

Prostheses for Syme's Amputation

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Whereas detailed information on Syme prostheses prior to the turn of the 20th century is not readily to be had, the catalogs issued by limb manufacturers in the early 1900's seem invariably to include a description of a prosthesis for the Syme stump. Of many different designs offered, some used articulated ankles (if space were available below the stump and socket), some used rubber feet without ankle joint. Wood sockets, steel-reinforced leather sockets, and even cast aluminum sockets were available. Though most manufacturers showed prostheses with a full-length anterior opening for entry of the stump, there also were designs employing a partial anterior opening, and at least one used a full-length posterior opening.

The descriptions accompanying the catalog presentation of these devices indicate that the originators were themselves aware of most of the problems involved in designing a prosthesis for the Syme stump. One design of the Winkley Artificial Limb Co. (16) had no ankle joint because, according to the designer, in many cases no known ankle unit small enough to fit into the available space could withstand the high stresses involved. When ankle joints were provided (Fig. 1, left), a steel-reinforced leather socket was used; when space limitations precluded use of an ankle joint (Fig. 1, right), use was made of a willow wood socket, presumably to provide a base for attaching the felt or sponge-rubber feet available at the time.

Gaines-Erb (6) used a wood socket with a full below-knee socket at the top and only a partial opening on the anterior aspect so that it was possible to make any desired distribution of weight-bearing between distal and proximal areas of the stump (Fig. 2). Marks



Fig. 1. Two types of Syme prostheses offered by the Winkley Artificial Limb Company, Minneapolis, circa 1910. Design at left incorporates an articulated ankle, that at right a foot without ankle joint, presumably of rubber.

(12,13) was aware of the need for distributing uniformly along each side of the tibia the loads developed on the stump during roll-over and, realizing that this requirement was rarely met with an anterior opening and lacing, attempted to solve the problem by using a cast aluminum socket with appropriate relief for the tibial crest and other sensitive areas (Fig. 3). A leather cuff closing the posterior opening encircled the shank to an anterior lacing, and the Marks rubber foot must have permitted a good cosmetic effect. An earlier version of the Marks foot, one of wood, illustrates the extent to which the inventor went to achieve resistance to the high forces developed in the area of the ankle (Fig. 4).

In a 1919 design by Bowler (1), dorsiflexion bumpers were replaced by a strap between the posterior surfaces of the socket and the foot

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(Fig. 5), a feature also suggesting an appreciation of the high stresses involved in the ankle-joint mechanism. Not only were the unit stresses in the resisting material thus reduced but during dorsiflexion the forces on the ankle joint itself remained compressive instead of becoming tensile, a condition favoring longer life. Instead of being in the usual medial and lateral positions, the metal straps reinforcing the leather socket were anterior and posterior, where they were least bulky and most effective



Fig. 2. Syme prosthesis offered by the Gaines - Erb Company, Denver, circa 1915. Note provision for weight-bearing about the proximal portion of the shank.

structurally. A Syme prosthesis available from the Columbus Artificial Limb Company (2) employed the posterior strap patented by Bowler and added an anterior elastic strap, presumably to maintain compressive forces on the ankle joint during plantar flexion (Fig. 6), but the idea of anterior and posterior reinforcing straps, as proposed by Bowler, was discarded.

In almost all cases, lack of materials easily molded and with adequate strength but light in weight resulted in a certain bulkiness and heaviness that tended to produce a certain amount of discomfort for the wearer

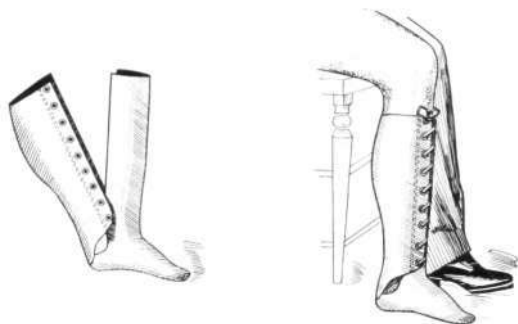


Fig. 3. Syme prosthesis offered by A. A. Marks, Inc., New York, early in the 20th century. The shank-socket, cast from aluminum, contained a posterior opening. A rubber foot was used routinely.

even if the fit itself were comfortable. In an effort to decrease weight and size, some prosthetists fabricated devices with marginal strength characteristics, devices which seldom lasted as long as comparable ones intended for leg amputations at other levels. The prosthesis that by 1940 seems to have been fitted almost routinely in both the United States and Canada consisted of a leather socket, reinforced with steel straps along the medial and lateral sides and made with a lacer and soft leather tongue along its anterior aspect (Fig. 7). Feet were generally of the so-called "conventional" type employing a single-axis ankle joint (often placed lower than usual) and incorporating foreshortened rubber bumpers. It was often uncomfortable, usually bulky because the sidebars projected beyond the bulbous end of the stump, and highly subject to mechanical failure of the sidebars.

With the introduction of plastic laminates (15) into the practice of prosthetics, research workers at the Prosthetic Services Centre of the Department of Veterans Affairs, Toronto, were quick to realize that the use of plastic laminates might well result in the development of a Syme prosthesis to a great extent free from the shortcomings of Syme prostheses previously used. Prior attempts to use laminated wood-veneer sockets had failed to produce practical prostheses owing to the difficulty of molding about the bulbous end, but the results encouraged the investigators to proceed with the then newly developed fabric-plastic laminates. The first model that showed promise (3) consisted of a socket molded of a polyester-Fiberglas laminate with a neoprene-crepe foot reinforced by a polyester-Fiberglas keel extending from the distal end of the socket (Fig. 8). To provide more comfort along the anterior aspect of the stump, the opening for

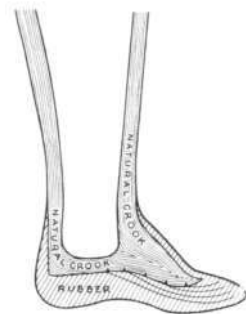


Fig. 4. An early version (circa 1889) of a Syme prosthesis manufactured by A. A. Marks, Inc. Socket and keel were formed from a single piece of wood so selected that the grain afforded maximum strength.

entry of the stump was cut out of the rear section of the socket, stability being obtained by replacing the cutout section and holding it in place by a metal fitting at the bottom and a strap and buckle at the top.

Although use of plastic laminate materially reduced bulkiness, and although the nonarticulated foot eliminated many of the problems associated with the so-called "conventional" unit, mechanical failure in the socket where the cutout was largest occurred too frequently for the new prosthesis to be adopted as a standard item (3). Fiberglas roving (loosely spun cords of Fiberglas molded in place along the edges of the cutout) increased the strength of the socket, but it was necessary to substitute

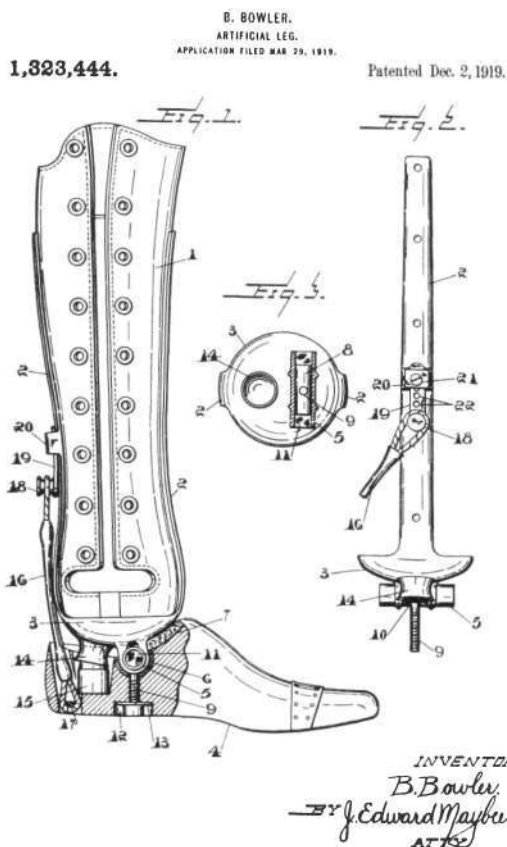


Fig. 5. Syme prosthesis patented by Bowler (1) in 1919. First known attempt to improve appearance by use of an opening on the side of the socket, reinforcing straps on the anterior and posterior surfaces. A flexible cable, another novel feature, provided resistance to dorsiflexion without placing the ankle parts in a state of tension.



Fig. 6. Syme prosthesis offered by the Columbus Artificial Limb Company, Columbus, Ohio, circa 1925. Some of the features of the Bowler patent (1) are incorporated. Cf. Figure 5.

epoxy resins (much better adhesion to the glass fibers) for the polyesters before fully adequate strength could be obtained. With a few refinements, this prosthesis (Fig. 9) is in use routinely today by the Canadian Department of Veterans Affairs (4).

Attempts by workers in the Artificial Limb Program in the United States to employ the Canadian technique using polyester-Fiberglas laminates led to the same kinds of mechanical failures experienced by the Canadians (5,7,8). In addition, a good proportion (14) of the Syme cases fitted could not continue to assume full end-bearing comfortably throughout the entire day. This experience, coupled with a reluctance to employ Fiberglas if the more convenient nylon stockinet (15) could be used, or to use the first-available epoxy resins because of the inherent toxicity of the wet, uncured resin when mixed with the hardener,² led to the development of the "Medial-Opening Plastic Syme Prosthesis" (Fig. 10) at the Veterans Administration Prosthetics Center (10,11). To reduce the unit stresses along the periphery of the cutout necessary for entry of the stump, the cutout was made in the medial wall of the socket (page 68). Unlike the posterior cutout in the Canadian version, the medial opening does

² The recent introduction of polyamide hardeners has since greatly reduced the risk of the fabricator's contracting dermatitis.

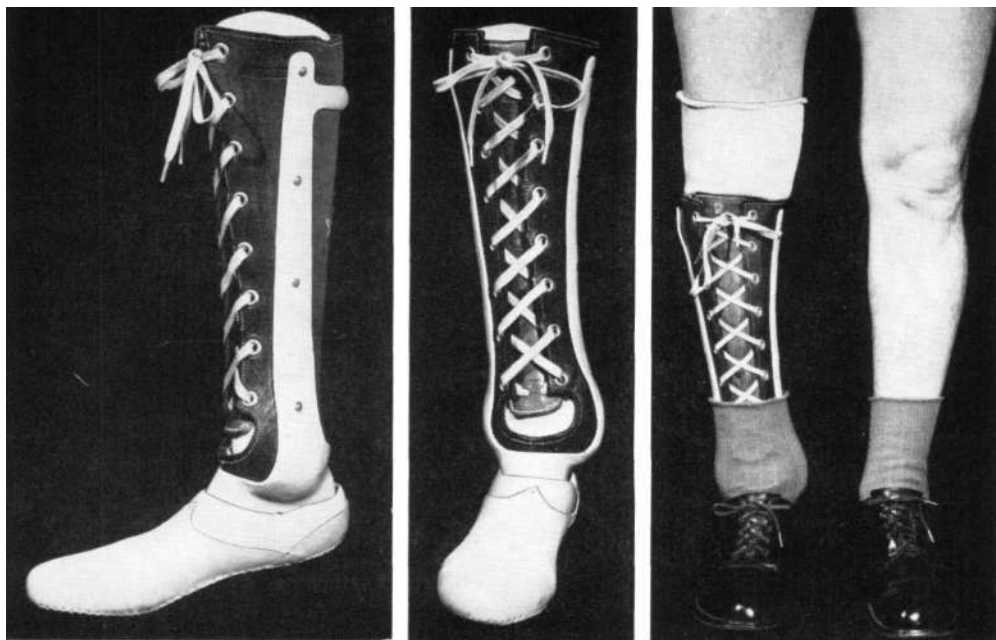


Fig. 7. Syme prosthesis typical of the era before introduction of plastic laminates into the fabrication of Syme prostheses.

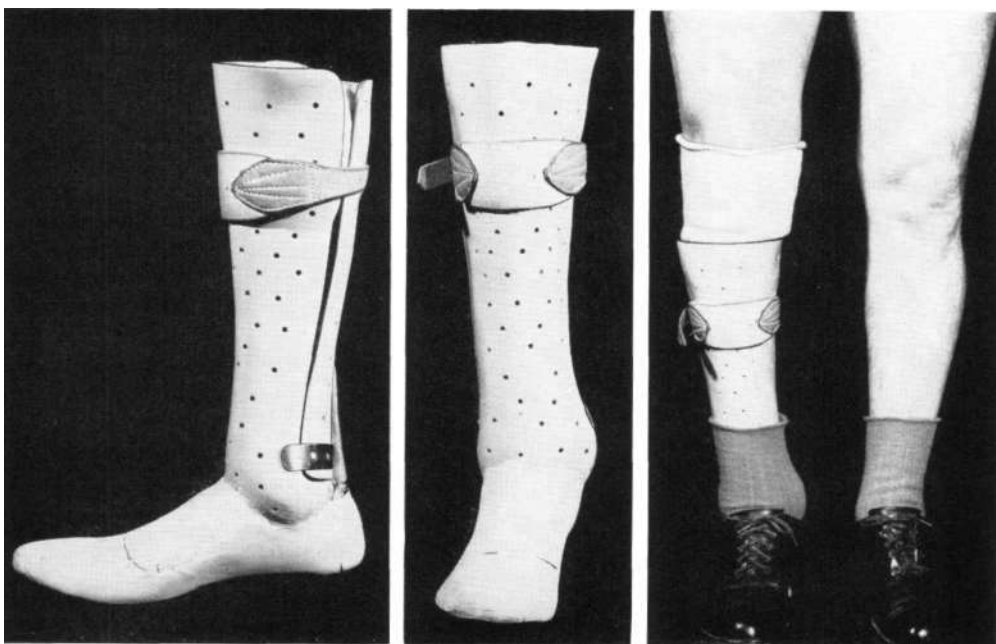


Fig. 8. An early version of the Canadian-type plastic prosthesis for Syme's amputation. The nonarticulated foot was in this instance constructed of a neoprene crepe of uniform density.



Fig. 9. The Syme prosthesis now adopted as standard by the Canadian Department of Veterans Affairs. The plastic laminate consists of Fiberglas cloth and roving impregnated with an epoxy resin, and the posterior opening extends the length of the shank.

not extend upward to the brim of the socket but resembles a door, an arrangement which permits the Syme case to be so fitted that all or any part of the weight may be carried along the brim of the socket. The foot is a commercially available version of the SACH foot (5).

Concurrent with the development of the medial-opening plastic Syme prosthesis at the Veterans Administration Prosthetics Center, the Prosthetics Research Center of Northwestern University introduced into the Canadian technique a number of refinements which might also be applied in fabricating and fitting the medial-opening type of prosthesis. Of especial interest are a new method of obtaining casts of Syme stumps and a method of attaching a SACH foot to permit greater latitude in alignment of the foot with respect to the socket,

including also a method of reinforcing the keel of a SACH foot should that be necessary in individual cases.

Manuals (4,10) containing detailed, step-by-step procedures for fabricating, fitting, and aligning the Canadian and the medial-opening Syme prostheses are available, and details of the Northwestern techniques have been published (9). An outline of all of these procedures is given here so that any might be adopted singly or in combination to meet the requirements of individual patients.

THE CANADIAN-TYPE PLASTIC SYME PROSTHESIS

TAKING THE MEASUREMENTS AND MAKING THE MODEL

All anatomical measurements necessary for constructing the Canadian-type plastic Syme prosthesis are taken while the patient bears his body weight on the end of the stump. Placed under the stump is a block of wood of such thickness as to maintain the pelvis in a horizontal position, and the anteroposterior dimension, the width, and the circumference of the stump are recorded, all at the level of the largest part.³ For use later on in the alignment procedure, a line perpendicular to the floor and passing through the mediolateral center of the patella (Fig. 12) is marked on the stump with indelible pencil for eventual transfer to the plaster model.

After all sensitive areas and bony prominences, including the tibial crest throughout its length, have been similarly marked with indelible pencil, a cast is made using plaster-impregnated bandage, a longitudinal cut being made along the posterior mid-line to permit removal of the cast. Thereafter, a model of the stump is made by filling the cast with liquid plaster of Paris, a bar or pipe being inserted in the soft plaster at the proximal end to provide an extension to be used later in holding and handling the model.

MODIFICATION OF THE MODEL

Upon removal of the cast, a finishing nail (Fig. 13) is driven all but 1/4 in. into the bottom

³ A special device, consisting of two wedges that can be moved with respect to each other so as to provide for rapid adjustment (Fig. 11), has been found to be a useful improvement over the single wood block.

of the model at the intersection of an anteroposterior extension of the vertical reference line and a medio-lateral line bisecting the area on the bottom of the model. The bulbous end is now built up by adding plaster until the dimensions conform to those recorded while the stump was bearing weight. At the same time, in order to allow space for a sponge-rubber pad in the finished socket, a layer of plaster $1/8$, in. thick is added to the bottom portion and faired in, leaving the nail protruding $1/8$ in. So that a recess to receive a foot nut will be formed in the finished socket, a piece of leather or other suitable material $1/8$ in. thick and $1\ 1/4$ in. in diameter is pierced at its center and positioned on the protruding nail. To provide relief for the sensitive areas and bony prominences, skived leather patches are added to the model as appropriate.

The path of the sawline to be used in forming the cutout for stump entry is marked on the model, and metal wedges (Fig. 14) are inserted to facilitate the later re-establishment of the sawline on the exterior of the socket. The sawline itself is located by establishing on each side of the model a point $3/8$ in. behind the anteroposterior mid-line of the model at the top and another point $1/4$ in. behind the same mid-line at the level where the stump begins to bulge (Fig. 13). Two metal wedges are inserted well apart on each of these lines, $1/4$ in. being left to protrude. After the model has dried thoroughly and three coats of cellulose-acetate lacquer have been applied, it is ready for use in fabricating the prosthesis.

LAMINATION

In the lamination of Fiberglas with epoxy resins, rapid work is essential to obtain the best structural results, and accordingly it is desirable here that this operation be performed by two persons working together. The model is held vertically in a vise, a brush coat of epoxy resin is applied, and a length of 10-strand



Fig. 10. Syme prosthesis developed by the Veterans Administration Prosthetics Center, New York. The nylon-dacron-polyester socket is provided with an opening in the medial wall. Weight-bearing may be divided, in any proportion, between the proximal rim and the distal portion of the socket.

Fiberglas roving is laid along the anterior side of each of the vertical portions of the sawline and fanned out over the end of the bulbous portion of the model (Fig. 15). The multiple-strand roving is held in place by encircling the model and roving with a piece of single-strand roving.

A piece of Fiberglas cloth 4 in. longer than the length of the model and 2 in. wider than its circumference at the largest part is laid up over the model so that the surplus length is placed distal to the bulbous end, and the whole is tied in place with single-strand roving (Fig. 15). The surplus length is then slit vertically every 2 in. along the periphery and laid over the bulbous end of the model, and the entire piece of cloth is saturated with the resin. Three additional pieces of Fiberglas cloth of the same size are applied in the same manner but are so placed that none of the vertical overlaps coincide.

To complete the lamination, four pieces of

Fiberglas cloth 2 in. wide and about 2 in. longer than twice the length of the model are applied, one at a time, with the transverse centers of the strips located over the bulbous end and positioned approximately 45 deg. apart (Fig. 16). The entire assembly is held in place by a spiral wrapping of single-strand roving, and after application of a final brush coat of resin a snugly fitting sleeve of polyvinyl alcohol film (PVA) is pulled over the layup, the lower end being tied snugly to the holding rod, the top end trimmed to a point 5 in. from the end of the

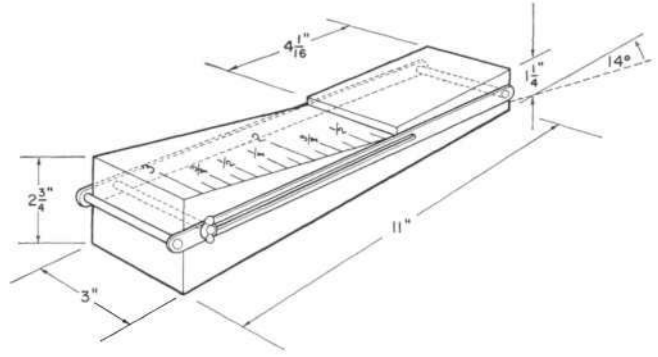


Fig. 11. Special device used in taking measurements of the Syme stump while the stump is bearing weight.

model. To compress the laminate and to remove air and excess resin, the layup is wrapped tightly in spiral fashion with a strip of PVA 2 in. wide, the wrap starting from the holding end of the model (Fig. 17). To the excess resin thus forced upward into the top end of the sleeve there is now added as much chopped roving as possible so as to form an extension around which the foot may be fabricated.

After curing for 30 min. at room temperature (or 45 min. at 250° F. if time is important),⁴ the laminate is cut, with a cast cutter or other suitable device, along the lines defined by the protruding wedges. At the lower portion of the cutout, large radii are used, and the lowest point reached is just proximal to the point of maximum anteroposterior socket diameter.

MAKING THE FOOT

After the laminated parts, socket and cutout, have been removed from the model, the extension is so shaped by grinding that the foot

⁴ In an alternate, and preferable, procedure, the layup is allowed to gel at room temperature overnight and then, after the cutout has been made, replaced over the model, fastened in place by suitable straps, and cured for 30 min. at 225° F.

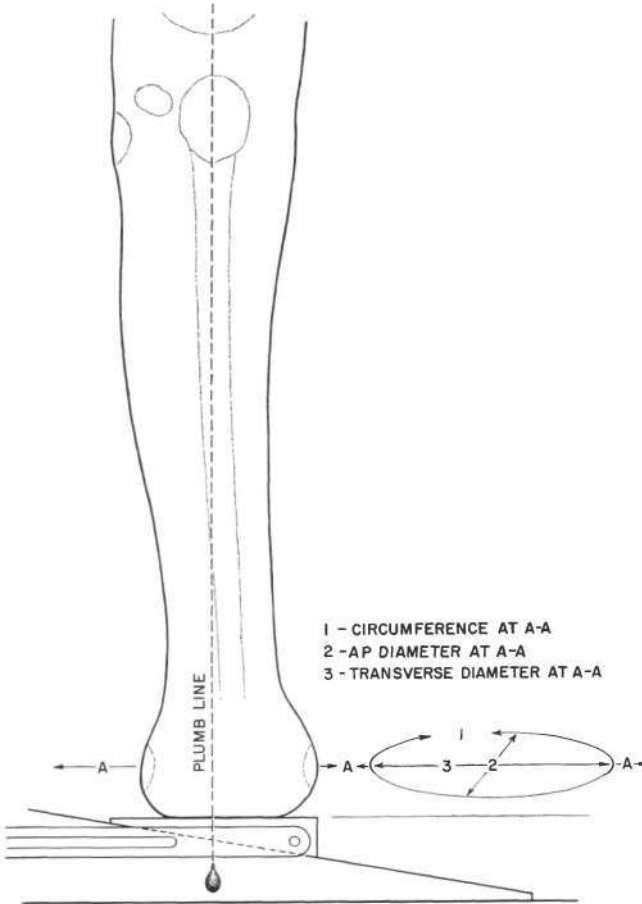


Fig. 12. Stump measurements required for fabrication of socket for the Canadian-type plastic Syme prosthesis.

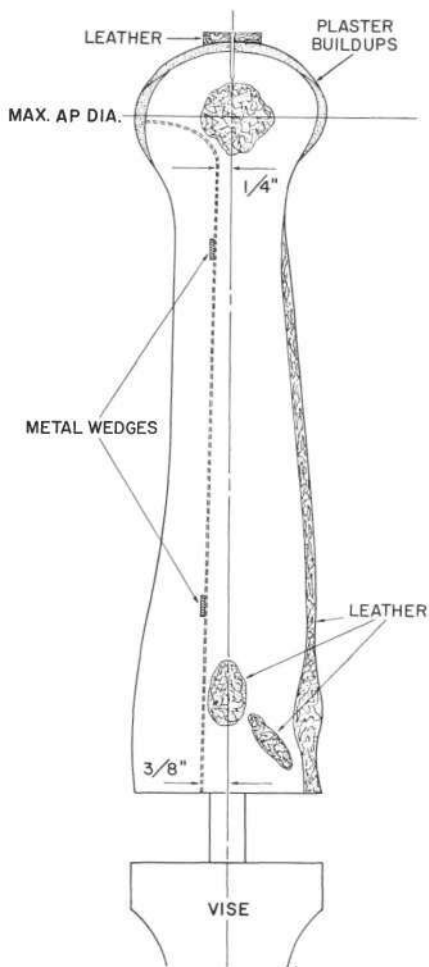


Fig. 13. Plaster model of stump just before application of Fibreglas. It is easier to modify the model before the plaster has hardened completely.

may be built around it. By means of a standard foot nut and a bolt 1 1/4 in. in diameter (Fig. 18), the keel (Fig. 19), formed from a strip of aluminum alloy (7075-T6) 1 1/4 in. wide and 0.128 in. thick, is fastened to the extension at the point indicated by the recess formed in the bottom of the socket.



Fig. 14. Steel wedge used to outline cutout, shown twice actual size.

For most adults, two thirds of the length of the keel is placed ahead of the center of the socket, but the proportion may be varied to suit individual cases. To

provide reinforcement during the fitting procedure, a piece of wood is bonded temporarily to the keel and socket extension by use of epoxy paste.

A 4-ply rubber-fabric belting 4 in. wide and four pieces of 18-iron neoprene sponge are now laminated (with Barge's cement) to the configuration shown in Figure 19, the neoprene layers being slotted to receive the keel. A wood block 4 in. wide and shaped to conform to curve A-A in Figure 19 should be used to assist in holding the layers in place while bonding is effected.

When the initial bonding of the neoprene and belting is fully set, a layer of 9-iron neoprene sponge is bonded to the underside of the belting, and a wedge of some resilient material is added to form the heel. Material for the heel, selected to meet the particular requirements of the individual patient, may be neoprene sponge, rubber sponge, solid rubber, or some other elastomer. Finally, the foot is cut and ground to the shape necessary to fit the shoe.

ALIGNMENT AND ASSEMBLY

Temporary attachment of the foot to the keel (Fig. 20) is effected by driving a 1/8-in. steel pin transversely through the heel section just ahead of the end of the keel (Fig. 19). The corset, the portion of the socket that has been cut out, is now provided with the means for holding it in place—a tongue-and-slot arrange-

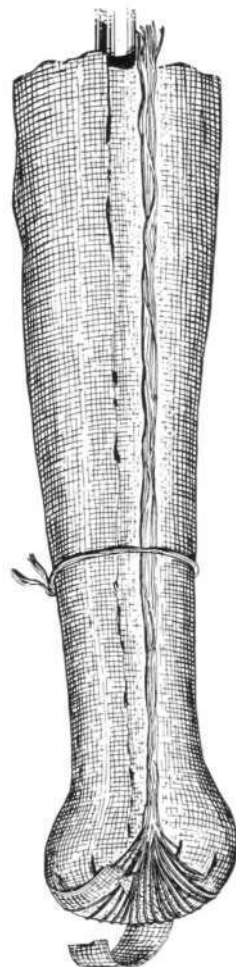


Fig. 15. First layup of Fibreglas roving and cloth. Note that roving is fanned out over ball of model.

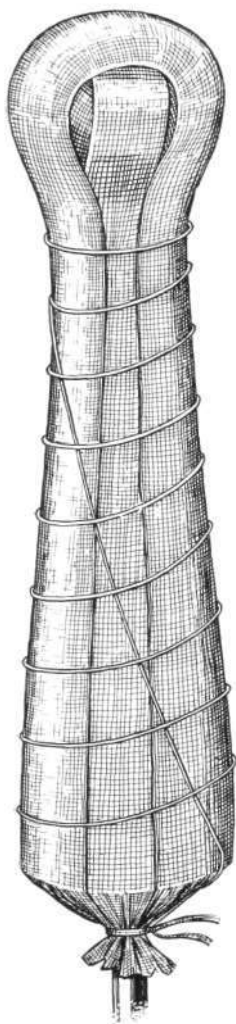


Fig. 16. Layup of longitudinal strips of Fiberglas cloth just before application of PVA bag.

obtained, a 1/8-in. hole is drilled through the aluminum keel into the socket extension, and a 1/8-in. dowel of cold-rolled steel (Fig. 19) is driven into the hole. The established alignment may thus be reproduced upon re-assembly during the finishing process. To achieve maximum rigidity of the keel, the temporary wood block is removed, two steel rods each 1/8 in. diameter are inserted into holes drilled in the anterior surface of the socket extension and allowed to extend into the cavity,

ment at the bottom (Fig. 21) and an encircling leather strap in the calf area (Fig. 9). Details of the parts required are shown in Figures 22, 23, and 24. The metal pieces are bonded and riveted to the laminated parts. Two buckles are recommended as a precaution against the possible loss of use of a particular eye in the strap (Fig. 9).

After a pad of felt or neoprene sponge, carved to fit the bottom of the socket and the end of the stump, has been placed in position, the prosthesis is ready for final alignment. The relationship between the keel and the socket may be changed by removing the attaching bolt and keel and changing the configuration of the socket extension, either by grinding or by adding shims. When the desired alignment has been

and the cavity is filled with a mixture of epoxy resin and chopped Fiberglas roving.

The aluminum surfaces must be clean to ensure an adequate bond. All gaps between keel and neoprene are filled with epoxy resin, and a fairing between the foot and socket is fashioned from a mixture of epoxy resin and fine sawdust, which after curing can be ground and sanded to shape. If desired, small holes may be drilled through the socket wall to furnish ventilation. When, after sanding, the outside of the socket and corset have received a coat of enamel, and when the neoprene parts of the foot have been sealed with two light coats of cellulose-acetate lacquer, the prosthesis is ready for use (Fig. 25).

THE MEDIAL-OPENING PLASTIC SYME PROSTHESIS

TAKING THE MEASUREMENTS

The anatomical data considered necessary for fabrication of the medial-opening socket are somewhat more extensive than are those suggested as being needed in the Canadian technique. In addition to determining the distance from the end of the stump to the floor

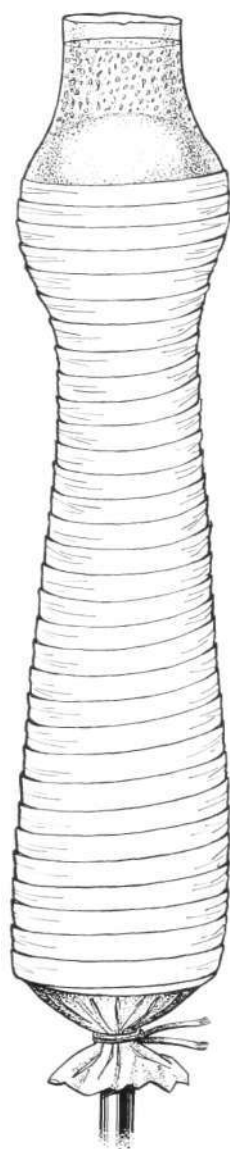


Fig. 17. Lamination for socket, ready for curing. Note extension for keel, formed by introducing resin and chopped Fiberglas roving into end of PVA bag.

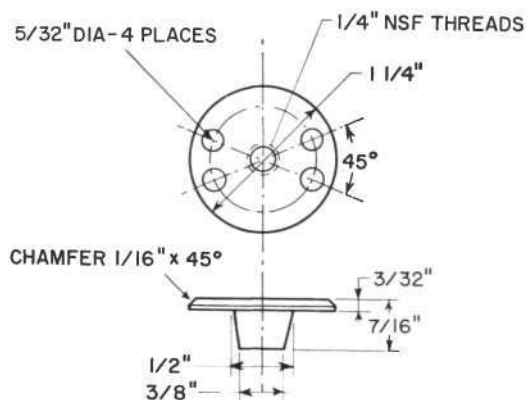


Fig. 18. Standard steel foot nut used by the Canadian Department of Veterans Affairs.

stump to the medial tibial plateau are read while the stump is free of weight-bearing. At each level measured, marks are made with indelible pencil. A form for recording the required information is shown in Figure 26.

MAKING THE CAST AND THE MODEL

To protect the stump from the plaster of Paris used in making the cast, a length of cotton stockinet, sewed at one end, is pulled over the stump and secured by an elastic band above the knee. Outlines of sensitive areas and bony prominences are made on the stockinet with an indelible pencil so that they will be transferred to the cast and in turn to the

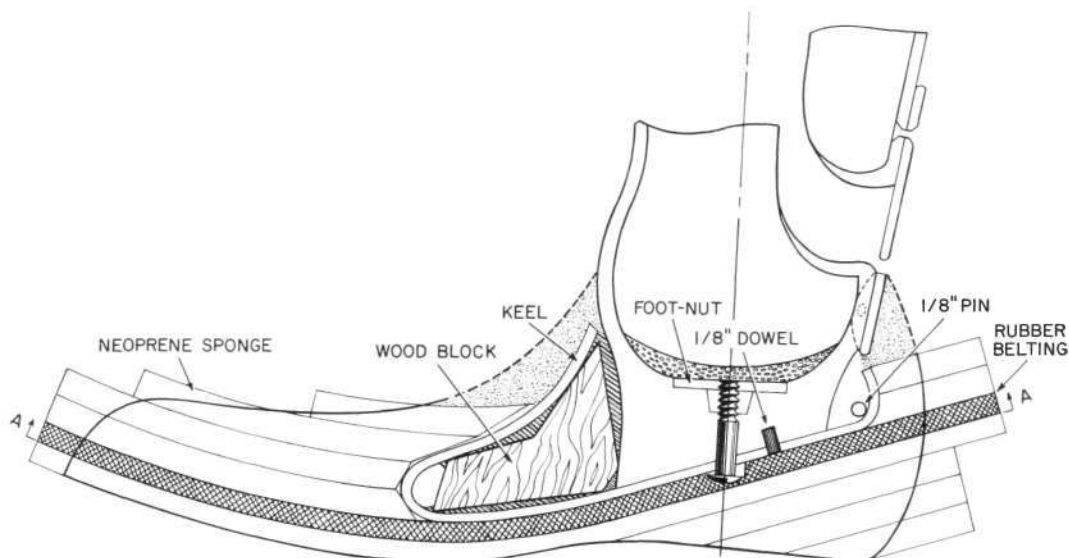


Fig. 19. Cross-section of foot and lower end of Canadian-type plastic Syme prosthesis. Before final assembly, the wood block is replaced by epoxy resin and chopped Fiberglas roving.

while the stump is bearing half of body weight,⁵ circumferential measurements of the stump are made at 1-in. intervals in the first 5 in. of the stump while it is in the weight-bearing condition. Besides this, circumferences at these five levels and also circumferences at 2-in. intervals from a point 5 in. from the end of the

⁵ Because a neoprene sponge-rubber pad will be used later in the end of the socket, it is recommended by VAPC that a sponge-rubber pad 1/4 in. thick be used between the stump and the supporting block (Fig. 26).

model for guidance in making appropriate modifications.

Although the particular method of obtaining a cast is not critical provided a faithful model of the stump can be obtained ultimately, the Veterans Administration Prosthetics Center suggests a method wherein the cast is made in two pieces, so as to eliminate the need for cutting the plaster to remove the stump.⁶ To

⁶ The same technique can, of course, be applied in obtaining any cast that requires separation for removal of the stump.



Fig. 20. Insertion of keel into neoprene portion of foot.



Fig. 21. Tongue-and-slot method of holding corset in place. Tongue and slot are held in place temporarily by the bolts and wing nuts. Epoxy resin and rivets are used for permanent attachment.

obtain the two-piece mold, the end of the stump is first wrapped with 3-in. plaster bandage to the level of greatest circumference (Fig. 27). A slab of five layers of plaster bandage 6 in. wide is then molded against the entire anterior half of the stump and secured in place by a few turns of 3-in. plaster bandage at the narrow part of the shank and again at the area just below the patella (Fig. 28). So that the cast, and hence the model, will approach the configuration of the stump in the weight-bearing condition, the plaster is allowed to harden while the patient bears weight through the distal end (Fig. 29), a sponge-rubber pad being placed between the bottom of the cast and the supporting block. As the plaster hardens, the edges should be faired to the stump.

Lateral and medial centerlines are now

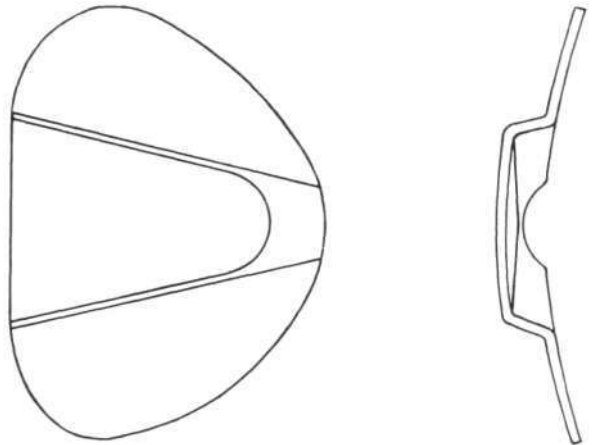


Fig. 22. Slot, shown actual size. Aluminum 0.040 in. thick.

drawn on the anterior portion of the cast for guidance in forming the parting line, petrolatum is applied to the exposed stockinet, and a similar slab of plaster bandages is molded to

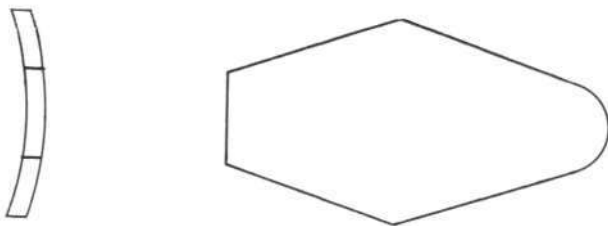


Fig. 23. Tongue, shown actual size. Aluminum 0.125 in. thick.

the posterior portion of the stump up to the lateral and medial centerlines (Fig. 30). Lines drawn transversely across the seams at several levels serve as reference points for proper reassembly of the cast after removal from the stump. Before pouring of the model is started, the indelible marks on the interior of the cast should be retraced to ensure a satisfactory transfer. For the pouring operation, the two halves may be held together by a wrapping of plaster bandage.

MODIFICATION OF THE MODEL

So that the finished socket will fit snugly along the sides of the tibia and yet not press unduly on its crest, plaster is removed from the model along each side of the area representing the tibial crest (Fig. 31), and a long leather patch, skived in the usual manner, is glued in place on the plaster. Skived leather patches also are attached at the points representing the malleoli, over areas corresponding to the flare of the condyles, and at any other points that will require relief in the finished socket (Fig. 32). Then the posteroproximal end of the model is flattened somewhat to provide for stability between socket and stump about the longitudinal axis. Finally, to make certain that the distal end of the socket will be of the proper volume to accommodate a sponge-rubber pad

for cushioning the end of the stump, a circular piece of sponge rubber 1/4 in. thick is skived and glued to the distal end of the model (Fig. 33). All modifications of the model are made with reference to the circumferential measurements taken earlier, *i.e.*, the measurements over the distal 5 in. of the stump during weight-bearing and those above during relaxation are maintained.

THE SOFT SOCKET LINER

To provide more comfort for those patients expected to take some or all weight-bearing along the proximal end of the socket, a liner of neoprene sponge rubber covered with horsehide is provided. When a liner is to be used, a horsehide sleeve is molded around the model upward from a point 5 in. below the medial tibial plateau. Sponge-rubber sheet 1/8 in. thick is formed over the horsehide, 3/4 in. of the distal end of the leather being left exposed (Fig. 33). The distal end of both the horsehide and neoprene are skived.

LAMINATION

Unlike the procedure described for fabrication of the Canadian-type plastic Syme prosthesis, wherein the corset (or cover for the cutout) consists of the laminate that was cut from the socket, in the VAPC prosthesis the socket and the cover for the cutout may be laminated separately. Thus, it is here possible to begin with a socket cutout a little too small, trim away only as much material as necessary to permit easy entry of the stump, and still have available a piece of laminate large enough for a cover.

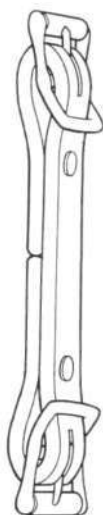


Fig. 24. Double-buckle assembly used to secure corset in place.

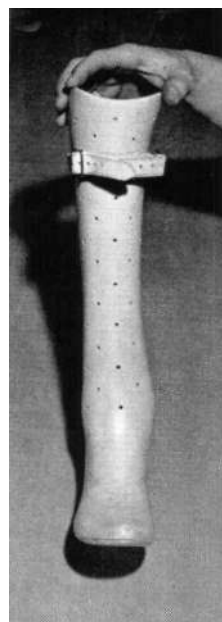


Fig. 25. Completed Canadian-type plastic Syme prosthesis.

To prevent adherence of laminate to the sponge-rubber pad (and to the soft socket liner if one is used), a snugly fitting sleeve of polyvinyl alcohol is pulled over the model and tied neatly at each end. The recommended laminate filler consists of two layers of dacron felt inside and ten layers of nylon stockinet outside. Like the PVA, the dacron felt must also be tailored into snugly fitting sleeves. If the nylon stockinet is cut into lengths slightly more than twice the length of the model, and if each length is then sewed transversely at the middle, a very neat layup can be obtained by successively pulling one half of a length over the model as far as possible and then pulling the other half over while turning it inside out. Instead of coinciding with one another, the individual transverse stitchings should be spaced equally as spokes in a wheel, the second being 36 deg. away from the first, the third 36 deg. away from the second, and so on (Fig. 34).

A sleeve of PVA film is now drawn over the layup, and a polyester resin is introduced. To date, best strength characteristics have been obtained from a mixture of 70 percent of the "rigid" type of resin and 30 percent of the "flexible" type (11,15).

Material for the medial cover is made by laminating three layers of nylon stockinet over the socket layup after it has been allowed to stand for one hour at room temperature. Resin is introduced on the medial side only (or only in that area selected for the cutout). After an additional hour of curing at room temperature, the entire assembly is subjected to a temperature of 180-190° F. for 25 min. The outer shell can now be cut and removed and the impregnated portion saved for use later (Fig. 35).

MAKING THE OPENING

The socket opening can best be cut out while the laminate is still warm. In order that the opening shall be the minimum needed for intro-

PROSTHETIC INFORMATION FORM

NAME _____ DATE _____
 RIGHT _____ LEFT _____ SHOE SIZE _____
 AGE _____ WEIGHT _____ PROTHETIST _____
 ACTIVITY LEVEL _____ OCCUPATION _____
 WEIGHT OF FINISHED PROTHESIS _____ DATE OF DELIVERY _____

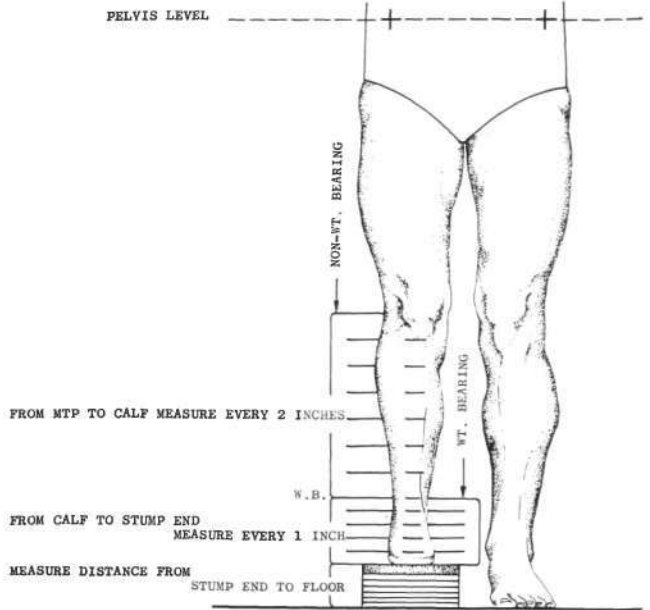


Fig. 26. Form for recording measurements and other information necessary for fabrication and fitting of a Syme prosthesis (VAPC type). From Iuliucci (10).

duction of the stump, the initial aperture is deliberately made undersize, later enlarged by trimming the edges little by little until the patient can insert the stump without experiencing discomfort. The outline of the initial opening is determined by a horizontal line 1 in. above the point of maximum circumference of the bulbous portion of the socket, two lines parallel to and medial to the line of the tibial crest (one being 3/4 in. medial, the other medial by 3/4 in. plus 1/4 of the circumference of the bulbous portion 1 in. above its maximum circumference), and a horizontal line at that point on the socket where the circumference is the same as that 1/4 in. above the point of maximum circumference at the bulbous end (Fig. 36). Because further trimming will be necessary, the dimensions of the radii at the corners are not critical at this stage.

After the initial cutout has been made, the excess material trimmed away, the plaster re-



Fig. 27. First step in obtaining a plaster impression of a Syme stump. A plaster bandage 3 in. wide is applied over the end of the stump to the level of greatest circumference.



Fig. 29. Stump under weight-bearing conditions while anterior and distal portions of plaster impression are allowed to harden. The posterior portion of the impression is applied later.

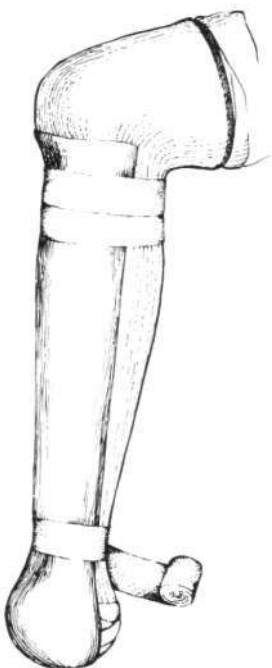


Fig. 28. Application of a slab of plaster bandage to anterior surface of stump to provide one half of a two-piece casting.

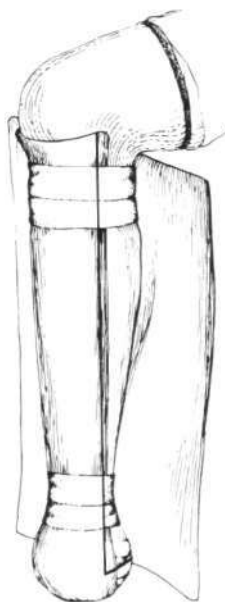


Fig. 30. Application of plaster-bandage slabs to form posterior portion of two-piece casting. Note parting line drawn on anterior casting.

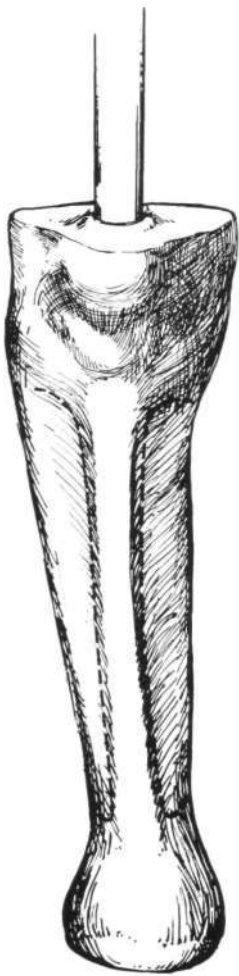


Fig. 31. Model showing where plaster should be removed so that in finished socket forces may be taken along each side of the tibial crest.

moved, and the proximal border of the socket trimmed, the cutout is enlarged enough that the patient can introduce his stump (Fig. 37). The radii of the corners should now be kept as large as possible, and the edges of the cutout should be smooth so as to contribute to the strength of the finished product by eliminating the high-stress areas commonly associated with mechanical nicks and notches.

ALIGNMENT AND ASSEMBLY

In most instances, satisfactory use can be made of one of the commercially available

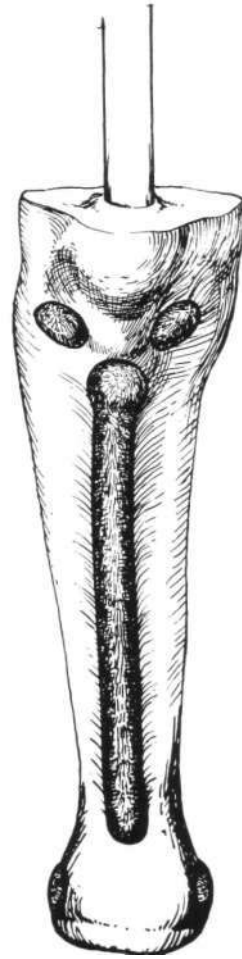


Fig. 32. Model with skived leather patches applied to provide in finished socket relief for sensitive areas.

SACH feet constructed especially for Syme prostheses. If not, a suitable SACH foot can be fabricated in accordance with the instructions given in the Canadian manual (4) or in the University of California report (5); or use can be made of the reinforcement technique introduced by Northwestern University (page 71).

When the commercial version is used, it is first shaped to fit the shoe, and a guide hole 1 1/4 in. in diameter is drilled in the keel to a height above the heel sole equal to the height of the block used while the anatomical measurements were taken (Fig. 38). The keel and neoprene crepe are then hollowed out to receive the

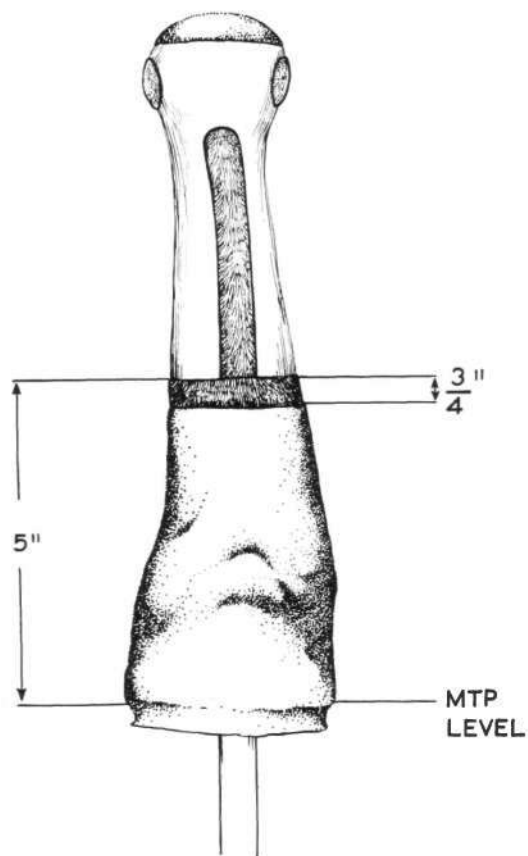


Fig. 33. Model with socket liner and sponge-rubber pad applied.

bulbous end of the socket. Because of the tendency of Syme stumps to bow toward the centerline of the body, usually both guide hole and hollow should be offset medially. Moreover, the foot should be placed as far forward as possible with respect to the socket and be set in a small amount of dorsiflexion (Fig. 39), and care should be taken to ensure that the bottom surface of the heel is parallel to the floor (Fig. 40). Such alignment should be effected by actually having the patient don the socket, place the distal end into the recess in the SACH foot, and assume a position of normal standing.

When initial, or static, alignment has been achieved, reference marks are made on the socket and foot to be used as a guide in reassembly, and masking tape (Fig. 41) is applied around the juncture of the two units to hold

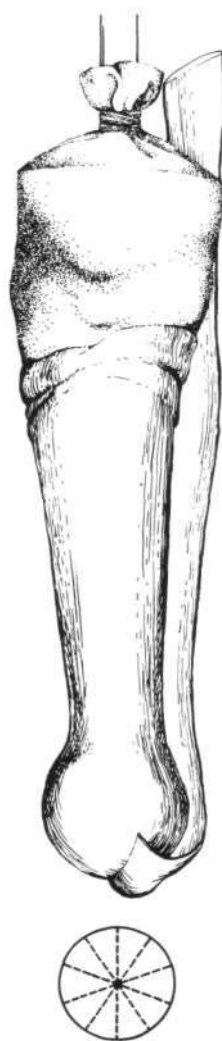


Fig. 34. Application of stockinet over model in preparation for laminating. Two layers of dacron felt have already been applied. Note seam sewed across stockinet to form neat layup at distal end of socket.

them in place while a 3/8-in. hole is drilled through the keel and socket to receive the attaching bolt. The hole in the socket is now enlarged to 5/8 in., and the hole in the keel is provided at the bottom with a 5/8-in. countersink to accommodate the nut (Fig. 42), both operations best being done with the prosthesis disassembled. A cover that will overlap the socket opening 3/4 in. around the periphery is cut from the section of laminate made for the purpose. After two single-buckle straps have been riv-



Fig. 35. Removal of laminate to be used later in fabrication of cover for opening in socket.

eted to the cover, a felt pad exactly fitting the opening is glued to the concave side, and the entire inner surface of the closure is lined with thin horsehide, care being taken to effect a rab-

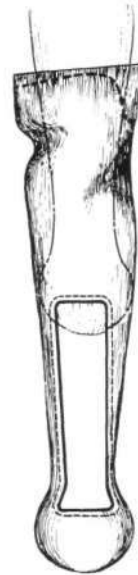


Fig. 37. Introduction of stump in socket to determine trim lines of cutout and, later, of proximal border.

betlike contour along the periphery of the felt (Fig. 43).

After the prosthesis has been assembled, dynamic alignment is effected under conditions of actual walking. Inserted into the socket in the form of contoured discs of sponge rubber is enough distal padding to distribute the forces as desired between the proximal end of the socket and the end of the stump. Slight changes in alignment can be brought about by enlarging the hole in the end of the socket.

Final finishing of the prosthesis includes bonding the foot to the socket, building up a smooth transition between foot and socket by use of a mixture of epoxy resin and chopped Fibreglas, and gluing the soft liner in place in the proximal area of the socket.

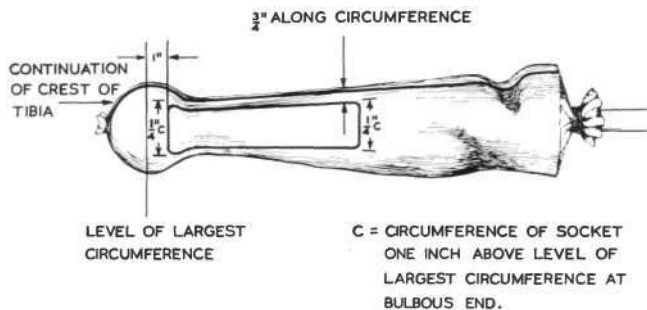


Fig. 36. Outline of initial cutout in socket.

DEVELOPMENTS AT NORTHWESTERN UNIVERSITY

TAKING THE CAST

Plaster of Paris in one form or another has been used for nearly a century in making impressions of limb stumps, and especially with the relatively new, quick-setting formulations it has proved to be fairly satisfactory. There are nevertheless certain disadvantages inherent in the use of plaster. Unless a separating medium is used, plaster will adhere to the skin. Cured plaster of Paris is extremely rigid, so that when plaster is used to take a cast of a stump like the Syme it is necessary either to cut the cast or to form it in two pieces. Furthermore, plaster is very dense and therefore heavy and comparatively hard to manage.

In an effort to overcome some of the difficulties associated with plaster, the Prosthetics Research Center at Northwestern University's Medical School has developed a procedure for taking a cast of a Syme stump with alginate, a material used by dentists in taking impressions of the gums and teeth. Because when mixed with water alginate gels rather rapidly into a rubbery solid, it seems especially useful in taking casts of bulbous stumps and of those intended to take end-bearing. To enable the gelled material to yield when the stump is withdrawn, the impression is made in a rigid, tapered cylinder lined with an oversize canvas bag which can be withdrawn so that the rubbery alginate is left free to be displaced as the bulbous portion is pulled through the narrow section of the impression (Fig. 44).

Since alginate solidifies so rapidly, and since so many factors (such as temperature and various impurities in the water used⁷) affect the rate of gelling, it is important always to check the gelling time on a small sample before actually taking an impression. The correct mixture should gel in about six minutes. A tapered can

⁷ In certain areas best results can be obtained only with distilled water.

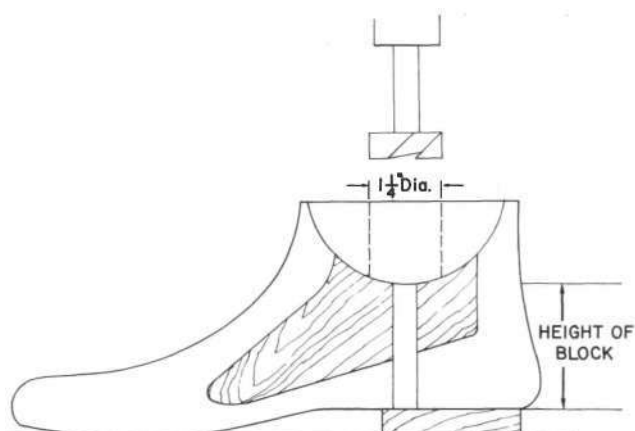


Fig. 38. Simplified cross-section of SACH foot showing certain modifications needed for use in Syme prosthesis. A hole 1 1/4 in. in diameter is drilled in keel to a depth corresponding to the height of the block used when measurements were taken (Fig. 26). The hole is used as a guide in removing material at top of foot to accommodate socket.

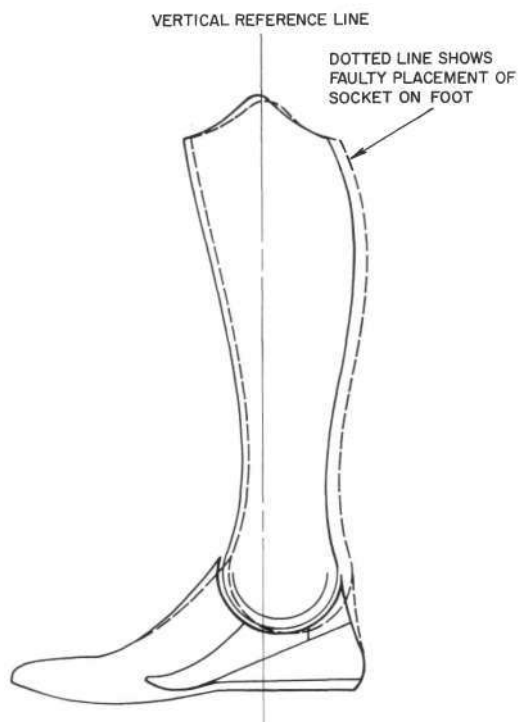


Fig. 39. Alignment of foot and socket in lateral view. Usually a slight amount of dorsiflexion results in best performance.

about 20 in. long, 5 1/2 in. in diameter at the bottom, and 6 1/4 in. in diameter at the top has

been found satisfactory for taking impressions in adults. The impression is taken while half of the body weight is borne by the stump,

i.e., while the pelvis is level and the patient is standing with feet together.

After the stump has been removed, the bag and alginate are replaced in the conical can for pouring of the model, which should take place as soon as possible because the alginate has a tendency to shrink rather rapidly after gelling.

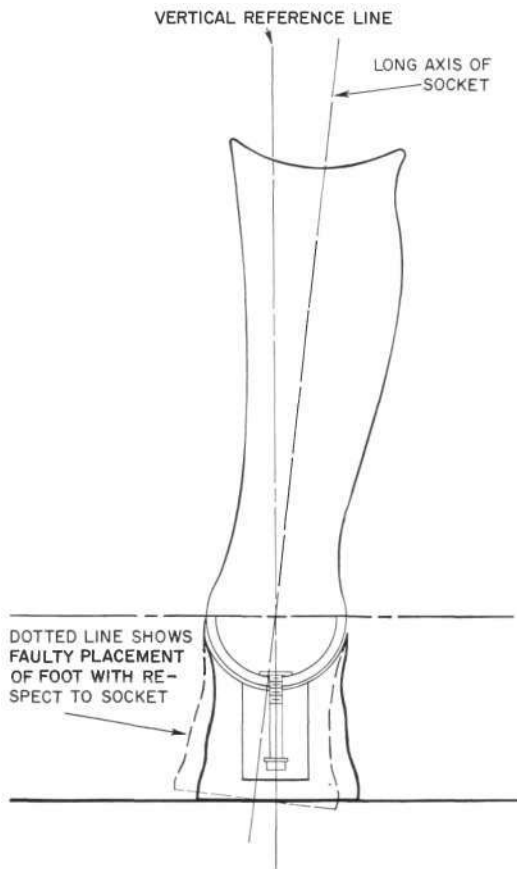


Fig. 40. Alignment of foot and socket in posterior view. The foot must be so located that the sole is parallel to the floor when the wearer stands in his own habitual position with hips level.

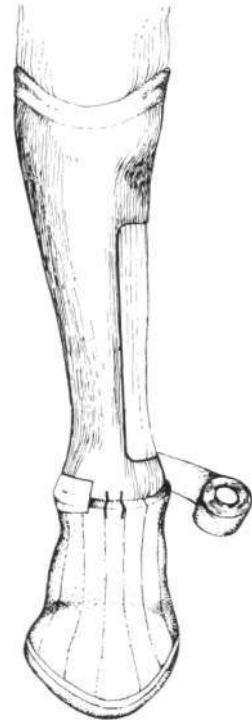


Fig. 41. Application of masking tape to secure foot to socket for drilling alignment hole through socket. Note reference marks used to ensure same alignment upon reassembly.

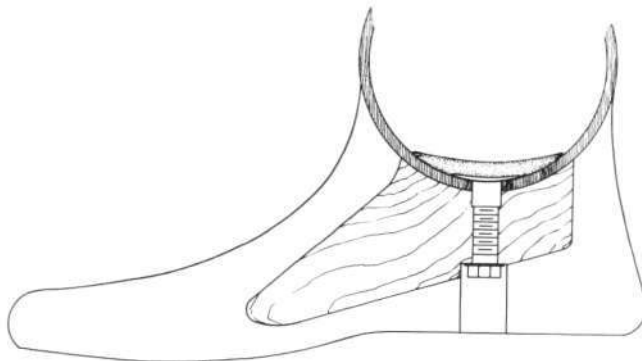


Fig. 42. Simplified cross section of foot and lower end of VAPC prosthesis showing attachment of foot to socket.

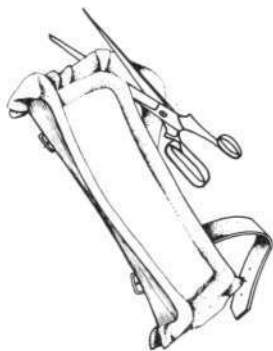


Fig. 43. Final step in fabrication of cover for opening in side of socket.

INSTALLATION OF THE SACH FOOT

To provide for wider degree of alignment adjustment than has been the case heretofore between the socket and the commercially available SACH foot, there has been developed a method of attachment employing a bolt with a spherical head (Fig. 45). Combined with an oversize hole in the socket, it permits some swivelling action between socket and foot. Adequate bearing area for the spherical bolt head is provided by laminating into the end of the socket a spherical washer (Fig. 45) having the same spherical radius as the head of the bolt.

Both washer and bolt head can be fabricated easily by use of plastic-laminating techniques.

A mold suitable for forming both pieces can be made by immersing in wet plaster of Paris a PVA-covered rubber ball, or other spherical object of suitable size, to a depth equal to about a third of its diameter (Fig. 46). The washer is formed by placing in the mold about eight layers of Fiberglas cloth saturated with epoxy resin, then placing the ball in the cavity and weighting it, and then curing the resin. Trimming the periphery of the washer and drilling a 1-in. hole in the center completes the job. The spherical bolt head is constructed by placing under the head of a standard 3/8-in. machine bolt 10 discs of Fiberglas cloth drilled with 3/8-in. holes, screwing the bolt into a hole drilled into the plaster mold, filling the cavity to the top of the bolt head with epoxy resin, and curing the plastic. When curing is complete, the top may be finished by sanding.

So that the spherical washer may be laminated into the socket, it is attached to the plaster model of the stump with beeswax (Fig. 47), care being taken at this point because the location of the washer with respect to the model determines the location of the foot with respect to the socket in a horizontal plane.

To enable the socket to be attached to the foot, a bandsaw is used to make in the keel of the foot a cutout conforming to the radius of the bulbous portion of the socket (Fig. 48). When the length of the stump dictates that the

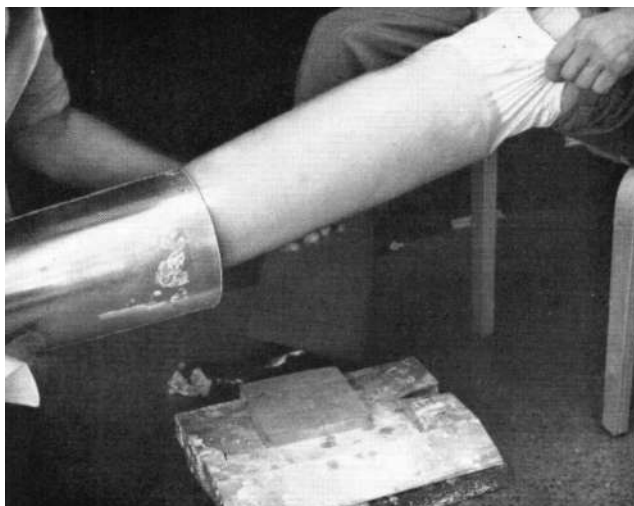


Fig. 44. Removal of stump, alginate mold, and canvas bag from canister.

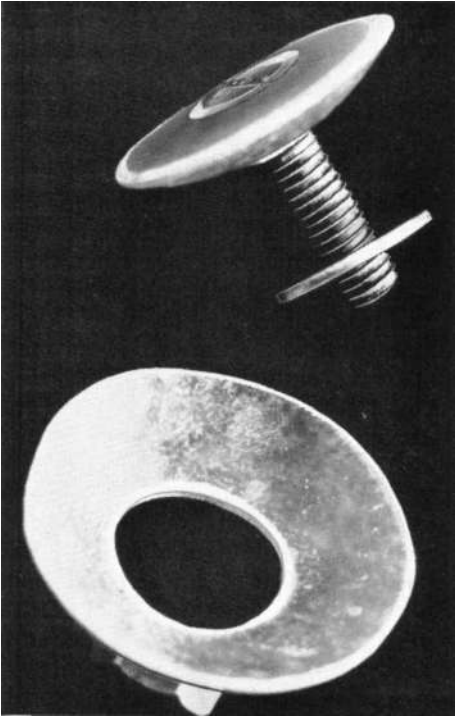


Fig. 45. Spherical-head bolt (top) and spherical washer used in attaching SACH foot to plastic socket to permit relatively wide range of adjustment. Spherical washer and spherical part of bolt head can be made using plastic-laminating techniques.

keel be so cut away as to weaken it significantly, the keel must be reinforced. In such a case, a wood screw is used to fasten the socket to the remaining portion of the keel (Fig. 49). The heel wedge and balata belting are peeled back, some nine layers of Fiberglas cloth, tailored to fit the keel and the end of the socket (which is covered with PVA film to prevent adherence), are laid up and saturated with epoxy resin, and the balata belting is screwed back in place (Fig. 50). After curing of the resin has been effected, a 3/8-in. hole is drilled through the keel reinforcement and the socket at the center of the spherical washer, the foot is removed, and that part of the hole which is in the socket is enlarged to 1 in. so as to match the hole in the spherical washer (Fig. 51).

Finally, a hole 1 1/4 in. in diameter is formed in the heel wedge and sole in such a way as to receive the wrench needed to tighten the at-

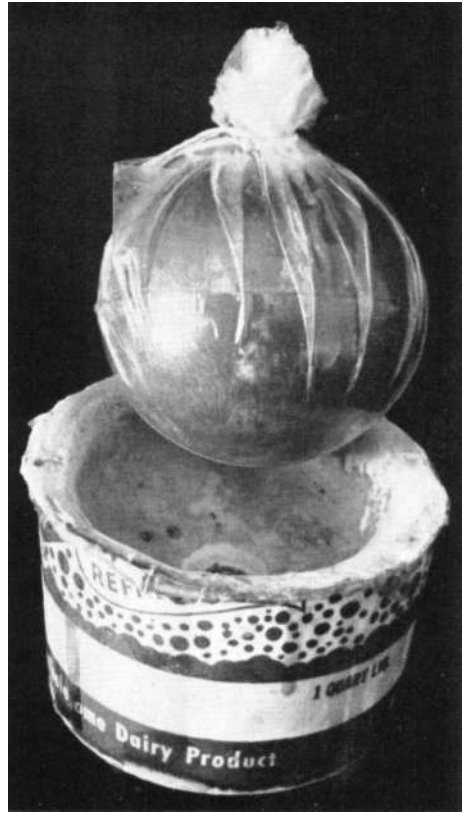


Fig. 46. Mold used in fabricating spherical washer and spherical bolt head. Convex portion consists of a rubber ball covered with PVA film. Concave portion is formed from wet plaster of Paris by pressing the ball in to a depth equal to approximately one third its diameter.

tachment nut (Fig. 51). The heel wedge having been modified to fit the contours of the reinforced keel and then cemented in place, the socket and foot can be assembled for walking trials. When all necessary adjustments have been made, the socket is bonded to the foot with epoxy resin and the space around the socket is filled with a mixture of resin and sawdust which, when cured, is ground and sanded to provide a suitable contour.

CONCLUSION

The several methods presented here for fabrication of a prosthesis for Syme's amputation have all been found to be useful. It seems reasonable to believe that some of the features of each method may be combined in order to suit the equipment of the individual prosthetist as



Fig. 47. Placing the spherical washer on the plaster model of the stump so that it may be laminated into the socket. Beeswax is used both to support it in the proper position and to fasten it to the model.

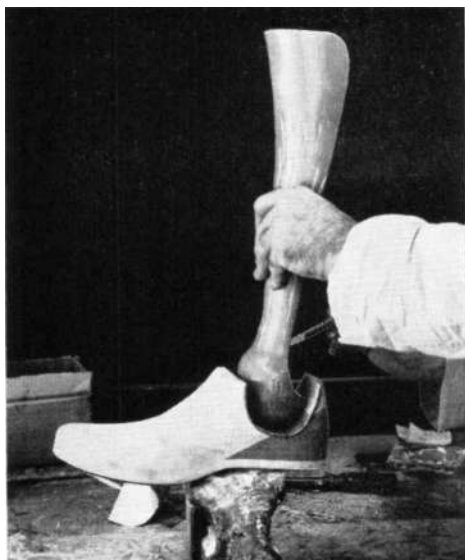


Fig. 48. View showing the type of cut made in the top portion of a SACH foot to accommodate a Syme socket.

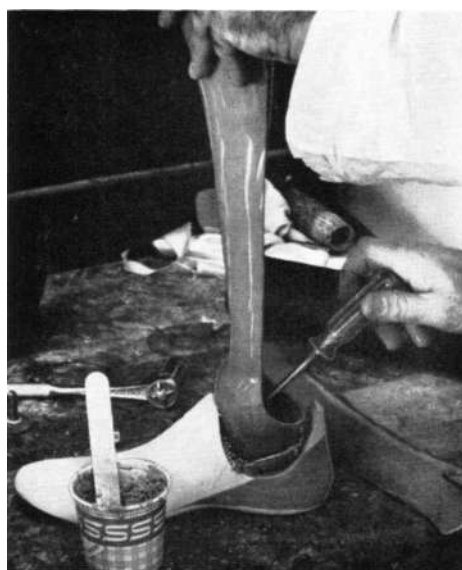


Fig. 49. Fastening the socket to the keel of the SACH foot with a wood screw.



Fig. 50. Fiberglass cloth, used to reinforce keel of SACH foot, being tailored to fit bottom of keel and socket. Note PVA film placed over socket to prevent adherence to fiberglass during laminating process.

well as to meet most effectively the requirements of the individual patient. For example, the technique offered by VAPC for fabrication of a cover for the cutout might well be applied

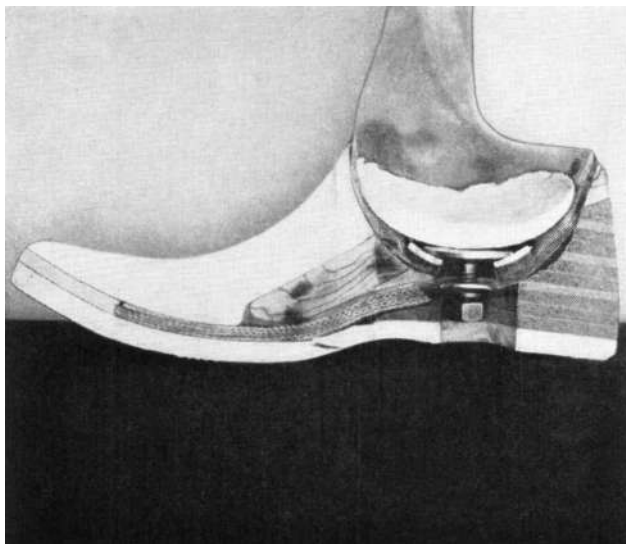


Fig. 51. Cross-section of completed prosthesis showing spherical head bolt, spherical washer, modified keel, and laminated Fiberglas reinforcement.

to fabrication of a prosthesis with a full-length posterior cutout as used by the Prosthetic Services Centre. The use of alginate as an impression material may be the method of choice for some prosthetists, while others may find the two-piece mold best for their use, especially if the local water supply contains certain minerals. The measurement-and-modification techniques described might be combined advantageously. Thus most of the individual methods are interchangeable between the basic prostheses described.

ACKNOWLEDGMENT

Any reliable article on the recommended methods of construction of a limb prosthesis must necessarily be based on the cumulative experience and the collective judgment of many workers in many places. Most of the material for this article was drawn from three pre-existing publications—*Construction of the Plastic Symes Appliance* (Technical Bulletin No. 32, Prosthetic Services Centre, Canadian Department of Veterans Affairs, Toronto, August 1959), *VAPC Technique for Fabricating a Plastic Syme Prosthesis with Medial Opening* (U. S. Veterans Administration, New York, September 1959), and *Recent Developments in the Fitting and Fabrication of the Syme Prosthesis* (*Orthopedic and Prosthetic Appliance Journal*,

March 1960). Much valuable advice and counsel was forthcoming from a number of highly accomplished persons, among them R. M. Turner, of the Canadian Department of Veterans Affairs, Ottawa, and C. S. Boccus, of the Prosthetic Services Centre, Toronto; Colin A. McLaurin and Fred Hampton, of the Prosthetics Research Centre of Northwestern University in Chicago; and Anthony Staros and Louis Iulicci, of the U. S. Veterans Administration Prosthetics Center, New York City. Of the 51 illustrations, the drawings not credited to original publications are the work of Annette Kissel, illustrator for the Veterans Administration Prosthetics Center in New York City, and of George Rybczynski, freelance artist of Washington, D. C. Miss Kissel executed Figures 26 through 43. Mr. Rybczynski prepared Figures 11, 12, 13, 14, 15, 16, 17, 19, 22, 23 and 24. The cooperative efforts of all these individuals are gratefully acknowledged and duly appreciated.

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