The SACH (Solid-Ankle Cushion-Heel) Foot

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Summary

On May 24, 1957, the Committee on Prosthetics Research and Development of the Prosthetics Research Board, National Academy of Sciences—National Research Council, recommended approval of the production models of the SACH* Foot for adult male amputees. Plate A shows one of these newly accepted prosthetic components whose design obviates a prosthetic ankle joint.

Concurrent with acceptance was the release of tentative manufacturing specifications as well as finalized instructions for installation and adjustment of the SACH Foot in the prosthetics shop. A pre-shaped oversize foot is now being manufactured under control of detailed specifications. Sizing and ordering criteria, final shaping, and assembly of the SACH Foot to prostheses are described in the installation and adjustment instructions which are part of this article.

Introduction

The basic functional principles of the SACH Foot are not new to the prosthetic technology. Many foot designs of similar types have existed for some time. However, concerted development and evaluation performed within the Federal Government's Artificial Limb Program between 1954 and 1957 have transformed diverse predecessors into one generally acceptable and standard manufactured design. The SACH Foot for adult male amputees**, although superficially simply in design, provides many of the foot and ankle functions required of prostheses. It is not a complex device, yet faulty construction, shaping, and prosthetic installation may very easily result, limiting function and causing early structural failure. Therefore, the Artificial Limb Program has recommended the release of tentative manufacturing specifications and precise installation and adjustment instructions. Adherence to the specifications by manufacturers and to the instructions by prosthetists will assure to all, limb dealers and patients alike, that the SACH Foot will always be the same valuable product which was carefully developed and evaluated in the Artificial Limb Program.

Development of the SACH Foot

A. A. Marks, in 1880, patented (1) an artificial foot for direct attachment to a prosthetic shank; no ankle joint was to be employed. The patent describes layers of rubber used to provide "sufficient elasticity" for toe action, particularly at toe-off. Although not *specifically* claimed in the patent, the heel portion of the foot had rubber of sufficient thickness to provide some degree of plantar flexion during walking. A core made from wood, or "any other suitable material" was shaped to provide, in a manner rather similar to the SACH Foot, a smooth roll-over or "rocker" action at the terminus of the stance phase.

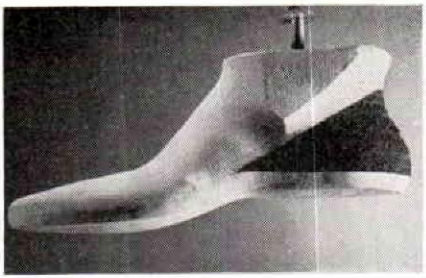
In a patent (2) of 1895, G. E. and W. L. Marks describe a similar artificial foot having an internal, inelastic core, but also specifying a rubber heel portion which contained a spring "being free to yield *with* the rubber."

*Pronounced to rhyme with "latch."

**Research efforts are already underway to develop SACH Feet for female and child amputees.

Plate A

Production Model of the SACH Foot



The patentees describe the foot as having "actions when under heel or toe pressure, as during the act of walking, which greatly enhance the value of the foot and facilitate its use by and add comfort to the wearer. . . . The foot may be made of sponge rubber for softness, lightness, noiselessness, and comfort . . . (to) insure the desired resiliency under heel and toe pressure."

During the years following the times of these early patents, limb-shops in the United States, as well as in Germany and Austria, have used feet of designs similar to the basic SACH Foot: an internal, rigid core or keel of proper shape and length with resilient materials provided at the heel and toe. In Canada, the design of a lightweight but durable Syme's prostheses with necessary foot-ankle function was facilitated by the use of SACH Foot principles.

J. Foort and C. W. Radcliffe of the Prosthetic Devices Research Project, Institute of Engineering Research, University of California (Berkeley) developed the first prototypes of the present version of the SACH Foot. Since the weight of a prosthetic foot is particularly critical, being located at the greatest distance from the lower extremity stump, developmental efforts were concentrated on the selection of lightweight yet durable materials. Previously, commercial feet of similar principle had been quite heavy and had exhibited structural limitations. The crepe shoe sole material successfully used by the Canadians in the Syme's foot construction was adopted to minimize weight and maximize durability. Development efforts at the University of California defined the shape and length of the wood keel and the proper shape of the foot exterior, particularly the heel cushion, a cemented sponge rubber laminate. The SACH Foot development was facilitated by the earlier work done by the UC-Berkeley project on fundamental studies of human locomotion(7).

Initial evaluations(3) of the UC-Berkeley SACH Foot yielded extremely favorable amputee reactions, particularly to the shock absorption of the heel and the "smooth transition of weight from heel to toe during the stance phase." However, the testing agency* questioned the effectiveness of the cement bonds in the heel cushion layers. A change in the specified adhesive was made by the UC-Berkeley development group. This change noticeably overcame the difficulties had with the laminate bonds. In June, 1956, it was recommended(5) that the SACH Foot be manufactured in small quantities so that production versions could be tested. Problems were then encountered in getting a consistently satisfactory product; these problems were noticed in the course of evaluation and were solved by the effective "feedback" of findings to the manufacturer. In the spring of 1957 production models were found to be acceptable to the testing agency(4) resulting in a May 24, 1957, approval by the Committee on Prosthetics Research and Development, PRB(6)

* Prosthetics Devices Study, Research Division, College of Engineering, N. Y. University.

Some Advantages of the SACH Foot

Absence of mechanical articulation in the prosthetic foot-ankle region eliminates maintenance problems due to frictional wear, manifested by objectionable noises, joint looseness, and thus, some instability and inconsistent function. Also, design and construction defects of the "conventional" foot's rubber bumpers and their housings have often resulted in repeated limb-shop maintenance and patient inconvenience. The direct assembly of the SACH Foot to the prosthetic shank overcomes these difficulties while furnishing necessary prosthetic foot-ankle function.

The heel cushion provides, at heel contact, a shock absorption more than equivalent to the plantar flexion of a conventional ankle. As the amputee walks over his prosthetic foot following compression of the heel cushion, the foot begins to simulate ankle dorsiflexion. The toe approaches the floor, the prosthetic shank rotates forward over the foot, and the heel cushion decompresses. Weight is gradually taken on the ball of the SACH Foot. Directly above the ball is the anterior end of the internal, rigid keel. Weight is now borne at two points, the ball of the foot and the partially compressed heel cushion. Finally, full weight is transferred to the forward end of the wood core, or keel. The length and shape of the keel are designed to provide a smooth roll-over or "rocker" action just prior to push-off. The location of this "toe-break" or roll-over line (the anterior end of the keel) is somewhat closer to the vertical center line of the prosthetic shank than is found in conventional feet with ankle joints. Since in the SACH Foot there is no ankle joint to provide dorsiflexion, it was necessary to reduce the "toe-break" distance. Nevertheless, the University of California (Berkeley) has found this reduced distance as being quite desirable, reducing energy consumption during walking, particularly up inclines.

Specifications of the SACH Foot

Tentative specifications(8) have been developed to cover the manufacture of the SACH Foot. These specifications *require* the feet to be preshaped oversize by a manufacturer. Since the SACH Foot is to be fitted to the amputee's shoe, it must be shaped carefully so as not to affect function adversely by limitations imposed by the shoe itself. It is necessary, for example, to be particularly scrutinizing in shaping the heel cushion, the toe section, and the arch area for proper fit within the shoe. Prosthetists will be able to purchase SACH Feet from manufacturers who have performed initial shaping in accordance with *specified* templates and patterns. The contours of the preshaped foot will guide the prosthetist in performing his final shaping for shoe fit. Thus, prosthetists should not, under ordinary circumstances, deviate grossly from the contouring provided by the manufacturers; material will be removed with care by following the detailed instruction (below) but, more importantly, by maintaining the proportions provided by the manufacturers.

The manufacturing specifications also detail heel cushion compression properties, as well as all-around dimensioning of the product. Tests performed by the Standards Laboratory* are specified as checks for both structural and functional characteristics. For example, the heel cushion delamination problem noted in the early development of the present SACH Foot would be observed during routine sampling and testing of manufacturers' products. Corrective steps could be taken by the Standards Laboratory

* Testing and Development Laboratory, VA Prosthetics Center, 252 7th Ave., N. Y., N. Y.

early enough to avoid generalized amputee inconvenience. Copies of the tentative specifications will soon be made available through the Office of the Executive Director, Prosthetics Research Board, National Research Council, 2101 Constitution Avenue, Washington, D. C.

Installation and Adjustment Instructions

The following instructions,** *Installation and Adjustment of the Solid Ankle Cushion Heel (SACH) Feet For Adult Male Amputees,* will be made available to prosthetists in the form of reprints of this article, which may be ordered from the headquarters of OALMA, 411 Associations Bldg., Washington 6, D. C. It is important that these instructions be carefully followed by limb-fitters so that they and their patients may avoid inconvenience and difficulty.

I. Functional Characteristics

The Solid Ankle-Cushion Heel Foot, i.e., SACH Foot, has been designed to provide shock absorption and ankle action characteristics equivalent to the normal ankle without the use of an articulated ankle joint. The action of the SACH Foot is accomplished by the use of two functional elements: a properly shaped wedge of cushioning material built into the heel, and an internal structural core or keel shaped at the ball of the foot so as to provide a rocker action. The cushion heel provides an action which not only cushions the heel impact efficiently, but also simulates normal plantar flexion very closely. This action is indicated in Figure 1. As shown in the drawings the foot is designed to be worn without any additional covering material.

The action of the foot is very smooth and the amputee is not conscious of sudden changes in resistance as is typically experienced in a conventional foot with an articulated ankle joint which includes a soft plantar-flexion bumper and a firm dorsi-flexion stop. At heel contact the heel cushion compresses approximately 3/8" allowing the forefoot to rotate toward the floor. This action, in combination with the additional forward inclination of the shank and foot as a whole, results in normal appearance during the first part of the stance phase. During the mid-stance, or roll-over phase, the body weight is divided between the heel and ball of the foot and there is a gradual transfer of weight forward. The shape of the structural core or keel under the ball of the foot provides support and a smooth rocker action at push-off. The distance from the ankle center forward to the toe break is shorter than in many conventional feet. This has been found desirable as one means of reducing the energy cost of walking, especially up inclines.

II. Sizing and Ordering Specifications

SACH Feet may be purchased in a rough-shaped oversize blank in three shoe-size ranges, 6-8, 8-10, and 10-12. Each size range has a common keel size, there being 1/4" difference in toe break-ankle distance between size ranges. In addition, the heel cushions are fabricated in three stiffnesses: soft, medium, and hard. The medium heel cushion will be found suitable for most applications. If, however, after trial or on the basis of experience it appears that the soft or hard heel cushion is more suitable for a particular amputee, the appropriate type should be ordered. However, in many cases where heel cushion stiffness is suspected of being the cause of poor function, the difficulty may be traced to improper installation, alignment or adjustment.

The apparent overlap in the sizes of SACH foot blanks can be used to advantage in order to compensate for differences in height between amputees.

** Reproduced from Reference 4, pp. 9-18.

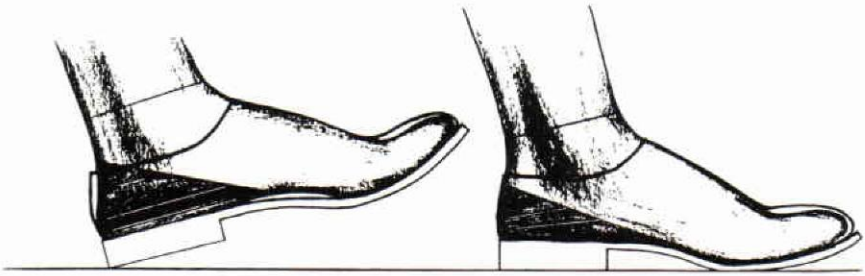


Figure 1—Simulation of plantar flexion by heel cushion compression.

Table I suggests a procedure for ordering of borderline-size foot blanks based on amputee height. Observations of this procedure will result in the keel length of the foot being more nearly compatible with the length of the prosthesis.

TABLE I—FOOT BLANK SIZE FOR BORDERLINE SIZES

Borderline Shoe Size	*Recommended Blank Size*	
	Below 5′ 9″	*Above 5′ 9″*
8	6-8	8-10
10	8-10	10-12

In ordering foot blanks, the following should be specified: (1) *Size range;* (2) *Right or Left;* (3) *Heel Stiffness Desired; e.g.* 8-10 *R Medium.*

III. Shaping

Do not shape the ankle portion of the foot above the shoe level until after final installation of the foot on the shank with proper toe out. *Leave the ankle area rough shaped for walking trials.*

The shaping of the SACH Foot is very important since both its function and appearance are influenced by its shape. There are three areas, as indicated in Figure 3, where particular care is required; these are:

1. the heel cushion.
2. the upper and lower surfaces of the arch of the foot.
3. the toe section.

The general foot contours necessary for the proper functional shaping have been preshaped into the oversize foot blank. Only minor changes in contour as necessary to reduce oversize dimensions are required. In particular no change should be made in the lower third of the posterior heel contour since this contour has been preshaped so as to provide the proper distance from heel to a line through the attachment bolt.

When inserting the foot into the shoe during fitting, always use a thin sock on the foot. Contouring the foot, as described below, can best be accomplished by sanding parallel to the laminations, using a cone or drum sander with a spindle speed of at least 1750 rpm.

The heel of the SACH Foot must be shaped so as to fit the shoe in both the relaxed and compressed conditions. The heel is shaped so as to fit the shoe tightly near the sole of the heel yet with considerable clearance near the brim of the heel counter. Approximately 1/8″ clearance should be allowed at the brim of the counter between the posterior, medial, and lateral

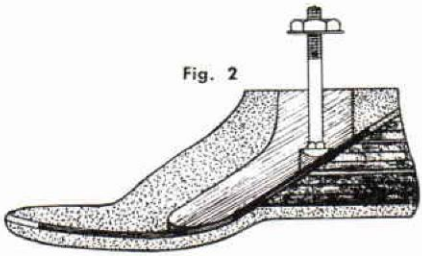
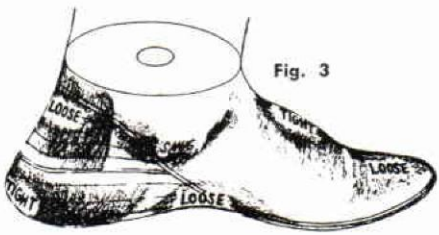


Figure 2—Cross-section of the Solid Ankle Cushion Heel (SACH) Foot.



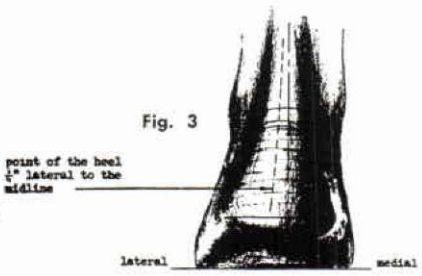


Figure 3—Shaping of the SACH Foot.

surfaces of the heel of the foot and the heel counter of the shoe. This clearance should decrease gradually and extend downward approximately two-thirds of the depth of the heel counter of the shoe. The lower third of the heel of the SACH Foot is fitted snugly into the heel counter of the shoe. The clearance near the brim of the shoe allows the heel cushion to expand as it compresses under load without interference between the shoe and foot. This clearance is also extremely important in preventing wear of hose.

In shaping the heel the point of the heel should be displaced approximately ¼" to the lateral side with the foot oriented straight ahead. As the toe of the foot is rotated laterally to give the proper toe out, the point of the heel will rotate back toward the mid-line and the point of initial heel contact will again be through the geometric center of the foot. If this is not done, weight will be transferred through the lateral side of the heel cushion at the time of heel contact.

The bottom surface of the arch of the foot must be shaped to provide a minimum of ⅛" clearance between the foot and the inner sole of the shoe. If clearance is not provided, the arch of the foot will contact the sole of the shoe as the heel compresses, resulting in restriction of motion, shoe damage, and wear of hose in this area.

The upper surface of the arch of the foot is shaped so as to hold the heel cushion against the counter of the shoe and to match the shoe-lacing gap on the natural side. The toe-break of the forefoot must be shaped so as to provide a looser fit than is typical with wooden feet. The flexible material of the forefoot expands with compression as the toe bends and this expansion must be allowed for in shaping the foot. Failure to provide sufficient clearance will restrict the toe motion and cause shoe damage.

IV. Installation

The SACH Foot is attached to a conventional wooden shank by means of a 3/8" steel carriage bolt. During manufacture the carriage bolt is inverted and its head is imbedded firmly into the lower surface of the hardwood keel. A solid section of wood in the end of the shank between 1½" and 2" in depth is required for installation.

Due to the soft nature of the materials used in the construction of the SACH Foot, an allowance for extra shank length is necessary in order to compensate for the compression of the foot under load. The average amputee requires an increase in length of ¼" for this purpose. Amputees weighing less than approximately 140 lbs., or where the hard heel cushion is used, may not require the full one-quarter inch.

After adjustment of toe out and walking trials, the foot is glued in position.

The step-by-step procedure for installation of a SACH Foot as a replacement for a conventional foot on a wooden shank is as follows:

1. Fit the foot to the shoe in accordance with instructions under Section III, Shaping.

2. Measure the distance from the knee center to the bottom of the heel of the conventional foot with shoe off.

3. Measure the distance from the hardwood attachment surface on the top of the keel to the bottom of the heel of the SACH Foot.

4. Subtract the second measurement from the first. This will give the distance from the knee center down to a point where a cut through the ankle would give an attachment surface for the SACH Foot which would result in exactly the same length of shank as with the conventional foot.

5. Increase the shank length by the amount of the ¼" compression allowance. A ¼" allowance is made by making a mark ¼" below the mark made in Step 4.

6. Extend this line around the shank parallel to the upper surface of the existing hardwood ankle base so that the attachment surface for the SACH Foot will be parallel to the floor when the amputee is standing on the prosthesis.

7. Sever the shank at this line.

8. Check to see there is a solid section of wood 1½" to 2" in depth at the lower end of the shank, then plug all existing holes in ankle block with doweling. If less than 1½" of wood is present, add wood or a mixture of thermo-setting resin and coarse sawdust inside the shank.

9. Layout position of a 3/8" hole which will accommodate the 3/8" foot-attachment bolt. The hole should be located approximately at the geometric center of the cut section at the ankle and bored at right angles to the cut section of the shank. Where any question exists, locate the hole to match the posterior surface of the shank and the Achilles tendon area of the SACH Foot.

10. Bolt foot in place without dowels and assemble the leg. Recheck fit of shoe and whether the upper attachment surface of the foot is parallel to the floor with the body weight carried on the foot. In a standing position the heel cushion should be compressed slightly.

11. After toe-out adjustment and walking trials, and before final delivery, the foot should be glued (or glued and doweled) in place and the attachment nut with lock washer securely tightened to prevent twisting.

Note: While gluing alone may be adequate, it is recommended that for maximum security the foot be both glued and doweled. The procedures for doweling are:

Place reference marks on shank and top of foot to indicate the toe-out alignment for later assembly. Remove SACH Foot from shank. Drill ¼" holes ½" deep into exposed surface of the wood keel anterior and posterior to the attachment bolt and parallel to it. Cut two lengths of 1" doweling 1¼" long. Trim one end of each piece to a point. Glue the dowels into the holes pointed end up. Place shank on attachment bolt and sighting to see that the alignment marks are in line, press down firmly until the sharpened dowels make an impression in the bottom of the shank. Using these marks as centers, drill ¼" holes 1" deep into the shank, perpendicular to the cut section. Apply glue to the protruding dowels, top of the foot and bottom of the shank and press together firmly. Install lock washer and attachment nut on the attachment bolt. Tighten securely. Use "Woodlock" or similar water resistant adhesive.

12. Finish shaping by sanding foot above shoe-top level to simulate the malleoli of the sound foot.

V. Adjustments

There are two types of adjustment possible with the SACH Foot: (1) change in heel cushion stiffness and (2) change in heel cushion thickness.

The heel elevation of the foot sometimes requires adjustment due to differences in shoe lasts. The SACH Foot is presently manufactured with an 11/16" heel elevation, i.e., the bottom of the heel is 11/16" above the level of the ball of the foot with the attachment surface parallel to the floor. Before any adjustment of heel elevation is attempted, it is important to recheck the clearance between the arch of the foot and the shoe (Section III, Shaping). The wedge angle of the heel cushion should not be changed.

An increase in heel elevation (decrease in heel cushion thickness) is indicated if there is excessive heel cushion compression when the amputee stands on the prosthesis with the top of the foot parallel to the floor. A limitation in plantar flexion in walking and/or a decrease in knee stability in both walking and standing may accompany this condition. The heel elevation may be increased up to 3/16" by sanding foam crepe sole material from the bottom of the heel. If an increase in heel elevation greater than 3/16" is indicated, improper sawing of the shank should be suspected. This should be corrected at the junction of the shank and foot by rechecking alignment; and resawing, sanding or wedging as necessary.

A decrease in heel elevation (increase in heel cushion thickness) is indicated where there is insufficient or no compression of the heel cushion in the standing position. This condition will be reflected in gait by excessive knee stability and a feeling of "walking over a hill." The condition is corrected by cementing shims of crepe sole material, leather or other firm flexible material to the bottom of the heel area using Stabond T-161 or equivalent until the desired heel cushion compression is achieved.

A change in heel cushion stiffness is indicated where a check of heel cushion compression in the standing position shows proper adjustment of heel elevation, yet observations indicate too soft or too hard an action while walking.

The step-by-step procedure for exchange of heel cushion in the SACH Foot is as follows:

1. Work on a smooth, level bench top.

2. Remove shoe from foot and stand shank on the bench with an 11/16" block under the heel.

3. Using carpenter's square, draw a vertical reference line on the medial or lateral aspect of the shank in approximate mid-line.

4. Mark edge of sole on medial and lateral sides to indicate the anterior point of the heel cushion.

5. Place the shank in a wood vise with *heel* up.

6. Use a sharp knife and cut out the heel cushion. Cut along the sole glue line first, bending the sole outward as the knife cuts; then bending the wedge out, cut along the inner glue line.

7. Remove irregularities in the cut surfaces of the foot with a fine rasp or coarse file.

8. Insert the new wedge, without adhesive, so that the point comes to the same location as the one removed (indicated by the marks made on the sole). Be sure the longest lamination is next to the sole.

9. Remove shank from vise and replace on bench with 11/16" block under the heel.

10. Check the line drawn on the shank to see that it is in alignment with the vertical arm of the square. Make any necessary corrections by forcing the wedge anteriorly or slipping it posteriorly until proper alignment is obtained.

11. Install the new wedge at the point selected, using Stabond T-161 or equivalent on the mating surfaces.

12. Shape the heel in accordance with instructions under Section III, Shaping.

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