanent; they are lighter in weight and made of flexible and resilient materials. Metatarsal corsets are generally used for ease in changing footwear and for cases of splayfoot.

HEEL ELEVATION

Heel elevation is sometimes needed to restore horizontal alignment to the pelvic girdle.

Foot Disabilities

Leg shortening, with or without pathologies of the foot, or a fixed equinus with no leg shortening are conditions that may require elevation of the heel.

Shoe Modifications

Cork Layers. For the patient with a short leg but no foot pathology, the orthotist simply builds up enough height under the heel of the foot to restore pelvic balance. For heel elevations of more than ½ in., cork sheets of varying thicknesses are stacked, cemented, and attached as a sandwich component (Fig. 28). The highest point should be at the heel, and the elevation should decline gradually at the ball of the foot, leaving the least amount of cork at the toes so that toe spring at pushoff is easier.

To estimate the proper elevation height before permanently mounting the cork, the orthotist should stack the cork layers one at a time under the affected leg until pelvic balance is achieved. Taping or gluing the layers temporarily to the shoe will expedite the procedure. After temporarily taping on the elevation, the orthotist should attach a dummy heel to restore the heel-to-sole relationship so that the patient can ambulate and his gait be studied.

Metatarsal or Rocker Bars. A metatarsal bar or a rocker bar can be installed as an integral part of the cork elevation, and rollover can be increased by shifting the apex toward the heel. In a high elevation, the faster rollover facilitates a more normal gait pattern since longer strides can be taken more smoothly.

FIGURE 28. Heel elevations. Top: sandwich; bottom: combination insert-sandwich division with rocker bar installed as integral part of cork elevation to facilitate faster rollover.

Flaring. For a fixed equinovarus condition, flaring of the sole or heel may be necessary. If so, it can be installed as part of the elevation. In a stock shoe, the outsole, heel, and welt must first be removed. Skin leather, matching the shoe upper, is then sewn (with the finished side facing and lying against the shoe upper) to the welt, insole, and upper. The cork is cemented in layers to the insole and shaped to the desired height and function. Another insole is shaped to the plantar surface of the cork, and the distal end of the elevation cover is reflected over the circumference and plantar edge of the insole, and sewn to a welt. A shoe shank, filler, outsole, and heel are added for completion.

STOCK SHOES WITH ORTHOPEDIC FEATURES

In order to offer the patient as much toe prehension as possible, the orthotist may recommend a shoe with a straight innerline last, also referred to as the "straight innerborder." This shoe differs from the stock shoe in that the anterior sole perimeter from the first metatarsophalangeal joint to the distal end of the hallux is a straight line, which permits the hallux to lie in normal alignment.

The "bunion-lasted" shoe also has a straight inner-line but is distinguished by the very close conformity of shoe upper to the area behind the first metatarsal head on the medial side (waist level of the foot). The snug conformity puts pressure on the abductor hallucis, with consequent forcing of the proximal phalange, and thus the entire hallux, toward the median line. This function helps to correct and relieve severe hallux valgus, which has a moderately mobile MP joint.

Stock shoes with orthopedic features, such as a long counter on the medial side, should be obtained when a rigid wall is necessary to retain the foot in the desired alignment. The long counter, extending between the heelbreast and the break of the shoe, can assist a longitudinal arch support in correcting a flaccid valgus or in preventing a rigid valgus from becoming more severe.

As previously mentioned, if the patient is to wear arch supports, he should be advised to purchase the straight inner-line shoe with blucher-type uppers. Such a combination will give his foot the extra space needed when the toes abduct and extend under weight bearing when a longitudinal arch support is used. If there is need for ankle support or immobilization of the ankle joints, high-quarter shoes should be obtained. Low-quarter shoes, however, can be used if a high-quarter-shaped cuff is sewn onto the upper.

Figure 29 is a diagrammed composite of several modifications incorporated into a high-quarter shoe for the relief of pain resulting from an ankylosed ankle or foot. Table 1 gives an overview of general foot disabilities and the shoe modifications usually prescribed in such cases.

Sach Heel Advantages

It is appropriate at this point to mention additional advantages of using the SACH heel. When there is a pathology that precludes ankle motion, a hard heel would cause the posterior forces at the calfband to be so great that instability at the knee joint would result. If the quadriceps is not strong enough to override this force, above-knee braces with locks have to be provided.

In contrast, the SACH heel not only absorbs shock and reduces posterior calfband pressures, but it also allows inversion and eversion, reducing the lateral calfband pressures when the brace-wearer walks on uneven ground. The SACH heel rubbers can be glued to the brace attachment with an epoxy adhesive, one layer of rubber being glued to another, including the thin rubber heel, with Stabond.

SUMMARY

The main purpose of shoe modifications is to restore as normal a foot balance as possible, i.e., a three-point weight-bearing pattern, with the weight evenly distributed between the first and fifth metatarsals and the apex of the heel.

By the proper application of various shoe modifications, the orthotist may effect:

1. Medial longitudinal arch support and/or lateral weight shift;
2. Lateral longitudinal arch support and/or medial weight shift;
3. Metatarsal arch support, anterior and posterior;
4. Metatarsophalangeal, interphalangeal, or tarsometatarsal joint immobilization;
5. Arch support and relief of tender tissue;
6. Balance at the pelvic girdle by heel elevation.

The shoe style upon which the orthotist generally prefers to base these modifications is the plain-toe blucher, with a ¼-in. prime leather sole and a hard rubber heel.

FIGURE 29. High-quarter shoe with combination of modifications prescribed for a painfully ankylosed ankle or foot. (a) High bilaterally extended counter; (b) reinforcing steels; (c) long steel spring; (d) SACH heel; (e) rocker bar. If the patient were obese, medial and lateral shank fillers would be used, and the SACH heel replaced by a heel of regular hardness to prevent rolling or vaulting over the shank fillers from heel strike to toe-off.

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TABLE 1.—*Foot Deformities and the Shoe Modifications Used for Their Correction*

Foot Deformity	Corrective Shoe Components [a]		
	Insert	Sandwich (in addition to solid steel shank)	Overlay
Amputation, ankylosis, or arthritis of: Interphalangeal, metatarsophalangeal, or tarsometatarsal joints (Lisfranc's).		Long steel spring	Rocker bar.
Taloscaphoid, calcaneocuboid joints (Chopart's).		Long steel spring and high-quarter uppers with reinforced sides.	Medial and lateral shank fillers, a rocker bar, and a SACH heel.
Subtalar, talocrural joints		High-quarter uppers with reinforced sides.	SACH heel.
Bursitis	Full-length innermold	Long steel spring	Metatarsal bar or rocker bar.
Calcaneal spur or pressure-sensitive heel tissue.	Longitudinal arch support and heel cushion.		SACH heel.
Equinus, fixed	Heel elevation	Cork heel elevation and heel-base elevation of other shoe.	Rocker bar.
Fractures, exostosis, hallux rigidus, or malunion.	Full-length innermold	Long steel spring	Rocker bar.
Hallux valgus	Full-length innermold.		

Leg shortening	Heel elevation	Cork heel elevation or heel-base elevator.	Rocker bar.
Metatarsal bone, shortening of the first	Elevator support for hallux and first metatarsal.		
Metatarsalgia	Regular metarsal pad or dancer pad or metatarsal insole or metatarsal corset.		
Pes cavus	Regular metarsal pad or dancer pad or metatarsal insole or metatarsal corset.		Metatarsal bar or Denver heel.
Pes planus: Laterally	Long counter on lateral side; lateral heel wedge; cookie or scaphoid pad.		Reversed orthopedic heel.
Medially	Cookie or scaphoid pad and longitudinal arch support.	Orthopedic heel wedge	Orthopedic heel.
Plantar warts	Regular metatarsal pad; dancer pad or metatarsal insole or metatarsal corset or full-length innermold.		
Valgus, flaccid	Cookie or scaphoid pad; long counter on medial side.		Orthopedic heel; medial sole-and-heel wedge.

See footnote at end of table.

TABLE 1.—*Foot Deformities and the Shoe Modifications Used for Their Correction*—Continued

Foot Deformity	Corrective Shoe Components [a]		
	Insert	Sandwich (in addition to solid steel shank)	Overlay
Varus:			
Ankylosed	Long counter on lateral side		Lateral flaring of sole, heel, or sole and heel.
Flaccid	Cookie or scaphoid pad; long counter on lateral side; lateral heel wedge; longitudinal arch with lateral heel support.		Lateral sole and heel wedges.

[a] The severity of the foot disability determines the need of a single component or a combination of components. The modifications listed in this table are those most commonly used with stock shoes, or stock shoes with orthopedic features. When two or more similar types are indicated, the orthotist selects the modification most appropriate for his patient.

A thorough shoe checkout is most important before applying modifications since the shoe is the foundation of the brace as well as the foot. Although the correction of foot deformities is not yet a biomechanical science, a knowledge of the foregoing principles of weight bearing and weight shift, will help the orthotist in selecting the proper shoe modifications to restore foot balance and to relieve pain.

ACKNOWLEDGMENTS

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