

# Construction and Fitting of the Canadian-Type Hip-Disarticulation Prosthesis<sup>1</sup>

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True hip disarticulation connotes removal of the femur at the acetabulum. But loosely within the hip-disarticulation category a residual length of femur, too short to control a prosthesis effectively, may be left. A much more drastic operation, the hemipelvectomy, removes all of the ischium, all of the pubis, and most or all of the ilium on the side of the amputation. In this discussion, a classical and idealized hip-disarticulation amputee is considered in outlining a method for making the Canadian-type hip-disarticulation prosthesis. Certain adaptations have been found suitable for the short-stump above-knee amputee and for the hemipelvectomy.

Consider the remaining functions of the hip-disarticulation amputee. The gluteal muscles have been pulled anterior and fastened at the suture line to form a rugged pad which supports the body's weight. Support forces are transmitted through this gluteal musculature and the ischial tuberosity to the stable pelvic base. Movement of the pelvis relative to the normal leg permits the amputee to position the artificial foot at the beginning of the stance phase of walking and aids in flexing the knee

at the end of the stance phase and in sitting down. Pelvic movement relative to the rest of the body enables him to secure balance on and to control the prosthesis. The tuberosity on the side of the amputation, the iliac crests, and the sacrum provide excellent keying points for securing the body in the socket. To minimize movement between the body and the socket for the most efficient transmission of forces, the socket must snugly enclose those areas providing support, suspension, and stabilization and must give relief for any sensitive areas or bony prominences.

The socketmaking technique, as worked out by the Prosthetics Research Group at the University of California, Berkeley, is described in detail in the report by Foort and Radcliffe (2). The socket is made by taking a female impression of the pelvis with plaster bandage, forming it into a check socket and making the necessary modifications, making a male model from the check socket, and using the model as a mold for the plastic-laminate socket to which the rest of the prosthesis is attached.

## TAKING THE CAST

To provide relief pockets for the anterior-superior spines, the posterior-superior spines, the spinous processes of the vertebral column, and any other sensitive areas, patches of 1/4-in. skived felt are attached to the body with adhesive tape (Fig. 1). To protect the body from plaster, a covering of cotton stockinet is pulled up over the lower part of the torso and extended well beyond the area where the socket is to be shaped (Fig. 2). In order to

<sup>1</sup> A contribution from the Biomechanics Laboratory, University of California, San Francisco and Berkeley, aided by U. S. Veterans Administration Contract VAm-23110 and by U. S. Public Health Service Grant RG-4856(C).

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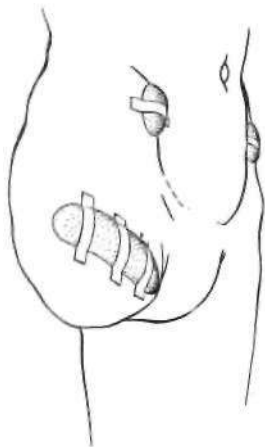


Fig. 1. Application of skived felt patches over pressure-sensitive areas of the stump and torso.

define accurately the areas which may require modification, the iliac crests and those areas which have been covered with felt are marked on the stockinet covering with indelible pencil. A mark around the waist, marks on the front and back mid-lines, and a mark extending from mid-line to mid-line around the normal leg at the level of the inguinal crease will define the approximate trim lines of the plaster

cast (Fig. 3). Metal strips may be placed over the mid-line marks to facilitate subsequent cutting of the wrap cast.

One way to get a good, snug fit for the socket is to take the wrapping of the upper part of the pelvis with the subject lying on his back on a cast table (Fig. 4, A). This position causes the viscera to move upward and backward and flattens the abdomen, thus reducing the distance from the anterior to the posterior wall of the cast and more sharply defining the iliac crests (Fig. 4, B and C). The cast of the lower

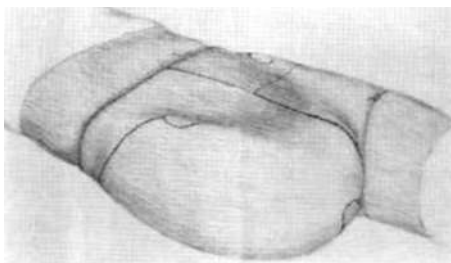


Fig. 2. Stockinet pulled over lower part of the torso well above the waist, tied at waist and around proximal end of sound thigh. Waist, mid-line, and bony prominences marked with indelible pencil.

pelvis is taken as a second step (Fig. 4, D). Snug fit is achieved by having the amputee bear weight on the stump as the cast hardens (Fig. 4, E). Three or four layers of plaster bandage are wrapped firmly around the upper part of the pelvis (*i.e.*, from about 2 in. above the iliac crests to just above the pubic symphysis) and then, with tension, diagonally over the iliac crest on the amputated side and under the crest on the normal side (Fig. 4, A and B). After the wrap is complete, a block of firm sponge rubber 2 in. thick is placed under the patient's lumbosacral region to force the back portion of the cast against the body (Fig. 4, C). By molding over the iliac crests with the hands while the cast is setting, and by pressing in firmly while the cast hardens, the operator obtains good suspension hooks.

When the upper portion of the cast has set, the amputee stands, and the stump area is wrapped with plaster bandage. To unite the two portions completely, the bandage is applied back and forth over the stump with several turns around the upper section of the cast (Fig. 4, D). While the cast is setting, the amputee bears full weight on the sponge-rubber pad now placed under the stump area (Fig. 4, E). Weight-bearing at this time keys the body within the socket between the weight-bearing platform and the suspension hook over the iliac crest on the side of the amputation. Up-and-down motion of the body within the socket is thus minimized. There may be some gapping of the cast in the gluteal area and lateral to the pubic area, but such

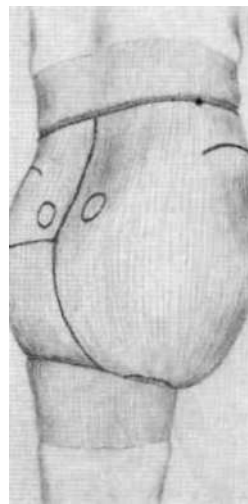


Fig. 3. Waist, mid-line, and bony prominences marked in the rear.

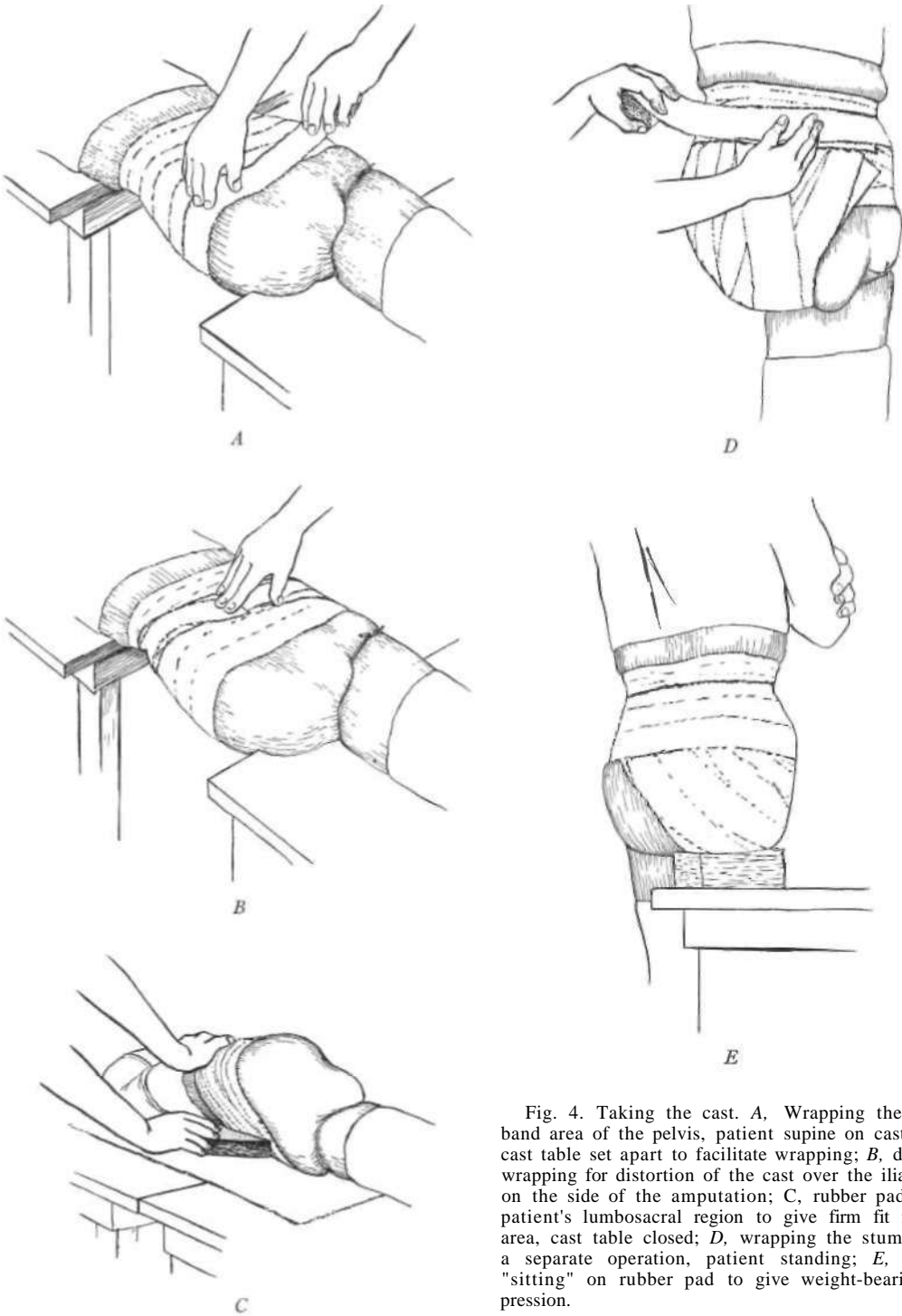


Fig. 4. Taking the cast. *A*, Wrapping the waist-band area of the pelvis, patient supine on cast table, cast table set apart to facilitate wrapping; *B*, diagonal wrapping for distortion of the cast over the iliac crest on the side of the amputation; *C*, rubber pad under patient's lumbosacral region to give firm fit in that area, cast table closed; *D*, wrapping the stump area, a separate operation, patient standing; *E*, patient "sitting" on rubber pad to give weight-bearing impression.

gapping will be closed with plaster when the cast is modified.

When the cast has set, it is removed from the torso by cutting at the approximate mid-lines, front and back (Fig. 5).

#### THE CHECK PROSTHESIS

The cast is rejoined, reinforced, split again, hinged posteriorly, provided with a buckled closure anteriorly, and attached to a pylon base (Fig. 6). To rejoin the two sections, they are aligned in their original position, and plaster bandage is wrapped around the outside. Plastic laminate, consisting of polyester resin, stockinet, and glass cloth, is applied over the plaster cast to strengthen it. Two layers of glass cloth about 4 in. wide are laid over the outside on the posterior mid-line. One layer of 8- to 10-in. stockinet is then pulled over the cast and tied at the opening for the normal leg. Polyester resin is painted over the fabric and allowed to cure, after which excess material is trimmed away.

The cast is now sawed along the posterior mid-line, and a hinge is fastened over the cut. When the hinge is secured, the cast is sawed along the front mid-line, and a buckle-and-strap arrangement is attached. A block of wood about 4 x 4 x 4 in., scooped out to fit the bottom of the cast roughly, is attached to the cast with "gunk," a mixture of resin and sawdust, to serve as the base for the pylon.

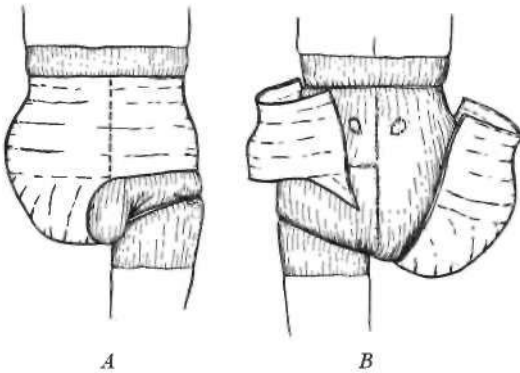


Fig. 5. Cutting and removing the cast. A, Cast marked on mid-line, front view; B, cast cut along anterior and posterior mid-lines, rear view.

The pylon must now be attached to the wood block in the proper alignment and the socket tried on the amputee for any necessary modifications. With the plaster socket on the amputee, marks are made on the side and front of the block to indicate the inclination of the peg. It should be so set that it will make the same angle with the floor at the beginning and end of the stance phase of walking and so that it will clear the normal leg in the swing phase. Typically, this will mean that the distal end of the pylon will be set somewhat forward as viewed from the side and somewhat lateral as viewed from the front. A hole is drilled in the middle of the block at the required angles, and a length of crutch-tipped dowelling is inserted.

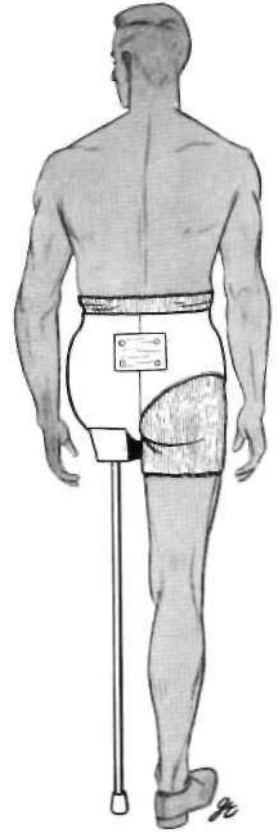


Fig. 6. The check prosthesis.

To test for discomfort, excursion, and restriction of body motion, the amputee now performs on the check prosthesis. He is asked to bend his body and normal leg in every direction, and the cast is cut down until there is complete freedom of motion. Taking care to leave the ischial seat intact, the medial side is cut away to relieve rubbing against the normal leg and the genitalia. The edges of the cast are then smoothed and flared with plaster, and gapping in the areas of the gluteus and pubis is similarly closed.

If there is ramus contact, the amputee usually will complain of it. This detail can be checked by locating the ramus with a finger

and having the amputee put full weight on the socket while dropping his pelvis on the normal side. If there is contact, the ischial seat and other weight-bearing areas should be built up with 1/8-in. layers of plaster until the ramus is sufficiently cleared. Fore-and-aft excursion can be detected by placing a finger alongside the tuberosity while the amputee steps back and forth on the prosthesis. Any fore-aft excursion will be reduced if the prosthetist slips a hand between the torso and either the anterior or the posterior wall of the socket. If the amputee then feels more secure, the anterior and posterior walls should be built up appropriately with plaster so laid that the forces are evenly distributed.

If the body has not been sufficiently stabilized in the socket in the up-and-down direction, the prominences will move along and out of the relief pockets established for them, and chaffing and painful pressures will occur. As a final check on excursion, therefore, the amputee should be walked in the check socket. Two hours of walking is usually enough to prove any discomfort. Further refinements may then be necessary:

1. If the musculature in the area of the iliac crest on the side of the amputation has atrophied, the extent of the hook in this region may need to be increased. An increase is indicated if a hand placed inside the socket under the hook makes the socket seem more secure on the amputee.

2. If, without causing discomfort, security is increased by inserting 1/8-in. pads between the stump and the weight-bearing area of the socket, the weight-bearing area should be built up accordingly.

3. If the body seems stabilized in the up-and-down direction but there is still pressure on the prominences, either the areas around the relief pockets must be built up with plaster, 1/8-in. at a time, or material must be sanded out of the pockets.

#### THE MALE MODEL

A hollow model is now made in the check socket. After the inside of the cast has been coated with petroleum jelly, a section of 8-in. stockinet is pulled over the check socket and tied closed around the pylon base. Sufficient thin plaster is then poured into the cast through the waist opening to coat lightly both the check socket and the stockinet closing the end (Fig. 7). When the first layer of plaster has set, successive layers of somewhat thicker



Fig. 7. Making the male model.

plaster are added until the model is approximately 1 in. to 1 1/2 in. thick. When the shell has hardened, a quart more of plaster is poured in, the stockinet is pulled across the opening, and the cast is inverted and placed on a table so that the plaster seals the end. The completed male model is removed from the check socket and dried.

#### THE PLASTIC SOCKET

To prepare the model as a mold for construction of the plastic socket, a hole is cut in the top (the waist), and a mandrel of 1-in. pipe about 2 ft. long is inserted and fastened with "gunk." The edges of the mold are trimmed so that the flares are not more than 1/4 in., and the whole is smoothed with fine sandpaper. To the surfaces which will become the open ends of the completed socket wooden blocks approximately 1/2 to 1 in. are attached with "gunk" (Fig. 8). They will later be used to secure the layers of fabric to the mold. A 1/4-in. pad of dense sponge rubber is placed over what will be the weight-bearing area of the socket. This pad will later be transferred to the corresponding area of the completed socket. A truncated cone of polyvinyl alcohol film is then pulled over the cast and tied to the mandrel at one end and to the leg-opening surface at the other (Fig. 9).



Fig. 8. Wooden blocks bonded to the model.

To reinforce the polyester resin, dacron tricot (a very strong fabric with one-way stretch) and glass cloth are used in construction of the socket. The dacron waistband will be limber enough to allow the socket to open, while areas of force concentration, reinforced with the glass cloth, will be strong and rigid.

Six layers of dacron tricot are used, each layer being stapled into place individually. The six layers of dacron are cut with enough material to wrap around the cast horizontally and with an overlap great enough to span the distance between the crests. These are fitted

and seamed to pocket the stump area (Fig. 10). Beginning at the vertical line of the normal iliac crest, the end of the material is stapled to the wooden blocks at either end of the model. As it is brought across the abdominal area, then around the back, continuing to its starting point, the dacron is stapled to the blocks (Fig. 11), the excess length of material being allowed to hang free. Alternating with the dacron, four layers of glass cloth are laid up over the stump area, extending upward to the crest (Fig. 12), and the lay-up is finished off with the final two layers of dacron tricot (Fig.

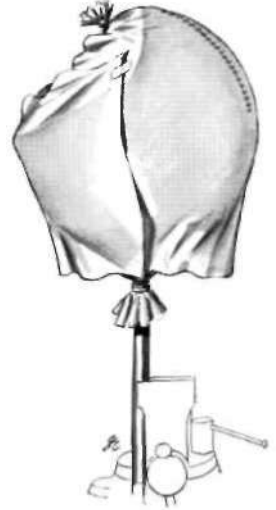


Fig. 10. Dacron tricot tailored to fit the model.

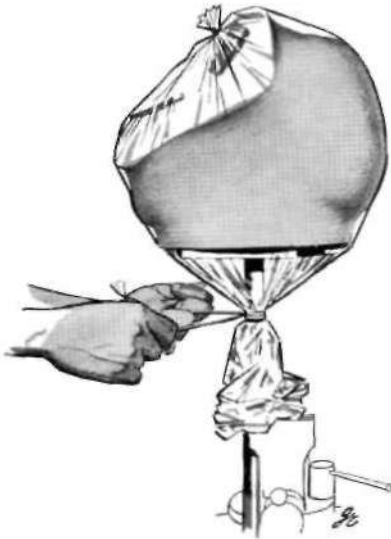


Fig. 9. Truncated cone of polyvinyl alcohol film drawn over the model and fastened top and bottom.



Fig. 11. Securing the fabric to the model.



Fig. 12. Glass cloth applied over the stump area.

13). When all the fabric has been applied in this way, the loose sections of dacron are brought across the front and stapled into position over a sheet of polyvinyl alcohol film (Figs. 14 and 15). The film separator prevents the overlap from bonding to the underlying section.

In order to get resin to the fabric under the film separator, it is helpful to place a polyvinyl alcohol funnel, approximately 2 to 3 in. wide and 2 ft. long, under the film separator before it is stapled into position (Fig. 14). The mouth of the funnel will be at the mandrel. After the film separator and the overlapping material have been stapled to the wooden blocks in final position, two similar funnels are placed over the front and back surfaces of the lay-up with the mouths at the mandrel (Fig. 16). A final truncated cone of polyvinyl alcohol film

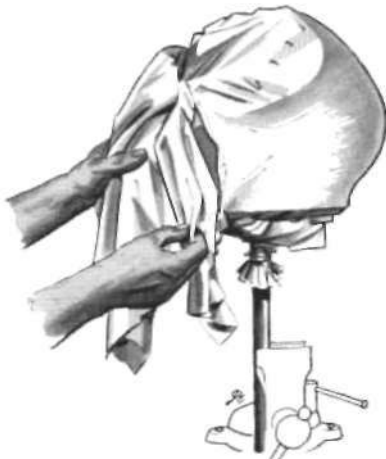


Fig. 13. Final lay-up of dacron fabric.

is pulled over the entire mold and tied in the area of the wooden blocks at the stump end (Fig. 17).

The required quantity of resin is weighed, mixed with catalyst, promoter, and pigments, and introduced into the fabric through the funnels, after which the funnels are removed (Fig. 18). The polyvinyl alcohol bag is tied closed at the mandrel, and the resin is squeezed through the fabric. When the fabric is completely saturated, excess resin and air bubbles are worked out toward both ends by "roping" (Fig. 19). Sponge-rubber pads are then bound over the undercut areas with Ace bandage in order to guarantee close adherence of the lay-up to the mold (Fig. 20).

The socket is released from the mold by cutting around the waist and around the opening for the normal leg approximately 1/2 in. from the final trim lines (Fig. 21). Care should be taken not to cut the hands on the sharp edges of the overlapping sections (Fig. 22). After the socket has been removed from the mold, the edges are trimmed on a sand-

ing drum.



Fig. 14. Application of PVA funnel and film separator under overlap of waistband.

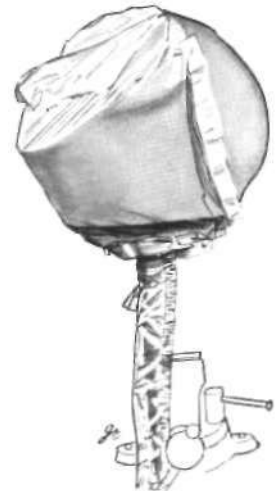


Fig. 15. Film separator and overlapping fabric stapled into position.



Fig. 16. PVA funnels applied to front and back of lay-up.

base, hollowed out to fit the front-bottom corner of the socket, is



Fig. 17. Truncated PVA cone placed over entire lay-up.

#### THE TRIAL LEG

The fixtures are attached to the socket, the socket is attached to a thigh section through the hip-joint assembly, and the thigh section is attached to the adjustable leg and the foot (Figs. 23, 24, 25, and 26). Attachments for the socket are the weight-bearing pad (Fig. 23), the belt-and-buckle arrangement, and the wooden base for the hip joint (Fig. 24).

#### WOODEN BASE

A block of wood 4 x 4 x 4 in. for the base, hollowed out to fit the front-bottom corner of the socket, is bonded in place with "gunk." When the resin has cured, the front-bottom corner of the block is cut off as close to the socket as possible to provide a surface to which to attach the hip-joint bearing. When the socket is in its normal position, this attachment surface will face downward and forward at a 45-deg. angle to the floor, so that when the hip-joint bearing is attached its axis will be approximately perpendicular to the line of progression and parallel to the floor (Fig. 25).

#### HIP-JOINT ASSEMBLY

The hip-joint assembly (Fig. 25) consists of a special bearing, a shaft, and two metal sidestraps. The bearing, which is lined with a bronze bushing, is machined out of a block of aluminum and includes four tabs with screw holes for attachment to the base of the socket. The shaft and sidestraps of the hip-joint assembly are from a 3 1/2-in. standard prosthetic-knee assembly.

#### THIGH SECTION

The thigh section is made from a 6- x 6-in. block of wood 12 in. long, with a core drilled from the middle at the edge of one end through the center of the block at the other. This hole facilitates pulling out wood from the interior of the thigh section later. A line is marked off 2 in. from the cored edge at one end, and, starting at this line, a diagonal cut is made to the opposite corner at the other end. The 6- x 6-in. face becomes the knee end, the 2- x 6-in. surface the hip end, and the vertical surface (6 x 12 in.) the front face of the thigh.

The sidestraps of the assembled hip joint are traced on the front face of the block equidistant from the sides, and the block is



Fig. 18. Resin introduced through the funnels, funnels ready to be removed.



Fig. 19. Saturation of the fabric and removal of air bubbles by "roping."





Fig. 20. Sponge-rubber pads applied to undercut areas to guarantee adherence to mold.

cut along these lines to extend somewhat beyond the side-arms and to flare out toward the end. The straps are then attached to the cut sides flush with the front of the block at the bolt end and so that the axis of the bolt will be approximately  $3/4$  in. above the top surface of the thigh block. The portion of the block which extends behind the axis of the hip joint is sawed as necessary to provide the platform for

the hip-stop bumper (Fig. 24).

To position the hip joint on the base, the amputee dons the socket and sits down.



Fig. 21. Cutting the socket free of the mold.



Fig. 22. Removing the socket from the mold.

Viewed from the front, the prosthetic thigh should be approximately parallel to the normal thigh and as close to the mid-line as possible, and the hip joint should be parallel to the floor and high enough on the base so that the back edge of the hip-stop platform is flush with the chair. The position of the bearing is traced on the block, and the free end of the thigh section is marked 2 in. back from the normal knee axis.

#### TRIAL-LEG ASSEMBLY

The socket is removed from the patient, the thigh section is cut where it was marked, and the components of the trial leg are assembled. The adjustable leg is attached to the knee end of the thigh piece, and the socket is attached to the thigh with screws through the hip-joint bearing. To prepare for alignment checks, a temporary hip-stop bumper, a temporary hip-flexion con-



Fig. 23. Finished socket with weight-bearing pad installed.



Fig. 24. Socket with wood block attached. Dotted lines indicate the saw lines.

trol strap, and a kick strap are attached to the leg, and the knee joint is located in a stable position (Fig. 26).

TEMPORARY BUMPER

A bumper of foam-crepe shoe-sole material is tacked temporarily to the hip-stop platform in such a manner that when the socket is

against the bumper the vertebral spine will be in its natural position.

HIP-FLEXION CONTROL STRAP

One end of the hip-flexion control strap is attached laterally to the socket 2 in. behind the hip joint; the other is attached to the shank 3 in. below and 1/2 to 1 in. ahead of the knee joint.<sup>3</sup> The distance between these attachments is adjusted to provide the correct stride length.

KICK STRAP

The temporary kick strap is attached to the front of the shank at the same level as the hip-flexion control strap, passes over the knee in front, and attaches to the front of the socket 3 in. above the hip joint. The length of the strap is adjusted to provide the correct balance between heel rise and knee extension. Knee stability will be satisfactory if, when the knee is in full extension, the knee joint falls behind the line projected from the hip joint to the back of the heel.

<sup>3</sup> If the amputee is well adjusted to using a prosthesis and does not need the added stability offered by attaching the hip-flexion control strap below the knee, the distal end of the strap may be attached to the thigh section.

The prosthesis is now ready for sitting, standing, and walking adjustments. When the amputee is sitting, the prosthetic shank should be vertical, the knee axis approximately level with the normal knee center and the toe-out equivalent to that on the normal side. In the standing position, with a 2- to 3-in. standing base, the length of the leg should be such that the hips are level. The thickness of the hip bumper is adjusted to eliminate humping or arching of the spine. The patient now walks on the trial leg, and checks are made of knee stability, width of walking base, stride length, toe clearance, whip in the swing phase, and swing-phase control.

KNEE STABILITY

Although the knee has been stabilized on the bench, a number of factors may affect it in action. If the knee buckles, it may be that the hip bumper is contacting too soon and that its thickness needs to be reduced. A knee axis too far forward also will cause buckling.

WALKING BASE

With the toe-out of the prosthesis consistent with the natural toe-out, the medial distance between the heels is the walking base. If this base is found to be over 2 to 3 in., it should be made narrower by moving the foot in. If the feet are not clearing each other sufficiently, the base should be increased to 2 to 3 in.

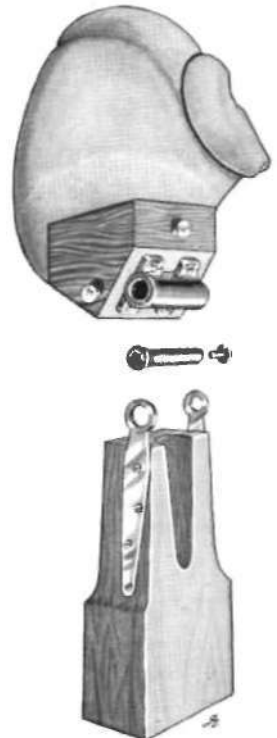


Fig. 25. Hip-joint assembly.

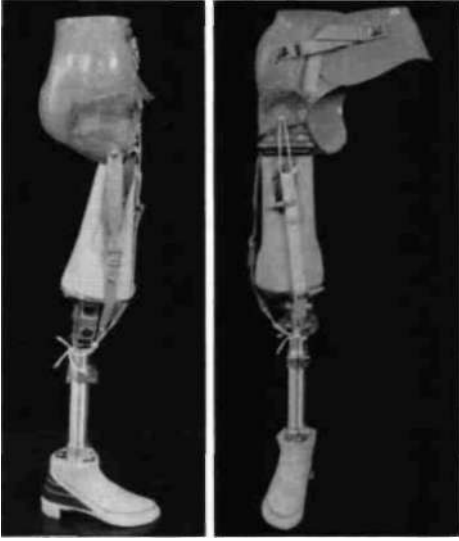


Fig. 26. Trial prosthesis set up on the UC adjustable leg.

#### STRIDE LENGTH

The distance between toe-off and heel strike should be approximately the same for the two legs. Stride length is adjusted by shortening or lengthening the hip-flexion control strap.

The thickness of the hip-stop bumper affects stride length. If the thickness of the bumper is increased, the angle at which the leg inclines forward at the end of the stance phase is reduced, and the stride is shortened. But bumper thickness should never be changed to improve control and stride length at the expense of comfort.

#### TOE CLEARANCE

A number of factors are involved in toe clearance—the length of the leg, the inclination of the foot, the amount of knee flexion in the swing phase, and suspension. Leg length is first adjusted, but the limb should not be shortened more than an inch. If scuffing persists, it is due to other factors. If the knee is not bending sufficiently, the toe will drag, and kick-strap tension should be reduced. If drop-off is causing the toe to scuff, a hand placed between the socket and the crest of the ilium on the side of the amputation should

eliminate it. In this case, either the suspension hook over the crest should be enlarged or the weight-bearing area should be built up with pads and the length of the leg reduced equivalently. Correction of scuffing may make the clearance too great, in which case leg length must be readjusted.

#### WHIP

Whip in the Canadian-type hip-disarticulation prosthesis typically takes a form comparable to circumduction in the above-knee prosthesis. Circumduction can be reduced by rotating the knee bolt externally. The degree to which the knee axis can be rotated is limited by the extent the foot will move medially in the sitting position. It may thus be necessary to effect at least some external rotation at the hip joint by cutting a wedge (with the apex medially) from the hip-joint base.

#### SWING-PHASE CONTROL

With alignment established, refinements can be made in swing-phase control. Heel rise at the beginning of the swing phase should be limited through adjustment of the kick strap rather than of the knee-friction units. The compound-pendulum system of the prosthesis does not allow the hip-disarticulation amputee to walk as fast as he would like, and it has been found that tensing the kick strap increases his speed more effectively than does increasing knee friction. This may mean that there will be some impact at the end of the swing phase, but it usually is quite tolerable because the hip joint flexes as soon as the knee comes against the extension stop, and the energy which would otherwise lead to impact is thus absorbed. Stride length may require periodic adjustment as changes are made in swing-phase control.

#### FINISHING THE PROSTHESIS

The leg is now ready to be used either as a training leg, or, after sufficient attention has been given to fit and alignment, to be duplicated (J). The only difference between duplicating the Canadian-type hip-disarticulation prosthesis and a standard above-knee prosthesis is that in the case of the former the thigh section rather than the socket is clamped in the jig.

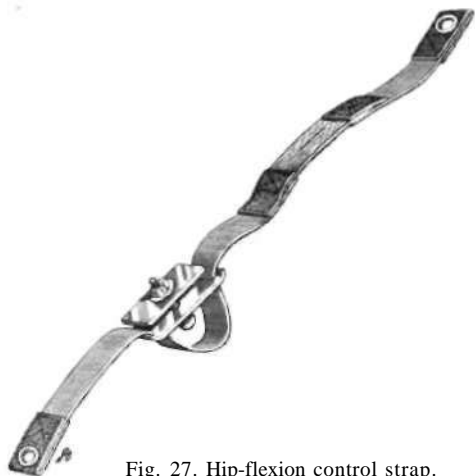


Fig. 27. Hip-flexion control strap.

The thigh section, shank, and foot are shaped and reinforced according to standard techniques (2). Weight of the thigh section is reduced by pulling wood from the inside. The hip joint is faired to the wooden base on the socket with "gunk" and tied to the base with three layers of resin-impregnated glass cloth extending about an inch beyond the wooden block. This reinforcement is smoothed and finished with a light coat of lacquer. For ventilation, the socket is perforated with 1/8-in. holes at 1-in. intervals, and padded areas are covered with nylon-coated leather or leather substitutes. The permanent kick strap and hip-flexion control strap are installed, their connections to the limb being such as to allow the straps to rotate about the points of attachment. The hip-flexion control strap (Fig. 27) is made of 1-in. vinyon or dacron webbing sewed on either end of a 4-in. section of heavy elastic webbing. For attachment to the prosthesis, a piece of leather large enough to include a 1/4-in. metal grommet (such as is used in below-knee corsets) is sewed at each end of the hip-flexion control strap, and a clamping arrangement is installed on the webbing

to permit length adjustment. The conventional kick strap is used, with the exception that it is attached proximally to the socket instead of to the thigh. Final adjustments are made to socket edges and to the permanent swing-phase controls.

The last step in the construction and fitting of the Canadian-type hip-disarticulation prosthesis is to provide a cosmetic fairing for the thigh section. A truncated cone of sponge rubber is made to fit over the thigh section so that it extends from just above the knee to the socket. The rubber cone is in turn covered with leather or a leather substitute extending beyond the rubber fairing at both ends, so that the covering can be attached to the thigh at the bottom and to the front and side of the socket with snap fasteners (Fig. 28). In order to make the fairing neat in both the sitting and the standing positions, a triangle with a 3-in. side and with the apex on the hip-joint axis may be cut from the lateral side of the covering and a piece of light elastic webbing substituted.

The procedures outlined for checking the prosthesis during construction and fitting can be applied equally well to the evaluation of hip-disarticulation prostheses.

#### ACKNOWLEDGMENT

The line drawings which accompany this article were prepared by Frank N. Todd, illustrator with the Biomechanics Laboratory

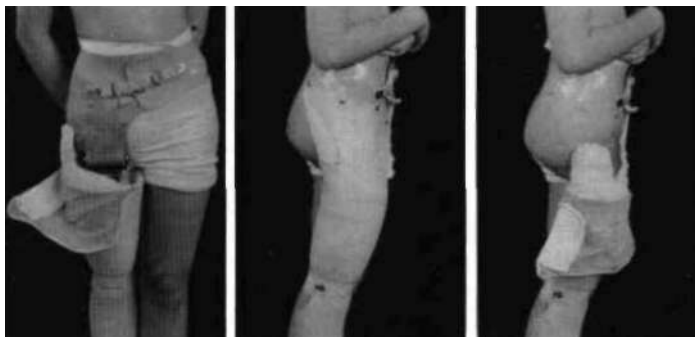


Fig. 28. Cosmetic fairing.

at the University of California at Berkeley. The halftones are by George Rybczynski, free-lance artist of Washington, D. C.

#### LITERATURE CITED

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