Spring 1964

# Artificial Limbs

## A Review of Current Developments

COMMITTEE ON PROSTHETICS
RESEARCH AND DEVELOPMENT

COMMITTEE ON PROSTHETIC-
ORTHOTIC EDUCATION

National Academy of Sciences
National Research Council

## NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL

The National Academy of Sciences—National Research Council is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare.

The Academy was established in 1863 under a Congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the Federal Government in scientific matters. Thb provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency.

The National Research Council was established by the Academy in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the Academy in service to the nation, to society, and to science at home and abroad. Members of the National Research Council receive their appointments from the President of the Academy. They include representatives nominated by the major scientific and technical societies, representatives of the Federal Government, and a number of members-at-large. In addition, several thousand scientists and engineers take part in the activities of the Research Council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the Academy and its Research Council thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the Government, and to further the general interests of science.

### COMMITTEE ON PROSTHETICS RESEARCH AND DEVELOPMENT
### COMMITTEE ON PROSTHETIC-ORTHOTIC EDUCATION

The *Committee on Prosthetics Research and Development* and the *Committee on Prosthetic-Orthotic Education,* units of the Division of Engineering and Industrial Research and the Division of Medical Sciences, respectively, advise the Veterans Administration and the Department of Health, Education, and Welfare in the conduct of research and education activities in the fields of prosthetics and orthotics; they provide means for correlating Government- and privately sponsored research in those fields.

# Artificial Limbs

VOL. 8 SPRING 1964 NO. 1

## CONTENTS



COMMITTEE ON PROSTHETICS RESEARCH AND DEVELOPMENT
COMMITTEE ON PROSTHETIC-ORTHOTIC EDUCATION

NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL

2101 Constitution Ave. Washington, D. C. 20416

**Artificial limbs is a publication of the Committee on Prosthetics Research and Development and the Committee on Prosthetic-Orthotic Education, National Academy of Sciences—National Research Council, issued twice a year, in the spring and in the autumn, in partial fulfillment of Veterans Administration Contract V1005M-1914, Vocational Rehabilitation Administration Contracts SAV-1019-64 and 64-94, and Public Health Service Grant AM 07145-07 from the National Institute of Arthritis and Metabolic Diseases.**  **The opinions expressed by contributors are their own and are not necessarily those of either of the committees.** **Library of Congress Catalog Card No. 55-7710.**

# Measurement and Evaluation

**Herbert R. Lissner, M.S.**[1]

> "I often say that when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure it in numbers your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge but you have scarcely in your thoughts advanced to the stage of science, whatever the matter may be."
>
> —*Lord Kelvin*

**M OST of us devote appreciable time in the course of daily activity to making** evaluations and forming value judgments. Every time we make a purchase, watch television, eat a meal—the list is endless—we make evaluations. Factors considered may involve monetary costs, saving of labor and time, ethical principles, aesthetic enjoyment, and many other matters.

In order to reach a final decision, it is usually necessary to combine, or even to counterbalance, evaluations made in many subsidiary categories. Those subgroups to which numbers can be applied, such as initial monetary cost and maximum attainable speed, are the easiest to consider, while those to which numbers cannot be easily assigned are more difficult to evaluate.

The establishment of standards is a recognized aid in the making of evaluations. Standards may consist simply of a set of lower limits; any product which fails to meet them is automatically eliminated from consideration. Examples of this hurdle or barrier type are some of the standards of the Underwriters' Laboratories for electrical appliances. A variant of this kind of standard may involve an upper as well as a lower limit, such as the "go—no-go" type. Conversely, a standard may involve the expression of a ratio of the specific item to the ultimate attainable, so each evaluation is a rating indicating how closely the limit is approached. A standard of this type is involved in the grading of examinations. (Even then the relationship between the score and the practical application is not always clear; the "A" student is not always successful in later life.) An intermediate form of standard is a rank ordering of individual

[1] Professor and Chairman of the Department of Engineering and Mechanics, and Coordinator, Biomechanics Research Center, Colleges of Engineering and Medicine, Wayne State University, Detroit, Mich. 48202; Chairman, Subcommittee on Evaluation, Committee on Prosthetics Research and Development.

items, along some defined scale, thus allowing comparison of each item with the average and its fellows.

All these types of standards are clearly of value, so the establishment of standards, at least tentatively, should generally precede the process of evaluation. In the production of materials and the fabrication of products of all kinds, industry and Government depend on established standards in making purchases, compliance testing, and the design of more complex products. For many years the American Society for Testing and Materials, the American Standards Association, numerous trade associations, and various Government agencies have sponsored development of standards and specifications.

Now what has all this to do with artificial limbs and braces? Evaluation serves one primary purpose in this case—the improvement of the product, a special type of man-machine combination. If the artificial limb could duplicate exactly all the functions of the natural limb in spite of the limited resources of power, sensibility, and control remaining available to the amputee, presumably we would have an ideal prosthesis. Minimal standards can rule out gross malfunctions, frequent and hazardous physical breakdowns, and obvious discomfort. Reasonably accurate lower and upper boundaries of physical dimensions to match specific categories of amputees can be established from anthropometric data illuminated by the best experience of the industry. In another sense, the physical strengths and practical minimal wall thicknesses set lower limits to weights, while maximal tolerable weights and inertias can also be estimated. By specifying the functional capabilities of the human limb we can establish the maximum standards we would like to achieve with our replacement. (The frequent recent suggestions of servo systems or "man amplifiers," though, imply that merely human performance may not be an upper bound.)

These standards of several types should be specified in many categories. Any problem, no matter how complex, can be approached by breaking it down into small segments which can be analyzed. It is only as we define the significant categories, establish and progressively refine standards, and make objective evaluations that further appreciable advances in artificial limbs and braces will be made.

# A Hemipelvectomy Prosthesis'

Fred Hampton, C.P.[2]

A Hemipelvectomy amputation involves removal of the entire lower extremity and half of the pelvis, separation generally being effected at the sacroiliac and symphysis pubis joints. Whenever possible the gluteus maximus and oblique abdominal muscles are preserved and usually are sutured together along the lower anterior aspect of the abdominal cavity. Because of disease or trauma, it is often necessary to remove the gluteus maximus, in which case the "stump" consists simply of a skin-covered abdominal cavity. The operative procedure is described and pictured in detail in *An Atlas of Amputations* by Dr. Donald B. Slocum (5).

Because there is no longer a skeletal structure on the affected side to assume the forces required during ambulation with a prosthesis, many workers have attempted to design sockets that will transfer weight-bearing loads directly to existing bony structure. Some have tried to use the ischial tuberosity on the unaffected side to support body weight, but with limited success. Others have felt it necessary to extend the socket so that the rib cage can absorb most of the weight-bearing forces, but this arrangement greatly restricts body motion and heat dissipation.

However, it has been found that it is entirely feasible for the "stump" to carry the loads if the socket is designed so that the semisolid abdominal mass of the stump is upward and medially toward the somewhat firmer area of the lower rib cage. Sometimes it is possible to utilize the sacrum for some support but relief for the coccyx must be provided because pressure on this sensitive bone almost always results in pain. Some additional support can often be achieved by utilizing the area of the gluteus maximus on the unaffected side.

Such support may be achieved by means of a piece of 1-in. Dacron webbing anchored to the inner distal area of the socket so that the anchor point is anterior to the ischial tuberosity on the sound side. The Dacron tape is led from its anchor point in the socket, under the gluteus maximus on the sound side, passing just distal to the trochanter and then diagonally across the anterior of the socket to a buckle (Fig. 1). Because the strap passes across the sound side at the level of the trochanter, it acts as a counterforce to the shearing action of the stump slipping in the socket under weight-bearing.

This article describes a method for fitting the hemipelvectomy patient in such a manner that the major loads are carried through the stump. The hemipelvectomy prosthesis incorporates many of the features of the Canadian hip-disarticulation socket, which was fully discussed in the Autumn 1957 issue of *Artificial Limbs.* However, the opening used for donning the prosthesis has been moved from the anterior portion to the lateral side of the socket. Greater stability is achieved by this arrangement since both the anterior and the posterior sections of the socket can contribute more support.

The hip-disarticulation socket utilizes the ischial tuberosity on the amputated side to support the patient in the socket, and the crest of the ilium for suspension of the prosthesis. In the hemipelvectomy case, the skeletal structure is absent and support of the patient in the prosthesis depends upon oblique upward pressure on the stump with an equivalent opposing pressure on the sound

[1] A contribution from the Northwestern University Prosthetics Research Center, Chicago, aided by U. S. Veterans Administration Research Contract V1005M-1079.

[2] Assistant Project Director, Northwestern Universitv Prosthetics Research Center.

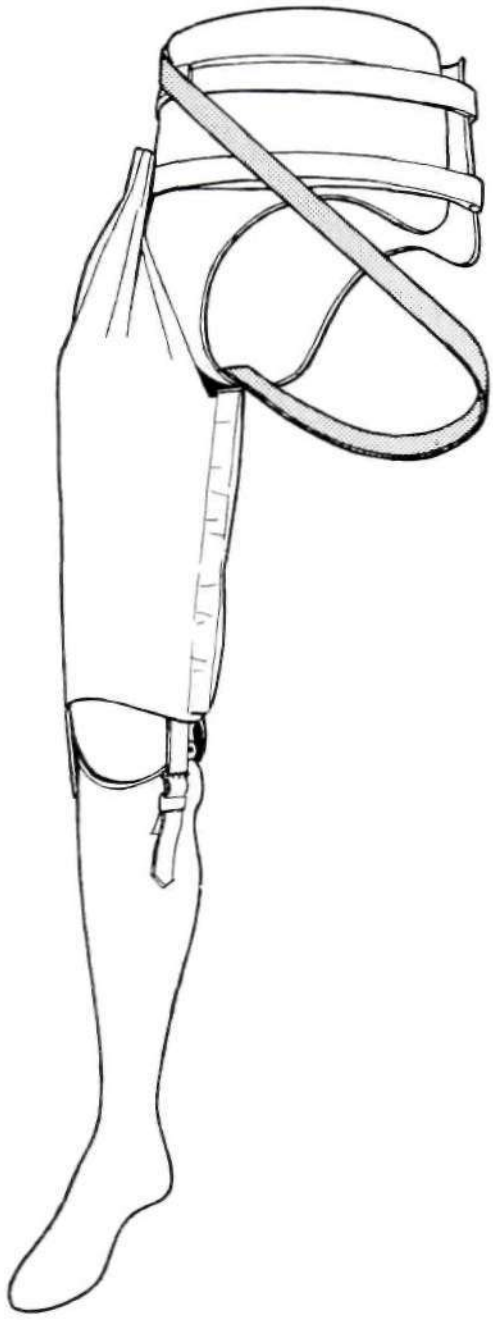


Fig. 1. Sketch shows webbing used as additional support to help to stabilize the amputee in the socket during stance phase.

side, obtained by the shape of the socket *(1)* (Fig. 2).

During casting, hip sticks (Fig. 3) are used to obtain the desired contours of tissues

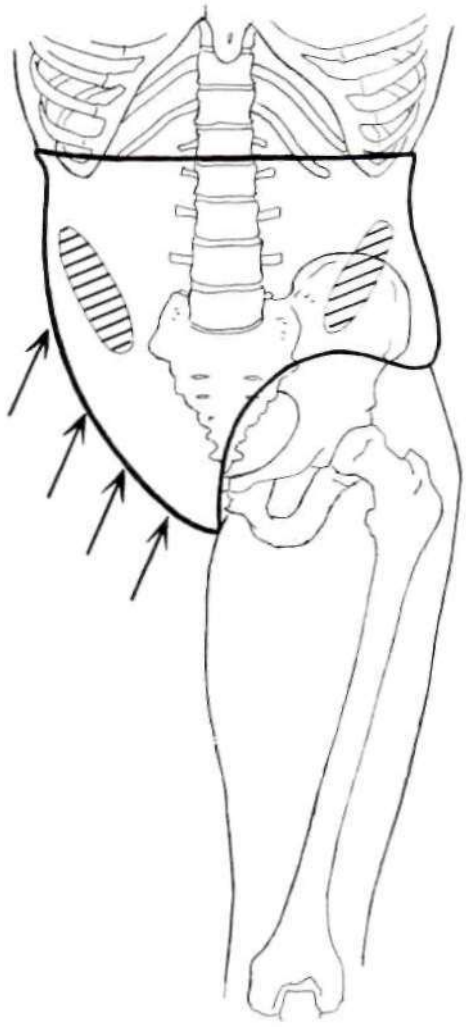


Fig. 2. Hemipelvectomy socket. Arrows indicate pressure applied by the socket to the "stump," upward and medially. Shaded areas indicate bulges produced by the use of hip sticks. The bulges aid in suspension of the prosthesis, in preventing rotation, and serve as guides for correct alignment while donning the prosthesis.

necessary for good suspension of the prosthesis *(2)*. Casting a patient while suspended in a sling is one method of compressing tissues in an upward oblique direction, resulting in a cast of the desired shape.

The hemipelvectomy prosthesis utilizes the principles of alignment of the Canadian-type hip-disarticulation prosthesis. Moreover, the mechanics of the hemipelvectomy prosthesis are essentially the same as those of the hip-disarticulation prosthesis (4).

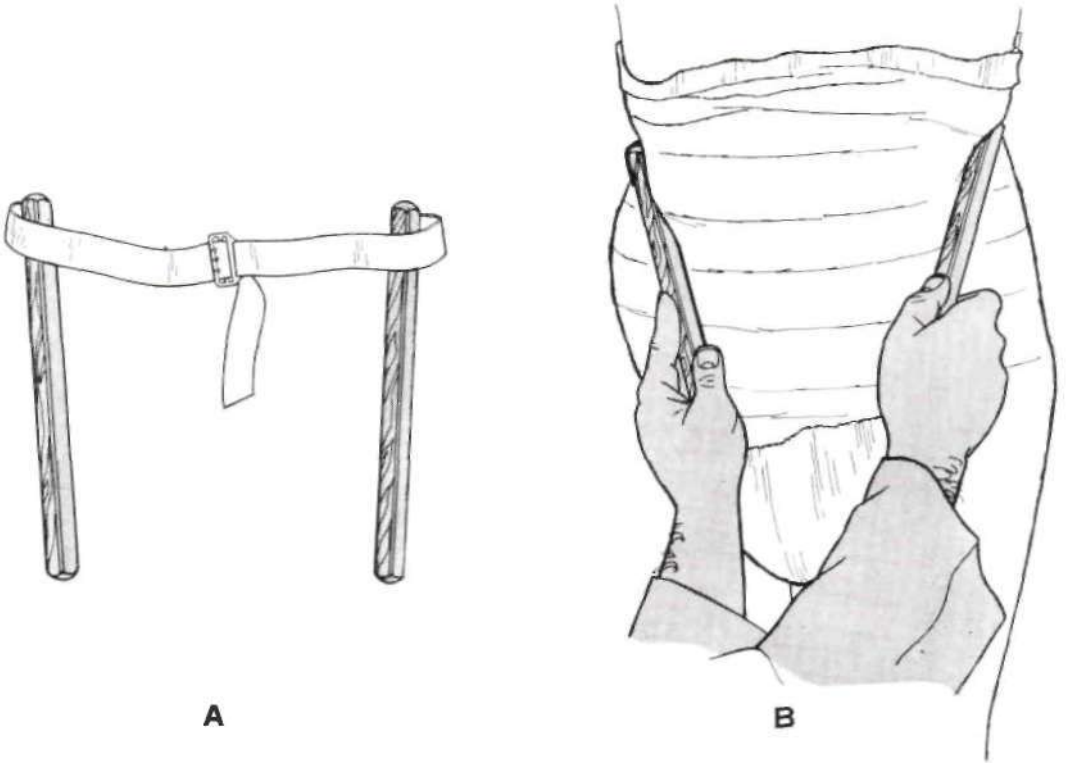



Fig. 3. Hip sticks. *A,* two sticks, approximately 14 in. in length, 1 in. in diameter, joined by a piece of 2-in. webbing, adjustable by means of a buckle. *B,* hip sticks as applied to the "stump" during casting to create relief for the crest of the ilium on the sound side and desired shape of tissues on the amputated side.

New features incorporated in the hemipelvectomy prosthesis are: First, silicone foam is used in the socket construction to fill the cavity at the location of the hip joint; silicone foam is nontoxic, easily used, and provides a surface that is not as slippery as the polyester laminates. Second, the attachment for the hip joint is an integral part of the socket. Third, there is an articulated thigh fairing which is lightweight, easily fabricated, allows reduction in the size of the thigh block, and greatly enhances cosmesis in both the sitting and standing positions. Fourth, there is a support strap under the ilium and around the trochanter.

The prosthesis includes the use of a single-axis knee and a SACH foot with a very soft heel wedge. This soft heel wedge increases the stability of the prosthesis at heel strike.

## EXAMINATION OF THE AMPUTEE

When an amputee with a hemipelvectomy stump is first seen, a visual examination will reveal scar tissue or other surface conditions that may affect the design of the socket. The location of sensitive areas should be noted so that they may receive special treatment if necessary. All hemipelvectomy amputations are not sectioned at the same level; some surgeons leave behind a small amount of the ilium or a small amount of the pubic bone. Palpation of the stump will usually permit determination of any remaining bony structure, but for definitive evaluation an x-ray of the pelvic area is desirable.

When all the conditions relative to the amputation are known and recorded on the Prosthetic Information Form (Fig. 4), the prosthetist is ready to proceed with the first step of prosthesis fabrication; namely, production of a model of the stump and adjacent areas.

## CASTING THE STUMP

It has been found that a minimum of modifications to the positive model is required if

## HIP DISARTICULATION AND HEMIPELVECTOMY AMPUTATIONS

Name _____ Date _____

Height _____ Weight _____ Age _____ Sex _____ Race _____

Date of Amputation _____ Type of Amputation _____

Cause _____ Right or Left _____

Previous Prosthesis? Type _____

Prescribed Prosthesis _____

Type Socket _____ Knee Joint _____

Hip Joint _____ Foot and Ankle _____

Tolerance of Ischial Pressure _____

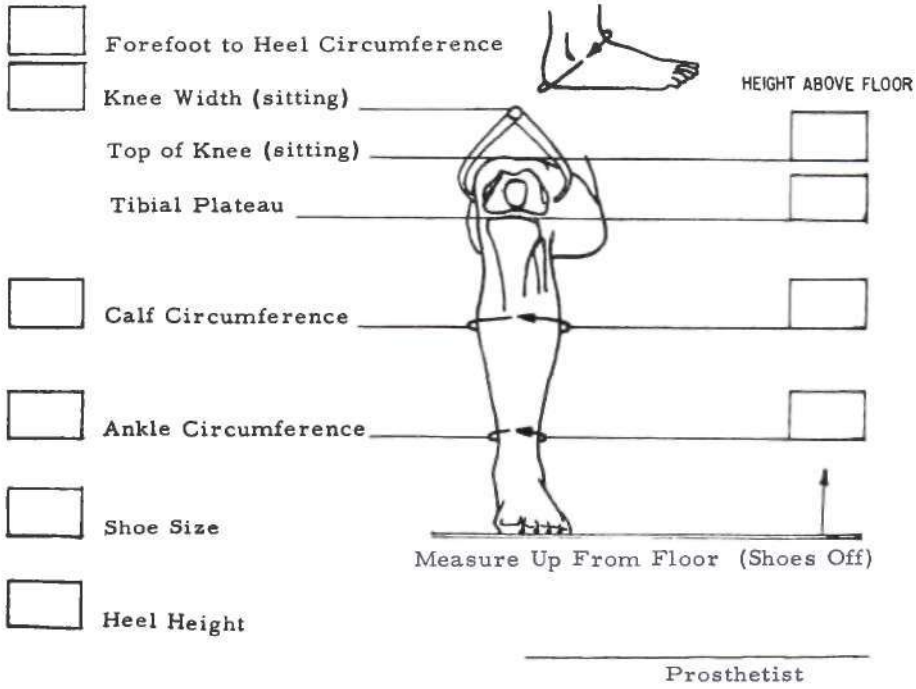
Comments on Special Considerations (Sensitive Areas, Scars, Some Femur Remaining? Any Pelvis Remaining? How Much?) _____

_____

_____

Make Tracing of Normal Limb, Anterior and Medial View, for Cosmesis

Distance from Ischial Tuberosity to Floor (No Shoe) _____




_____

Prosthetist

Fig. 4. Prosthetic Information Form.

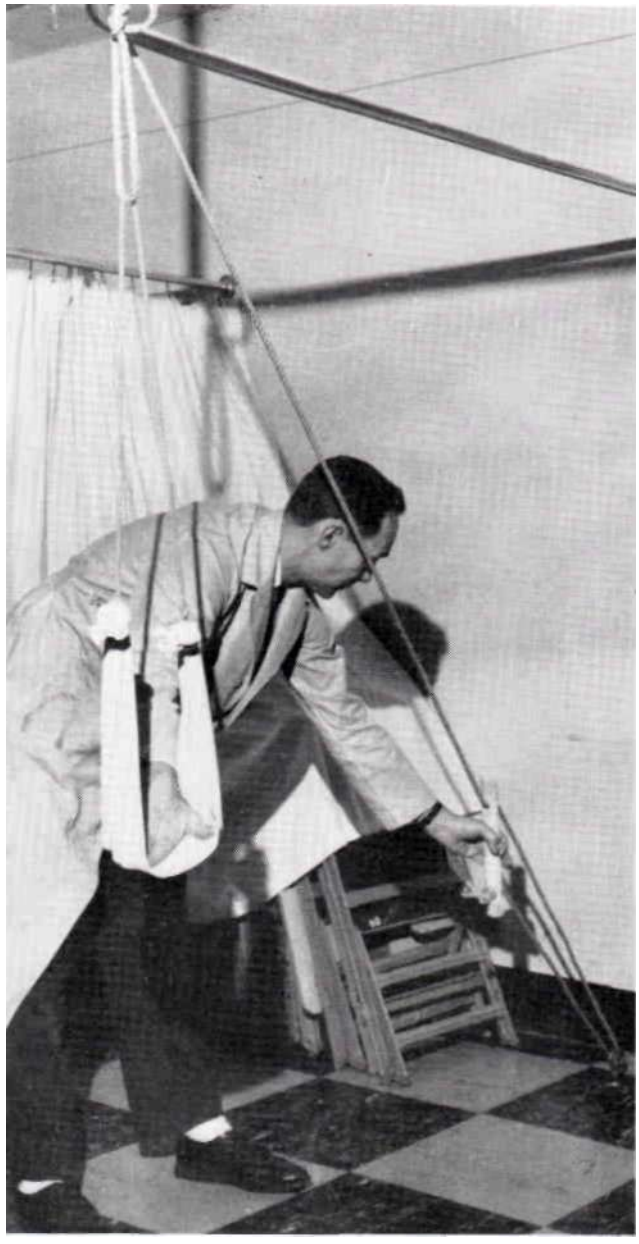


Fig. 5. Adjusting the sling to obtain proper height.

the cast is taken under weight-bearing conditions. To achieve these conditions, a simple adjustable overhead sling is used. The arrangement shown in Figure 5 utilizes existing structure in the laboratory and a tent-rope tension bar to achieve height adjustability, but a number of equally satisfactory designs can be devised.

The seat area of the sling may be made with a piece of 6-in. or 8-in. stockinette tied to the rope at both ends. The stockinette should be long enough to clear the outline of the superior brim of the socket.

In taking the cast, hip sticks are used to assist in locating and providing relief for the anterosuperior spine of the ilium on the

sound side, and to produce a similar impression on the amputated side. This impression assists in suspension of the prosthesis and helps to prevent rotation of the socket on the stump.

Materials required for taking the cast are:

| | |
|---|---|
| 4-in. or 6-in. plaster bandages | Indelible pencil |
| 3-ft. length of 8-in. or 10-in. stockinette | Plumb bob |
| Two 3-ft. lengths of 1-in webbing | Yardstick |
| Four harness clamps | Paper |
| Container with water | |

## PREPARATION OF THE PATIENT

A 3-ft. length of stockinette (8-in. or 10-in. width as required) is pulled up on the amputee until it is quite snug on the sound thigh. Proximally, it should cover half the thorax. The stockinette is secured with 1-in. webbing over the shoulders and should be pulled tight enough to give some support to the stump mass (Fig. 6).

The distal portion of the rib cage and any areas that need relief are outlined with an indelible pencil. The remaining anterosuperior spine of the ilium is located and outlined. The trochanter on the sound side is located and marked.

An approximate outline of the socket is drawn (Fig. 6). The anterior distal portion of the outline starts at the pubic ramus and arcs upward along the inguinal crease on the sound side with clearance for the sartorius muscle, then passes down to a point just superior to the trochanter. The posterior distal portion of the outline passes from the midline of the body to a point just lateral to the ischial tuberosity, then arcs upward to join the anterior line superior to the trochanter. The proximal outline circumscribes the body at the level of the tenth rib.

Fig. 6. Tentative outline of socket drawn on stockinette.

SLING ORIENTATION

The amputee is seated in the sling after it has been positioned approximately for height. Pressure on the stump should be diagonally upward and toward the opposite shoulder. Therefore, the sling should pass diagonally across the body to the sound side. A piece of 1-in. webbing under the axilla on the sound side will hold the rope away from the neck and face of the amputee.

Fig. 7. Orientation of amputee in sling. Retention strap adjusted just distal to trochanter on sound side.

A slot is cut in the sling posteriorly and just superior to the seat area. Another slot is cut opposite this in the anterior section. A piece of 1-in. webbing is pulled through these slots, around the thigh, and clamped together to prevent the seat from sliding on the stump (Fig. 7).

The amputee is instructed to place more weight on the sling than on the sound leg, and the sling is adjusted for height. It is ascertained that the seat area is contacting the remaining ramus.

The setting of the hip sticks is checked. The length of the webbing should be adjusted to fit the patient so that the groove for relief of the remaining ilium and a corresponding groove on the amputated side will be in the proper position. The fulcrum of the hip sticks should be slightly posterior to the crest of the ilium to obtain leverage necessary to bring adequate pressure against the proximal posterior portion of the plaster wrap.

WRAPPING THE STUMP

The procedure of wrapping the stump usually requires two people. Except for obese cases, the patient is removed from the sling for application of the plaster wrap. This is done to contain the tissues and so prevent lateral distortion of the stump when weight is reapplied in the sling. An obese amputee, however, should not be removed from the sling. The wrap cast should be made to incorporate the stockinette initially, because it is too difficult to wrap the stump and properly orient the patient back into the sling before the plaster starts to set,

The wrap is started at the lateral proximal brim on the sound side and is brought diagonally upwards across the anterior (Fig. 8). Moderate pressure is placed on the wrap, but ridges should be avoided. The stump should be completely wrapped just past the outline previously drawn on the stockinette. Care must be taken to include the trochanter on the sound side. While the wrap is still wet, the amputee is positioned back in the sling, and the ropes are adjusted until he is standing erect, with at least equal weight being borne on the amputated side.

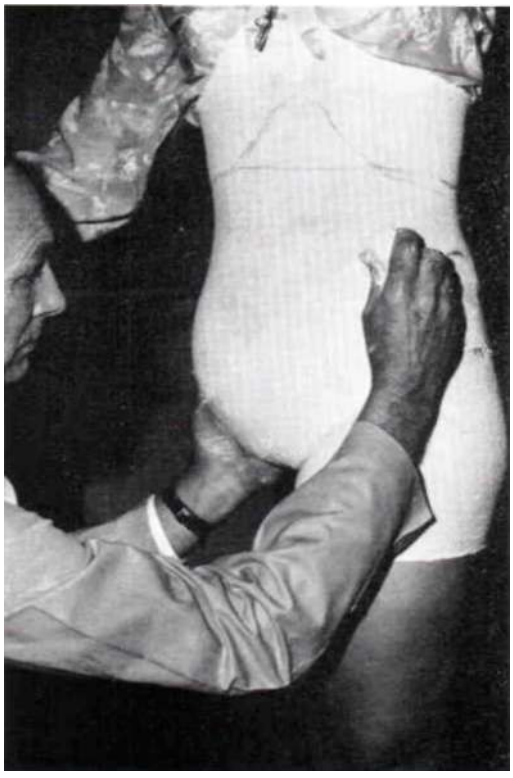


Fig. 8. Beginning diagonal wrap of stump.

The webbing of the hip sticks is placed across the back of the patient and under the stockinette sling, if it is bridging. The sticks should slant diagonally down just medial to the anterosuperior spine of the ilium on the sound side and a corresponding position on the amputated side. The crest of the ilium on the sound side is palpated by hand to ensure that the hip sticks are not impinging on the anterosuperior spine of the ilium. When the hip sticks are in the correct position, they are held with sufficient pressure to ensure adequate relief. At the same time, an oblique upward pressure is exerted to the lateral distal area of the stump and a counterforce is applied on the opposite ilium. This condition is maintained until the plaster is set. The hip sticks are removed, and the cast is reinforced with additional bandages over the sling. The wrap should touch the remaining ramus, and a portion of the gluteus on the sound side should be included.

Fig. 9. Locating trochanter on sound side.

The trochanter is marked (Fig. 9), and the amputee is removed from the sling.

The patient is then placed on a table with the stump toward the near side of the table. The gap between the plaster cast and the patient's abdomen is checked to determine if alteration to the wrap is required to contain the viscera and ensure an intimate fit to the socket (Fig. 10). The plaster wrap is cut from the proximal to the distal rim just medial to the socket section. The gap, if there is one, is eliminated by pushing the cast down to meet the abdomen, care being taken not to squeeze the cast mediolaterally and so disturb the placement of the bulge caused by the hip sticks on the sound side (Fig. 11). One side of the cut is covered with vaseline to a depth of approximately 4 in. to facilitate removal of the cast.

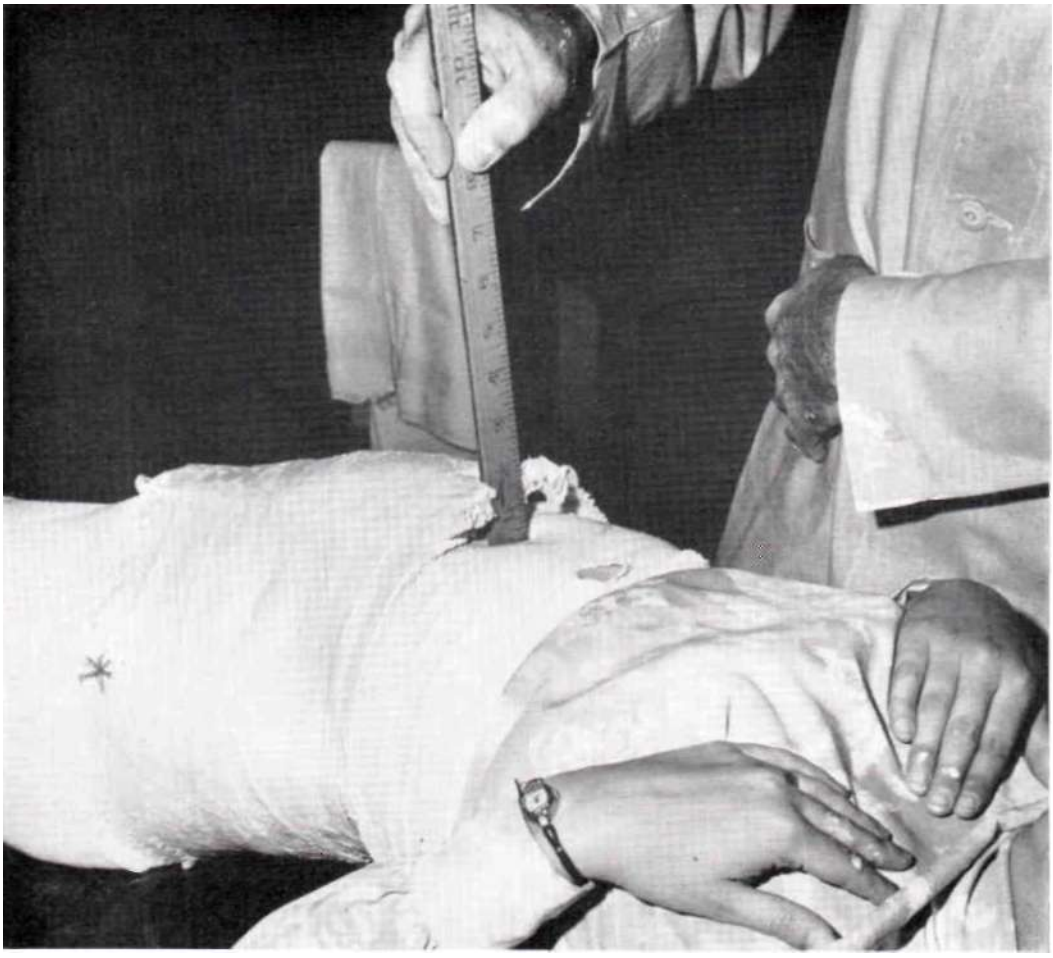


Fig. 10. Checking the gap between the cast and the patient.

A panel of plaster-of-Paris bandages approximately 8 in. wide is formed and laid across the front of the cast, the cast being held in the desired position. Lines to relocate the position of the panel and the cast are drawn, and the cast is secured on the patient by means of a web belt. This will prevent the cast from spreading when the amputee stands and will result in more accurate datum lines.

With the amputee standing, the cast is checked for lit and comfort.

REFERENCE LINES

To provide datum lines for alignment of the prosthesis, vertical reference lines are marked on the cast at this time.

The amputee should stand erect using an adjustable support under the cast. The spine should be straight and the shoulders level and at right angles to the line of progression.

A plumb bob is suspended from the sternum (Fig. 12), and a vertical line is drawn on the cast. A plumb bob is suspended from the spine, and a vertical line is marked on the cast. A plumb bob is suspended from tinder the axilla to bisect the trochanter on the sound side, and the line is drawn on the cast.

The cast is removed from the amputee and, after being cut down to the outline previously drawn on the stockinette, is used as a check socket. It should be checked for support and comfort under weight-bearing

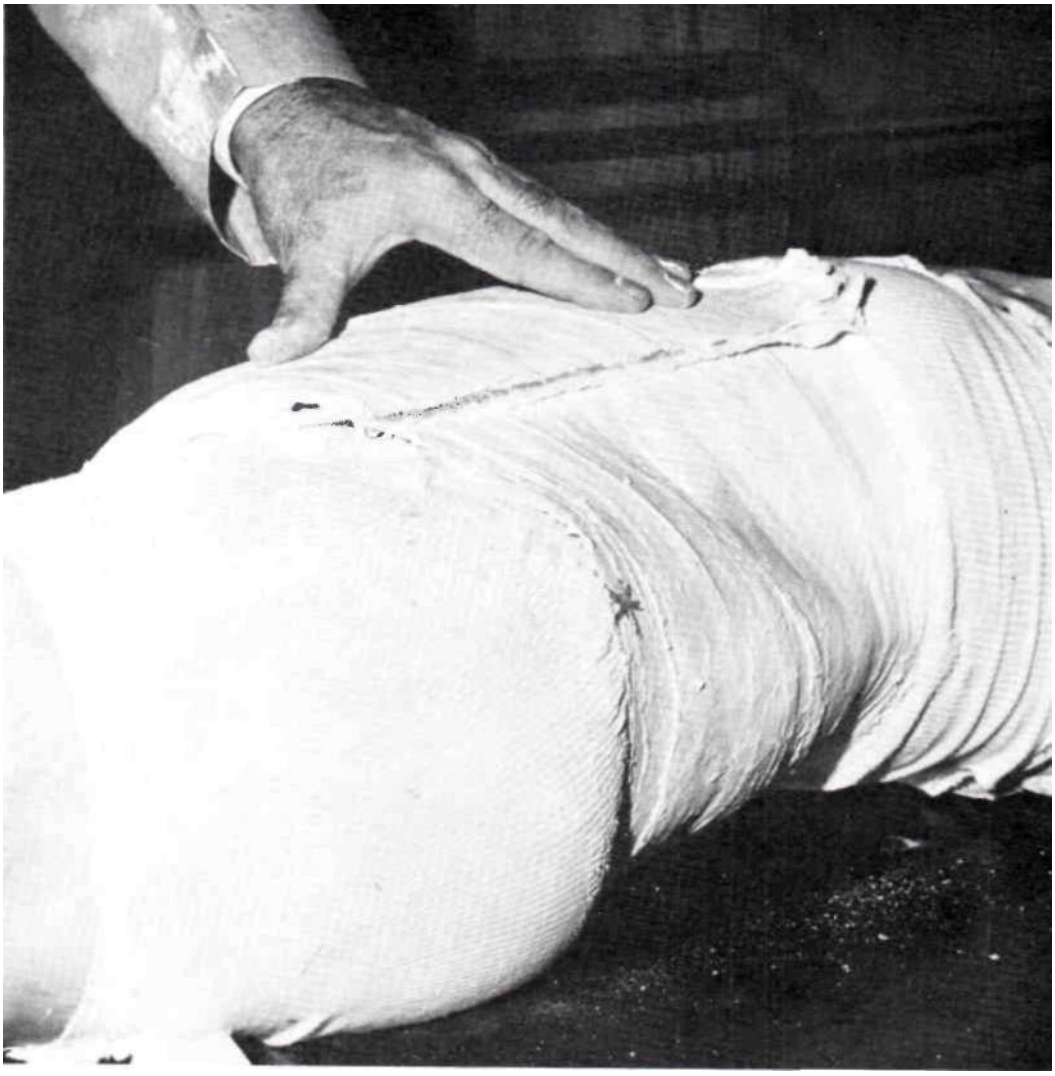


Fig. 11. Closing the gap by downward pressure.

while the amputee is standing, for pressure on the rib cage, and for clearance of the sound leg while the amputee is sitting. The area of the coccyx should be checked, also the area providing relief for the anterosuperior spine of the ilium on the sound side.

### POURING THE PLASTER POSITIVE MODEL

The common method of forming the plaster positive model is to pour the negative cast full of a plaster slurry. A mixture of plaster and vermiculite in equal proportions results in a lighter model and one that is quite easy to work. A slush, or hollow model, may be used, but care should be taken to make the model thick enough for it to withstand the pressures involved when lamination is carried out.

The leg opening is closed, and the cast is reinforced with plaster bandages. A separator such as vaseline or silicone spray is applied to the inside of the cast.

The reference lines are reestablished if they were covered by the reinforcement.

A sheet of paper large enough to extend beyond the cast is laid out and divided into four equal parts by means of two perpendicu-

Fig. 12. Use of plumb bob to obtain reference lines on cast.

lar lines. The cast is placed on the paper so that the vertical reference lines on the cast coincide with and are vertical to the lines on the paper. The cast is secured in this position by blocking it up with plaster.

After the plaster has been poured into the cast to form the positive model, a pipe is inserted not only to provide for ease of handling but also to act as a pathway for the air to be drawn out of the laminate by a vacuum pump. A paper cup is installed on the pipe, as shown in Figure 13, to keep plaster from clogging holes that have been drilled in the pipe to allow the passage of air. The pipe is inserted so that it is aligned with the vertical reference lines; thus it can be used as a reference line when the negative mold has been removed.

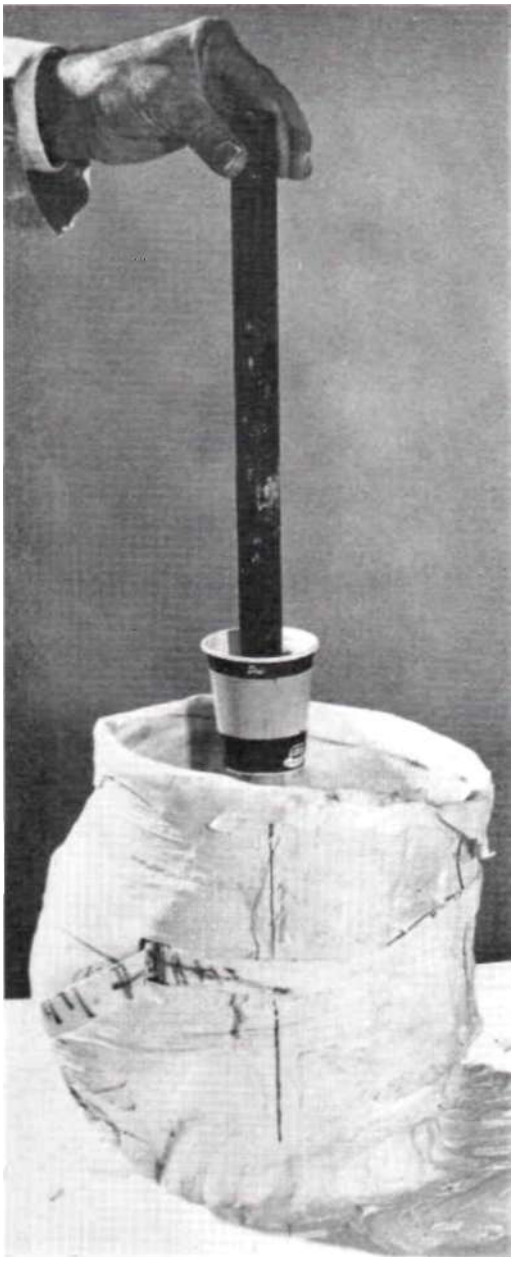


Fig. 13. Setting pipe vertically using vertical lines on cast as reference.

## LOCATION of THE HIP JOINT

Before any modifications to the positive model are undertaken, a buildup is made so that the finished socket will contain a flat area suitable for installation of the hip joint. Instructions given here are for the so-called

Fig. 14. Scribing 45-deg. line on cast.

Northwestern hip joint,[3] a unit which provides for alignment adjustment.

The hip joint should be placed laterally to provide adequate clearance in the crotch area, placed well forward to ensure adequate stability during the stance phase of walking, and high enough so that the extension stop does not interfere with sitting.

If the hip joint is placed too far to the rear, the amputee will be insecure, the joint will interfere with sitting, and more energy will be expended in walking. If it is placed too far forward, the prosthetic knee will extend past the normal knee when the patient is seated. This condition can be partially alleviated by shortening the thigh and lengthening the shank. However, a compromise in the location of the joint is essential.

Location of the hip joint in approximately the optimum position may be achieved by the following method:

Before the positive model is removed from the cast, a reference trochanter, the point on the cast directly opposite the trochanter on the sound side, is established. By means of a height gauge, the trochanter mark on the cast is transposed to a point vertical to the layout line on the opposite side. A point on the surface of the cast 1 1/2 in. vertically below this point is marked. Through this last mark, a line is drawn on the cast at an angle of 45 deg. A useful aid for this is a piece of wood approximately 1 in. thick, cut on an angle of 45 deg. (Fig. 14). In scribing the line, the pencil must be held flat on the 45-deg. surface.

All reference lines from the cast are cut through to the positive model by use of an awl. When the cast is removed, the lines are marked on the model with an indelible pencil.

An outline of the socket is drawn on the model. Heretofore, it has been the common practice to cut the anterior portion of the socket to allow entry and exit of the torso. Experiments at the Northwestern University Prosthetics Research Center have shown that more stability between patient and socket can be achieved if the opening is made on the lateral wall.

## MODIFICATION OF THE POSITIVE MODEL

To provide additional relief for the antero-superior spine of the ilium on the sound side, a skived piece of leather or a plaster buildup 1/4 in. thick on the positive model should be adequate.

[3] NHJ-100, Hosmer Corp., Santa Clara, Calif.

The anterior section of the model usually has a ridge caused by overlapping during the casting procedure. This ridge should be eliminated by removal of plaster. If there is a large bulge posteriorly in the gluteal area, the bulge should be reduced by removal of plaster. Sometimes the angle of the lateral wall will continue to the ramus. If this is apparent, the distal seat area may be modified and flattened slightly by removal of plaster in order to minimize slipping. Any other ridges should be removed, and the entire model should be smoothed with files, wire screen, or sandpaper. A good finish may be obtained by wet sanding with a piece of Wetordry Fabricut.

Moisture must be contained in a new model to prevent the PVA bag used as a separator from becoming wrinkled. Application of a sealer, such as Ambroid or parting lacquer, will serve to retain moisture.

Leather tongues used at the closure of the socket will deteriorate from sweat. A molded flexible polyester tongue is more durable and sanitary. It should be formed to the model before the flare is added to ensure a smooth transition from the tongue to the socket surface. The tongue is made by laminating four staggered pieces of nylon stockinette across the proposed opening with a flexible mixture of polyester resin (60 per cent Laminac 4134 to 40 per cent Laminac 4110 is an adequate mix). After the tongue has set, it should be trimmed to the desired shape and taped to the model.

The outline of the socket on the model is built up to provide a flare with a radius of approximately 3/4 in. The buildup is accomplished by folding a piece of 4-in. plaster bandage lengthwise approximately seven times, wetting it, and laying it on the outline as a beading. The plaster bandage is formed over the tongue to provide a lateral opening at least 1 in. wide. The beading is formed to the desired flare and smoothed with plaster (Fig. 15). The flare should be coated with Ambroid or parting lacquer.

The model is now inverted and mounted in a vise with the sagittal plane vertical. The mounting pipe should be set at an angle of 45 deg. to the horizontal, with the anterior surface of the model upward (Fig. 16). The 45-deg.

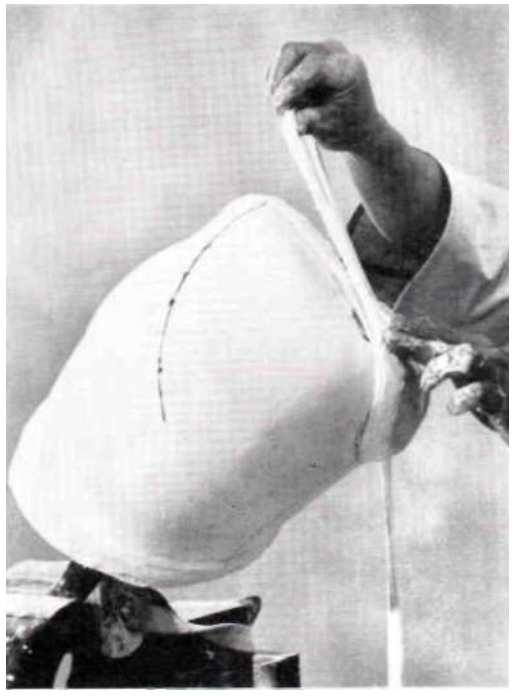


Fig. 15. Construction of flaring.

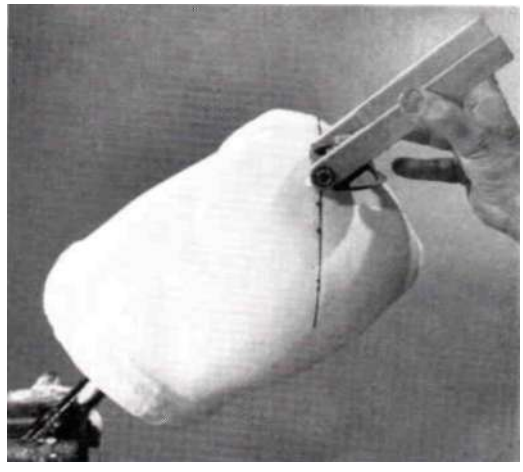


Fig. 16. Positioning joint on positive model using 45-deg. line as reference. (Model is held in vise at 45-deg. angle, so 45-deg. line, previously scribed, is now vertical.)

line on the model should now be vertical, and it should be extended past the flare, both proximally and distally.

The configuration of many hemipelvectomy sockets will not allow sufficient clearance for the joint in the crotch area. To allow the joint to be placed more laterally and to provide a flat area for mounting the joint, it is necessary to build up the positive model with rigid polyurethane foam.

The principal considerations in planning the joint location are: First, the flat area must be large enough to receive the mounting plate (about 2 3/4 in. in diameter). Second, the flat area will be horizontal when the model is mounted at the 45-deg. angle. Third, usually the axial center of the joint is somewhat anterior to the 45-deg. line. (It should be kept as close as possible to the line, but the joint must not be permitted to interfere with the sitting position.) Fourth, in most hemipelvectomy sockets, the joint will project beyond the lateral edge of the socket, but it should not project further from the midline of the body than the corresponding joint of the sound leg.

Fig. 17. Pouring polyurethane foam into cardboard form.

Fig. 18. Anterior view of positive model showing flat area necessary to receive hip joint.

Cardboard is formed on the positive model to form the buildup for the joint location and to allow for contours that will blend well with the socket. Polyurethane foam (Pelron 4-lb. density No. 9664[4]) is mixed and poured into the cardboard form (Fig. 17). As the foam is being shaped, care should be taken to shape the area immediately medial to the joint to permit full adjustment of the joint. Figure 18 shows the completed buildup on the positive model for the location of the hip joint.

## SOCKET FABRICATION

Although it is not necessary to use any specific laminating procedure, the vacuum technique described in this article is presented as one that has produced consistently good results in the Northwestern University Prosthetics Research Center *(3)*.

Radial suction grooves are cut with a sharp knife from the crest of the flare on the positive model to the cup, or approximately eight 1/8-in. holes are drilled through the model into the cup, the holes being so situated as to ensure the evacuation of air from undercuts.

[4] Pelron Corp., Lyons, Ill.

A thin smear of vaseline or motor oil is applied over the sealed surfaces of the model and the polyurethane foam buildup. (Caution: Ambroid should not be applied to the polyurethane foam; the thinner in the Ambroid will soften the foam.) A light plaster slurry is used to blend the edges of the foam into the contours of the socket. A light plaster wash is then applied to the foam and allowed to dry. Ambroid, then vaseline or oil, may be applied to facilitate pulling the PVA separator over the model.

A tailored PVA bag is pulled down over the positive model. One end is gathered and tied over the area of the sound leg. The other end is taped tightly around the pipe. Three or four holes are punched in the bag near the cup.

Fabric is applied as follows:

1 layer 1/2-oz. Dacron felt.
1 layer nylon stockinette.
7 layers of glass cloth over the joint and seat areas The pieces of cloth should be of varying size to produce a gradual transition in rigidity.
1 layer Dacron felt over all.
5 layers of nylon stockinette pulled on tight and tied to the pipe.
A PVA bag is pulled down over the layup and taped tightly to the pipe.

Resin, in an appropriate amount, should be prepared in the proportion of 80 per cent rigid Laminac 4110 to 20 per cent flexible Laminac 4134. ATC catalyst—2 per cent of the weight of the resin mixture—is added and spatulated thoroughly. Appropriate pigment, amounting to about 2 per cent of the weight of the resin mixture, should be added: 12 drops of Naugatuck # 3 promoter results in approximately 20 min. working time. This will vary according to temperature and humidity.

One method of impregnating the fabric with the resin is to pour the resin into the top of the outer PVA bag and "string" the resin downward, working it into the layup, especially into the reinforced seat area, to obtain complete saturation. After the resin has been "strung" into the layup, the vacuum is applied and a head of resin is maintained at the top to prevent air from being sucked into the laminate. Insofar as possible, air is excluded from the top of the PVA bag, and the bag is tied off tightly at the top.

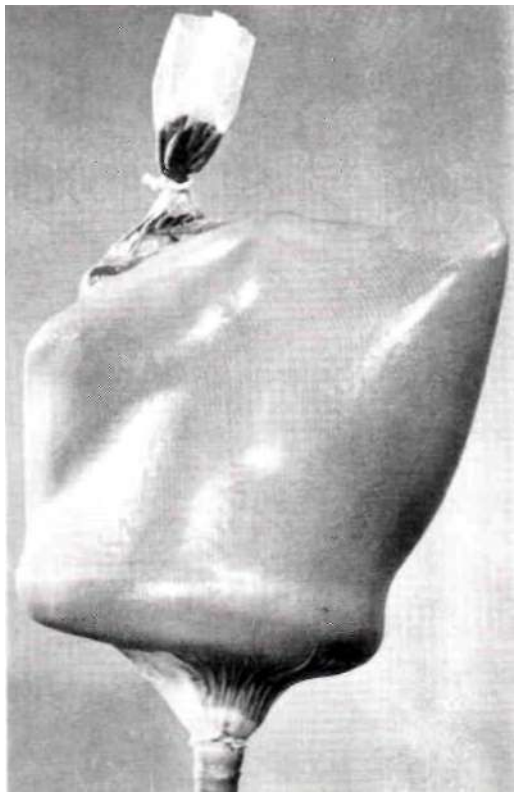


Fig. 19. View of laminate of socket using vacuum technique.

Another method is to apply vacuum prior to "stringing" the resin into the layup. In this procedure, the resin is poured into the top of the PVA bag, which is then tied off and vacuum is applied. The resin is then "strung" down into the layup.

In both procedures, the hands must be used to force the resin from undercuts, considerable "stringing" downward must be done to remove bubbles, and "stringing" upward to remove excess resin.

Low negative pressure should be maintained until the plastic has set (Fig. 19). Excessive vacuum will pull the resin from the laminate, causing "starving."[5]

[5] At sea level, the atmosphere will support a column of mercury 30 in. high. Most vacuum gauges, therefore, are calibrated in inches of mercury (in. Hg.), reading from 0 to 30. 10 in. Hg. negative pressure means 10 in. of mercury below atmospheric pressure.

## REMOVAL OF SOCKET FROM POSITIVE MODEL AND REPLACEMENT OF POLYURETHANE FOAM BUILDUP WITH SILICONE FOAM

With the flare as a guide, a Stryker cast cutter is used to cut through the laminate along the outline of the socket. If a molded tongue has been attached to the positive model, care should be taken when making the cut on the lateral side. It is prudent to leave a little extra laminate for subsequent trimming.

The polyurethane buildup for the location of the hip joint is removed from the positive model. The positive model is smoothed in this area, and a thin smear of vaseline is applied. A piece of lightweight stockinette is stretched over this part of the model and stapled in place.

Using the back plate as a template, three 1/4-in. holes are drilled. The center hole is drilled with a 1/2-in. drill. The back plate is mounted in the socket with two bolts and nuts. The bolts should not be cut.

The socket is replaced on the stump model and secured tightly with a web belt or friction tape (Fig. 20). It is in position for the injection of silicone rubber through the 1/2-in. center hole in order to provide support for the amputee over the area of the hip joint.

In choosing the silicone rubber to be used, it should be remembered that Silastic 386 Foam Elastomer is relatively soft and may not be capable of supporting the weight of the amputee, while Silastic 385 Elastomer forms a solid rubber which will, if used by itself, add considerable weight to the prosthesis. Accordingly, a mixture of 70 per cent by weight of 386 with 30 per cent by weight of 385 is recommended. This is poured into a caulking gun. The 386 catalyst—6 per cent by weight of the mixture—is added, and the mixture is spatulated for 25 seconds. Because of the small amount of catalyst, the viscosity of the Silastic, and the shape of the chamber of the caulking gun, it is very difficult to get a homogeneous mix if spatulated by hand. A mixing rod should be formed that can be used in conjunction with a 1/4-in. electric drill. A rotary up and down movement should be used, mixing for 25 seconds. It is then injected through the center hole of the spherical plate to fill the

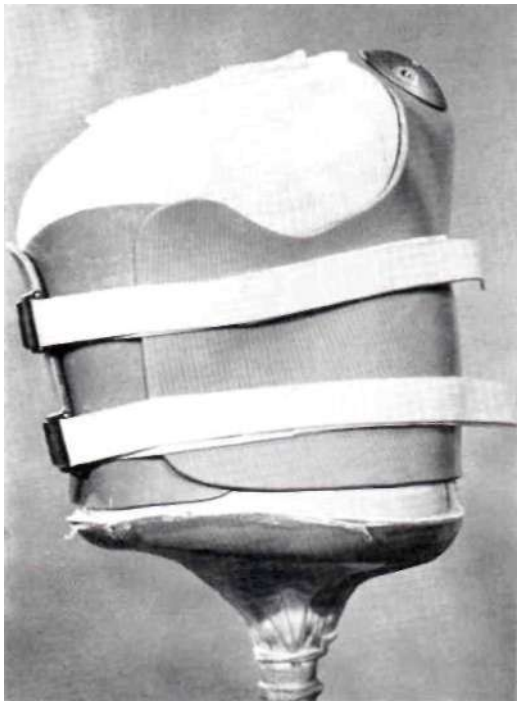


Fig. 20. Socket replaced on stockinette-covered cast preparatory to injection of foam.

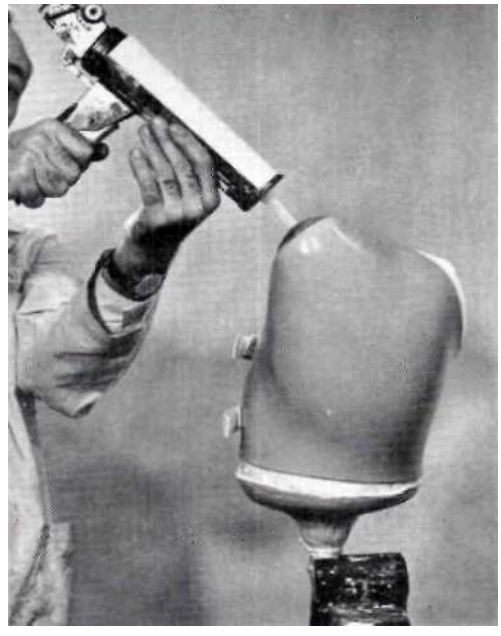


Fig. 21. Injection of silicone foam through center hole of spherical plate.

socket cavity (Fig. 21). The mixture will expand approximately four times its volume during foaming. If necessary, more of the same mixture is added until the cavity is filled.

The socket is removed from the cast. The silicone pad is removed and the nuts are removed from the two bolts. The spherical plate is attached to the socket with three 1/4-in. flat head bolts. The bolts should be locked tight with a locking compound. The bolts are threaded into the spherical plate with a screwdriver, but they should be tightened with vise grip pliers applied to the protruding threaded portion of the bolt. If this spherical plate is not tightened sufficiently, movement and noise will result. The bolts should then be cut and ground to maintain the spherical contour (Fig. 22).

The edges of the socket are sanded and buffed to provide a smooth radius.

For fitting purposes, the foam pad is secured in the socket by means of friction tape. It can be glued to the socket when the prosthesis is being completed. The edges of cloth reinforcement on the foam should be trimmed, and the surface coated with a skin of Medical Silastic S—5391 Elastomer (Fig. 23).

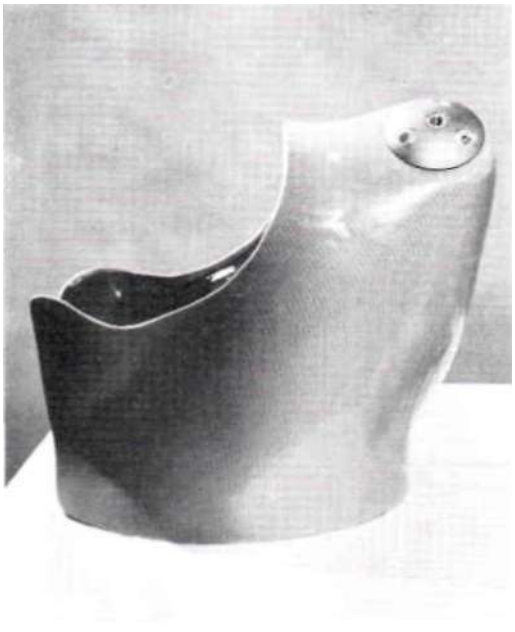


Fig. 22. Socket with spherical plate attached.

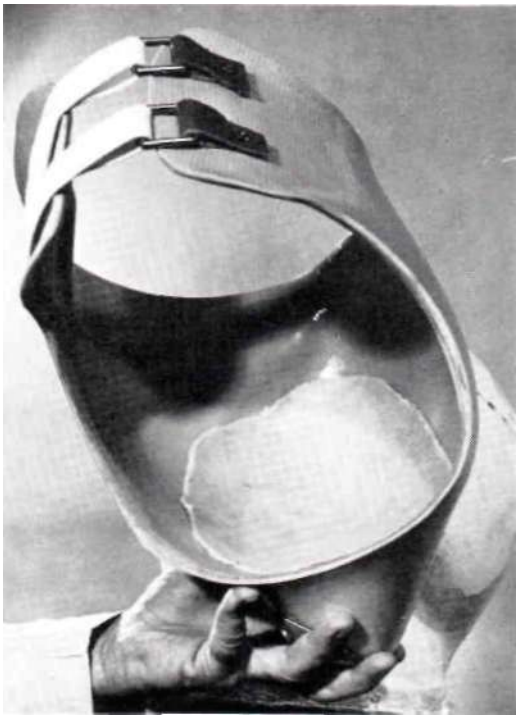


Fig. 23. View of silicone foam pad with stockinette reinforcement.

## LAYOUT OF THIGH BLOCK

One method of determining the configuration of the thigh block is as follows:

1. On a large piece of paper, line A is drawn to represent the length of the foot (Fig. 24). The distance from the end of the heel to the center of the ankle bolt is measured and marked on line A.

2. Line B is drawn perpendicular lo line A from the point representing the foot attachment bolt. The length of this line is the distance from the ischial tuberosity to the floor.

3. On line B a point is located equal to the height of the medial tibial plateau (MTP) plus 1 1/4 in. for adults. The location of the hip joint often causes the prosthetic knee lo protrude beyond the sound knee when the patient is in the sitting position unless the thigh is shortened and the shin is lengthened. Therefore, 1 1/4 in. is added to the dimension between the floor and the MTP.

4. Two inches above this point a 6-in. line is drawn to represent the attachment plate of an adjustable leg. This line is drawn 3 1/2 in. anterior of and 2 1/2 in. posterior of line B.

5. A line is drawn at right angles to line B at its topmost point. This line, D, represents the height of the level of the seat of the ischium from the floor.

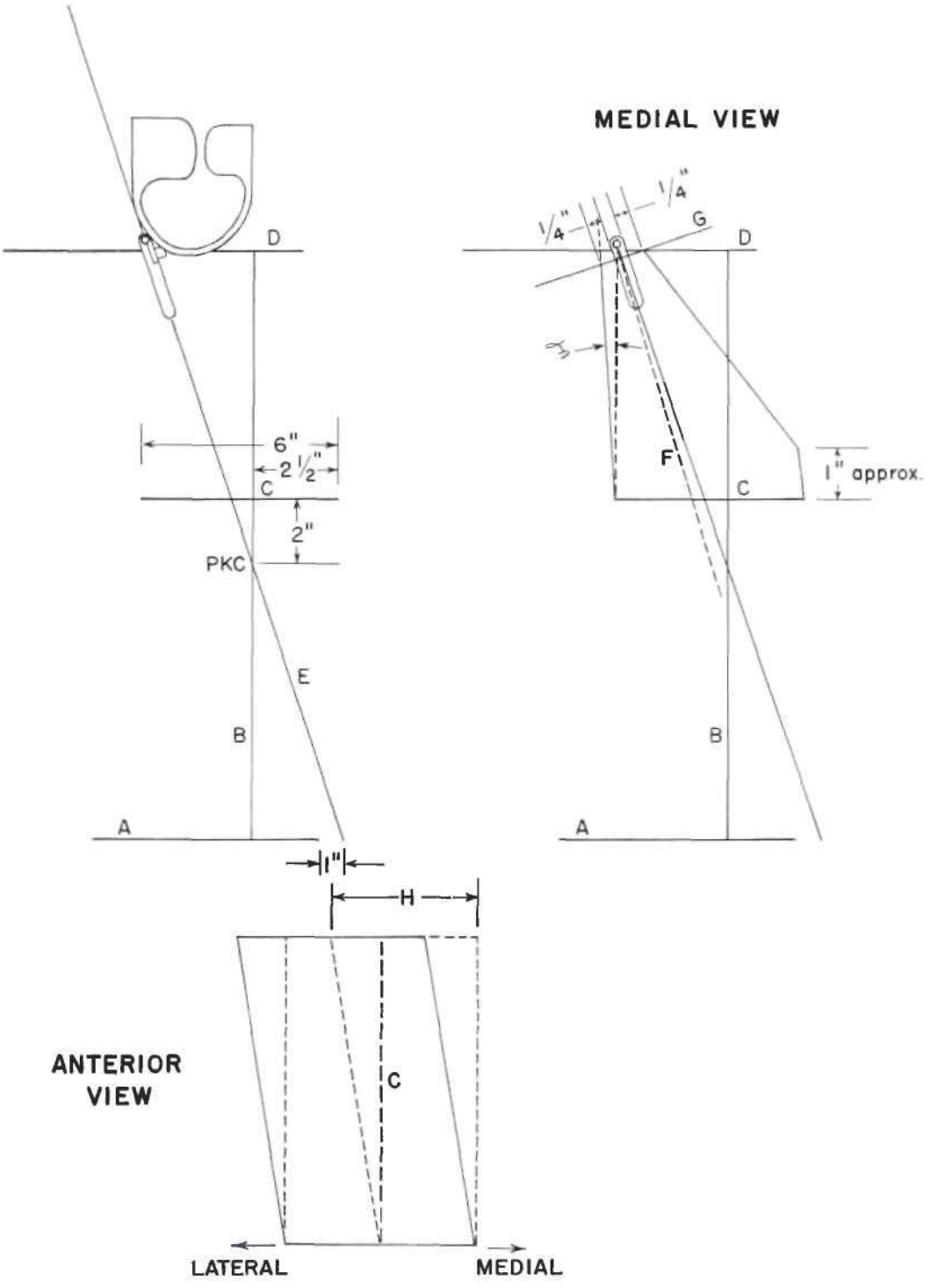



Fig. 24. Schematic drawing (not to scale) for layout of thigh block.

6. From a point 1 in. behind the heel, line E is drawn to intersect the prosthetic knee center (PKC) and the horizontal line D.

7. The socket is superimposed on the layout, with the joint attached and in a neutral position. The inner edge of the socket must fall on line D and the hip joint center must pass through line E.

8. The hip joint is adjusted so that the angle of the straps with line D is 73 deg. in order to maintain the 45 deg. originally planned for the placement of the hip joint.

9. The position of the side straps is marked and outlined, line F, and also the offset for the shoulder of the straps, line G.

10. There should be 1/4 in. of wood anterior to the hip joint. Therefore, from a point 1/4 in. anterior to the shoulder of the side strap outline, a line should be drawn connecting with the anterior end of the socket attachment plate line. (Angle *a* in Fig. 24 is the flexion angle.)

11. From a point 1/4 in. posterior to the shoulder of the side strap outline, a line is drawn to form the posterior outline of the thigh block. Often, this is not a direct connection with the posterior end of the socket attachment plate line, as this would not provide sufficient thickness of wood for screws at the attachment plate of the adjustable leg.

12 An anterior view is drawn of the thigh section in which the proximal center point is offset the equivalent of the distance from the center of the artificial hip joint to the vertical support line on the prosthesis, less 1 in. (distance H in lower part of Fig. 24). This establishes the approximate angle of adduction needed in the thigh block. The objective is to place the artificial foot in the approximate amount of adduction.

13. The thigh block, of correct length, is positioned with the lateral side up and angle *a,* obtained from step 10 above, is inscribed upon it.

14. The thigh block is positioned with the posterior side up. A goniometer is placed with one arm parallel to the lateral side of the posterior wall; the other arm, set in the angle required, should lie across the posterior wall and connect with the flexion angle previously established. If the adduction required is excessive, it is sometimes necessary to bend the side straps. A bend of approximately 8 deg. is usually sufficient. Care must be taken not to produce nicks and notches in the side straps which may cause premature fracture.

15. The table of the saw is set at the adduction angle and a cut is made along the flexion line.

16. The hip joint is centered on the thigh block, and the width of the straps is marked. The outline of the straps should be left showing after the excess wood has been cut away. Enough wood must be left for the socket attachment plate. Care must be taken that the distance between joints is accurately reproduced on the thigh block, otherwise binding will result when the joint is assembled and shimming will become necessary.

17. The joint is clamped to the thigh block. After the two indicated 1/4-in. holes have been drilled, the joint is bolted to the thigh block.

## BENCH ALIGNMENT OF PROSTHESIS

Two general rules to be followed in the bench alignment of the prosthesis are: First, the socket should be the correct height above the floor, with the transposed point of the ischium directly over the center of the foot. Second, the knee should be set in slight hyperextension so that a straight line drawn through the hip joint intersects the floor about 1 to 1 1/2 in. behind the heel.

It is recommended that a SACH foot with a soft heel wedge be used. A knee extension aid is important; it is provided by a piece of 1-in. elastic which also functions as a stride length control. This is adapted for temporary use on the adjustable leg by mounting a piece of leather on the socket approximately 2 in. behind the hip joint in such a way that the elastic strap can pass through the attachment. For a woman, the extension aid is built into the knee mechanism and the socket bias strap is secured to the distal thigh block. One end of the elastic is screwed to the shin 2 in. down from the PKC, and the other end of the elastic is secured by a buckle mounted in the corresponding position on the other side of the shin. A keeper of 1/2-in. Dacron webbing, with a buckle, is positioned about 1 1/2 in. proximal to the knee bolt. This keeper should be adjusted so that it holds the bias strap anterior to the knee bolt center when the patient is standing and walking but allows it to pass posterior to the knee bolt center when the patient is sitting.

Velcro offers a convenient method of closure for the lateral opening of the socket (Fig. 25).

When the prosthesis is assembled, the axes of the hip joint and of the knee joint should be essentially parallel to the floor and at right angles to the line of progression.

## STATIC AND DYNAMIC ALIGNMENT

Satisfactory suspension of the prosthesis often depends upon the proper application of

Fig. 25. Arrangement of closure straps using Velcro.

the socket (Fig. 26). The stump should be forced as far laterally as possible and the closure straps should be tightened alternately until the amputee is well supported. The ischial support strap should be secured last. The relief provided by the socket for the anterosuperior spine of the ilium on the sound side is a useful guide in orienting the socket to the patient. The socket should then be checked for fit and comfort under weight bearing in the areas of the ramus, the coccyx, and the rib cage. Lateral stability of the socket should be evaluated by supporting the prosthesis against a chair and asking the patient to raise his good leg without leaning over the prosthesis.

The alignment line from hip center through PKC to a point behind the heel should be verified for stability. It should be ascertained that the height of the prosthesis is correct; that the extension bias strap is forward of the PKC; that there is no friction in the knee joint; and that the bumper and stop are in contact. The patient should not be in a forced position of lordosis, and the socket should not exert pressure proximally in the back. If either of these conditions exists, the bumper is contacting the stop too soon and the socket should be tilted backward by means of the adjustable hip joint. If the bumper is not in contact with the stop, correction should be made by adjustment of the hip joint.

The amputee should then sit upright in a hard chair, and the anterior distal portion of the socket should be inspected for clearance of the thigh. If the amputee tends to lean to the amputated side, the exterior gluteal area of the socket should be built up with foam for support and to improve cosmesis. It should be ascertained that there is no pressure between the proximal edge of the socket and the rib cage; that the thigh block clears the chair; that the shank is vertical; that the prosthetic knee axis does not protrude excessively beyond the normal knee center; that toe-out is approximately correct; and that the extension bias strap is holding the shank in flexion.

In training the amputee to walk, he should be impressed with the importance of standing upright by holding his hands parallel to or slightly posterior to the long axis of his body. If he leans forward to watch his feet, the hip bumper will not contact the stop, making it impossible to propel the leg forward. He should alternately bear his weight on the prosthesis and then lift it clear of the floor. To initiate flexion of the knee, the amputee should be

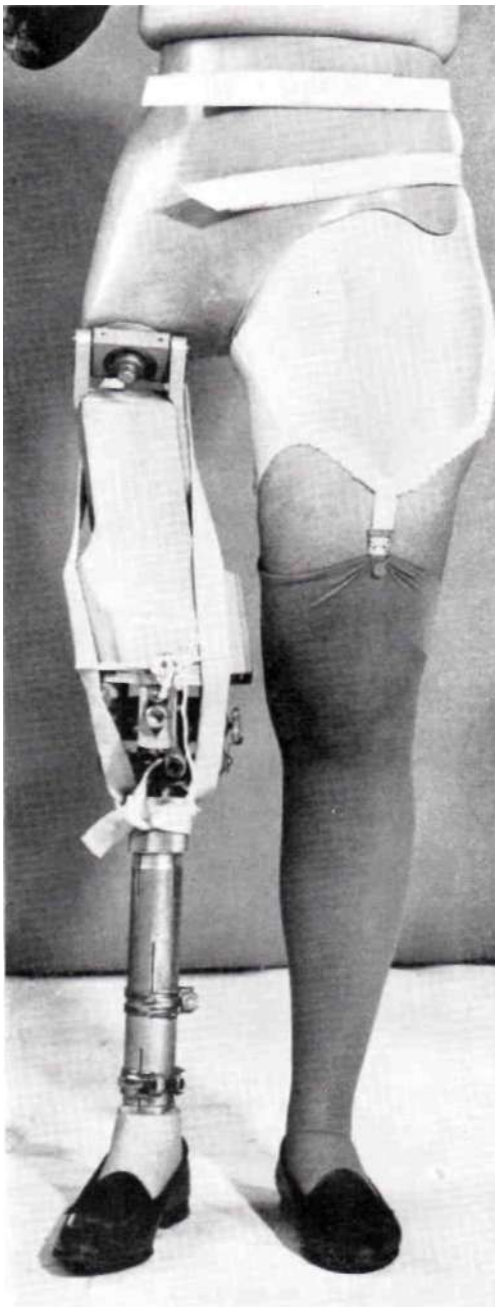


Fig. 26. Socket mounted on adjustable leg preparatory to dynamic alignment.

instructed to "scoop" his stump and pelvis forward and flex his spine. This should be jepeated a few times and the bias strap adrusted to obtain the proper stride length.

The amputee should be instructed to take a few steps. If the knee appears unstable just after heel contact, the durometer of the heel wedge should be checked, and it should be determined whether the shank is reaching full extension; whether the knee is in some hyperextension; whether the hip joint is contacting the stop before the foot is flat on the floor; and whether the alignment line runs correctly from the center of the hip joint through the center of the knee joint to 1 1/2 in. behind the heel of the shoe. To eliminate medial or lateral whip, rotational adjustments are necessary at the knee or hip axis.

Many amputees wear a stump sock, which decreases the friction between the patient and the socket during the stance phase and loses some of the socket's support. To increase the friction, it is sometimes advantageous to line the lateral aspect of the socket with a rubber material or with horsehide.

If toe clearance is still a problem, the length of the prosthesis should be reduced. The

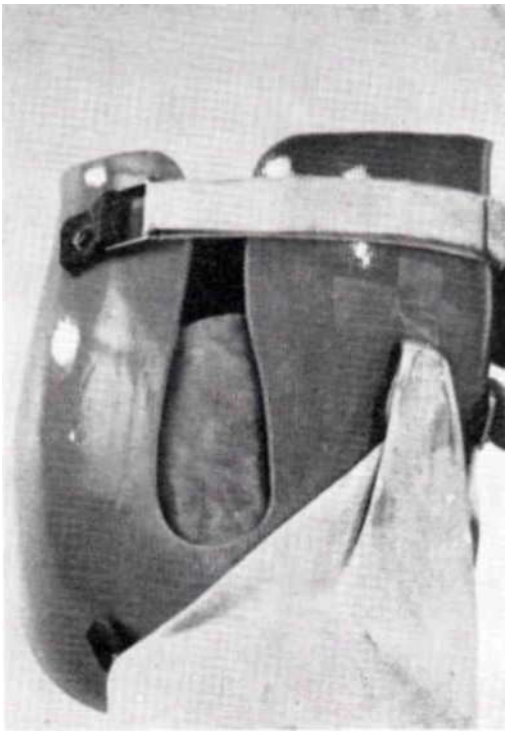


Fig. 27. Teardrop opening in socket on amputated side.

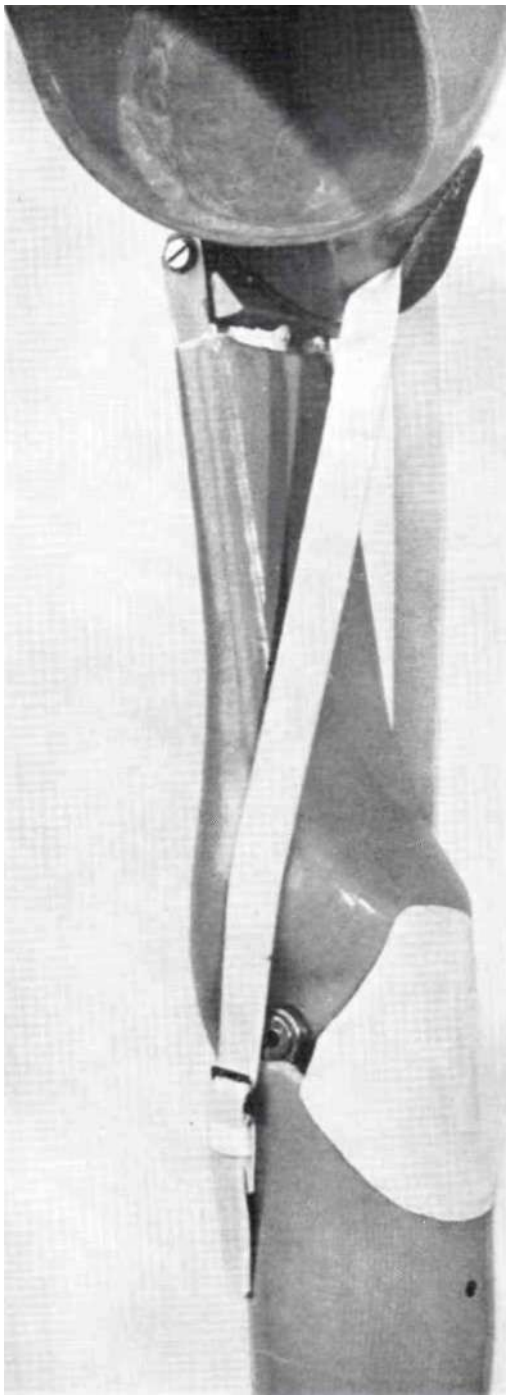


Fig. 28. Finished thigh block in reassembled prosthesis.

Fig 29. Cardboard used as template for metal portion of thigh fairing.

hemipelvectomy amputee will tend to vault on the sound foot to increase the clearance of the prosthesis. This tendency should be minimized as much as possible, but it must

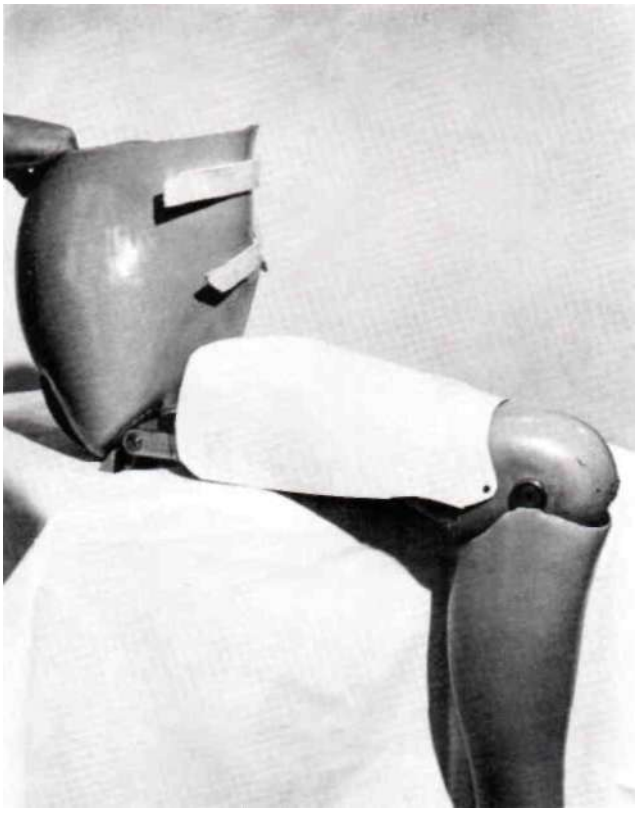


Fig. 30. Template shown on prosthesis in sitting position.

be remembered that the patient cannot "hike" his pelvis on the amputated side since there is no remaining skeletal structure. Where obesity is a problem, it is sometimes necessary to use a shoulder strap to aid suspension.

If the patient experiences rotational instability in the socket, a "teardrop" cutout on the lateral aspect of the socket will help to alleviate the problem and to aid suspension. The cutout should be approximately 2 in. wide at the lateral proximal edge of the socket and extend three-quarters of the length of the socket (Fig. 27). The foam insert in the socket should be removed before the panel is cut out. The edges of the panel should be sanded smooth to prevent cracking. A strap and buckle or Velcro should be attached proximally for closure of the cutout. When the prosthesis is donned, this strap should be loose and should be tightened last.

## DUPLICATING AND FINISHING

For duplicating and finishing, the socket is removed and the duplicating jig is used; excess wood is removed from the thigh block and the block is faired into the knee; the knee, thigh, and shin sections are laminated; the keeper for the extension bias strap and all straps and buckles are riveted; and the prosthesis is reassembled (Fig. 28).

## THIGH FAIRING

The chief purpose of the thigh fairing is to compensate for the differences in circumference between the thigh block and the sound leg, both in standing and in sitting. This must be done without impairing the function of the prosthesis.

A light, articulated fairing has been developed at the Northwestern University Prosthetics Research Center. It utilizes a piece of

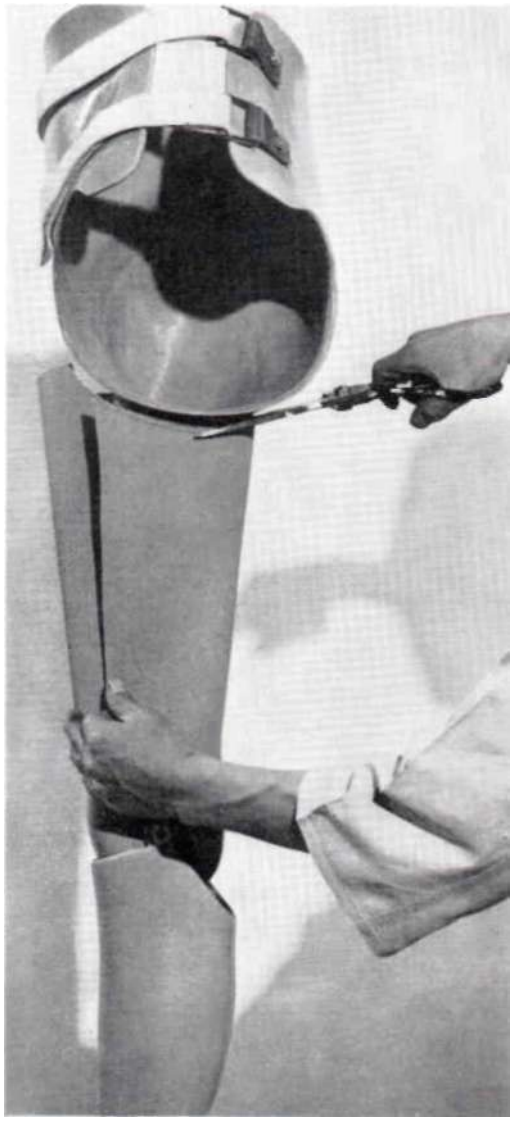


Fig. 31. Contouring rubber portion of thigh fairing.

1/32-in. light aluminum alloy, 1/8-in. Kemblo rubber, and lightweight horsehide, with Velcro for closing. It is pivoted distally by two screws just superior to the knee bolt and fastened proximally by a snap fastener to the anterior wall of the socket.

A piece of cardboard is used to make a pattern for the aluminum (Fig. 29). Distally, it should be wide enough to receive the pivot screws approximately 11/2 in. superior to and vertical to the knee bolt center. Anteriorly, it forms an upward arc. To allow the pivot action, the posterior section is open and the anterior proximal section is cut away so that the socket can be fully flexed without touching the cardboard. The posterior medial and lateral edges govern the amount of anterior displacement of the fairing in the sitting position and the fullness of the thigh in the standing position. In the sitting position, both edges should be in full contact with the seat of the chair (Fig. 30). The cardboard pattern should fit close to the anterior thigh block in the standing position and should be cut and formed to allow the medial and lateral contours of the Kemblo rubber fairing to blend in with the contours of the socket (Fig. 31).

Fig. 32. Open view of completed thigh fairing.

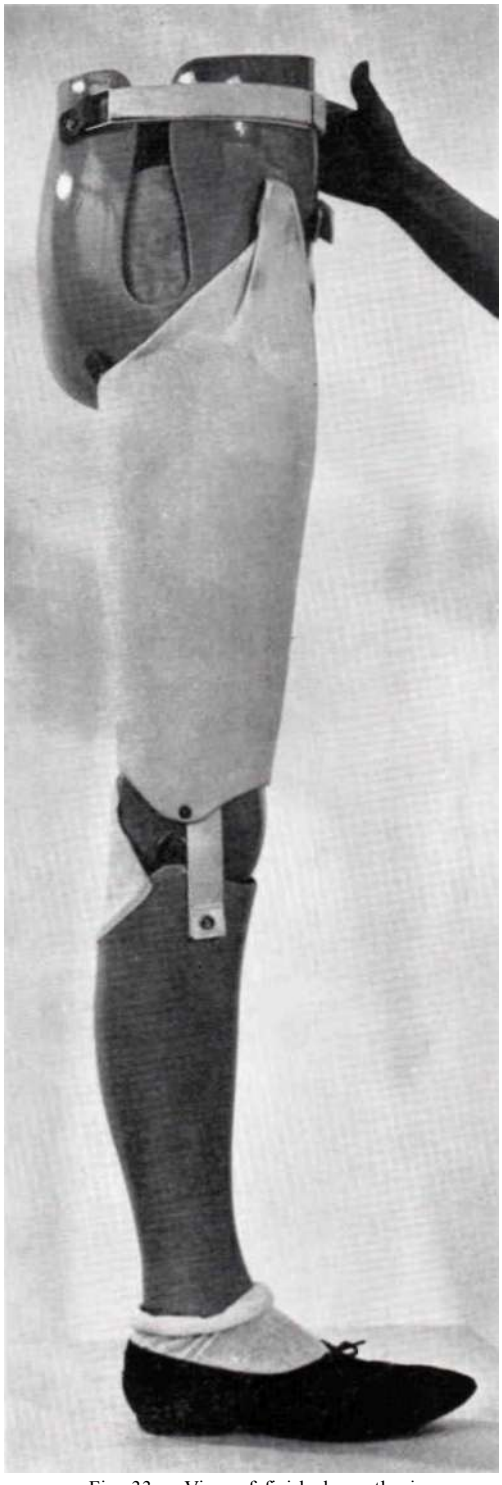


Fig. 33. View of finished prosthesis.

After the aluminum has been cut out, it is formed to the desired shape and attached with a screw to the knee. A sheet of 1/8-in. Kemblo rubber is wrapped around the metal to obtain the desired fullness (Fig. 32). The Kemblo should be long enough to start at the distal end of the aluminum and fair in proximally to the contours of the socket. The distal edge is skived to blend in with the metal form. The anterior proximal edge of the Kemblo should come up to meet the socket in the sitting position. The posterior proximal edge should meet the socket during the stance phase. The Kemblo is glued to the aluminum form.

The Kemblo rubber is covered with lightweight horsehide, and the leather is rolled over the edges of the rubber.

The fairing is attached to the socket anteriorly by means of a snap fastener. The leather continues from the medial and lateral sides to produce a triangle anteriorly with enough slack to allow displacement of the fairing in the sitting position. In the standing position, the attachment should return the fairing and eliminate any slack in the attachment area.


## ACKNOWLEDGMENTS

For valuable assistance in the development of this prosthesis (Fig. *33)* and for help in the preparation of this article, I am most grateful to Colin A. McLaurin, B.A.Sc, Robert G. Thompson, M.D., H. Blair Hanger, C.P., Edwin A. Bonk, Mary Farnan, Walter Horiuchi, and Paula Hamilton.


## LITERATURE CITED


1. Lyquist, Eric, *Canadian-type plastic socket for a hemipelvectomy,* Artificial Limbs, Autumn 1958, pp. 130-132.
2. McLaurin, Colin A., and Fred Hampton, .4 *method of taking hip disarticulation casts using hip sticks,* Orthop. & Pros. Appl. J., June 1960, pp. 71-77.
3. McLaurin, Colin A., and Fred Hampton, *Fabricating hip disarticulation sockets using the vacuum method,* Orthop. & Pros. Appl. J., June 1960, pp. 66-70.
4. Radcliffe, Charles W., *The biomechanics of the Canadian-type hip-disarticulation prosthesis,* Artificial Limbs, Autumn 1957, pp. 29-38.
5. Slocum, Donald B., *An atlas of amputations,* C V. Mosby Co., St. Louis, Mo, 1949, pp. 244-249.

# Acceptability of a Functional-Cosmetic Artificial Hand for Young Children, Part I[1]

SIDNEY FISHMAN, PH.D.[2] AND
HECTOR W. KAY, M.ED.[3]

The need for a functional and cosmetically acceptable artificial hand for juvenile amputees has existed for many years. A voluntary-opening hook which has been available for a number of years in a variety of sizes was until recently invariably prescribed for children. In response to the demand on the part of both children and parents for a functional device with a more natural appearance, the Army Prosthetics Research Laboratory (now known as the Army Medical Biomechanical Research Laboratory) undertook in 1958 to develop a child's voluntary-opening hand. Earlier studies *(2)* had shown that a spectrum of five sizes should satisfy the needs of the entire arm-amputee population from childhood to maturity. Size No. 1 was the designation given to the smallest. Because it was hoped that a mechanism developed for the Size No. 1 hand might be suitable for use also in Size No. 2 and perhaps in Size No. 3, the smallest size was given the first priority. The Sierra Engineering Company[4] contracted to manufacture this hand and two other companies (Kingsley Manufacturing Company[5] and Prosthetic Services of San Francisco[6]) were enlisted to manufacture suitable cosmetic gloves.

Following preliminary testing of a prototype model, modifications to eliminate certain shortcomings were incorporated in 50 production models. A field test was initiated in April 1960 with evaluation of the cosmetic gloves included as an integral part of the study. Preliminary findings based upon experiences in fitting 20 children indicated that the hand was acceptable cosmetically and provided satisfactory function in the activities typically performed by children *(4).* The general workmanship and cosmesis of the gloves provided by both manufacturers had also achieved a satisfactory level after certain initial fabrication difficulties. However, several problems had been identified, the most serious of which was a lack of glove durability. Ridges and sharp edges on the exterior of the hand apparently contributed to rapid glove damage.

[1] Part II will appear in the Autumn 1964 issue of *Artificial Limbs.* Both Part I and Part II are based upon *Acceptability of a Functional-Cosmetic Hand,* published by Child Prosthetic Studies, Research Division, College of Engineering, New York University, New York, N. Y., in January 1964 *(1).* Part I covers the history and purposes of the study, a description of the experimental hand, a description of the sample used in the studies, an account of the reactions of the children, their parents, and others to the hand, observations of classroom behavior during the period, and prescription considerations. Part II will cover the children's performance of standard tasks with the hand and its functional capabilities and limitations. The studies reported were conducted under the auspices of the Subcommittee on Child Prosthetics Problems of the Committee on Prosthetics Research and Development, National Academy of Sciences-National Research Council, 2101 Constitution Ave., N.W., Washington, D. C. 20418. The research was sponsored by the Children's Bureau of the Department of Health, Education, and Welfare under a special grant.

[2] Project Director, Orthotics and Prosthetics, New York University, 342 East 26th St., New York 10, N. Y.

[3] Associate Project Director, Orthotics and Prosthetics, New York University, 342 East 26th St., New York 10, N. Y.

[4] Sierra Madre, Calif.

[5] Costa Mesa, Calif.

[6] San Francisco, Calif.

Fig 1 Child holding swing with artificial hand.

Accordingly, the original production-model hands were modified and then refitted to the subjects of the field study. Modifications included eliminating the glove-cutting edges, strengthening the floating-finger attachments and the spring mechanism of the thumb, and raising the cable exit. In November 1960 "old" hands revised in this manner began arriving at New York University Child Prosthetic Studies, and in April 1961 the manufacturer produced a series of new hands which incorporated all the modifications.

An Interim Report (5), summarizing the results of the field study to mid-May 1961, was prepared for the Subcommittee on Child Prosthetics Problems of the Committee on Prosthetics Research and Development, and the results reinforced earlier findings concerning the acceptability of the hand and gloves. The APRL-Sierra Child-Size No. 1 Right Hand was accepted as satisfactory for general use by child amputees on the basis of this report, and the study was terminated in the latter part of 1961.

Following the generally successful outcome of the evaluation of the Size No. 1 Right Hand, manufacture of the Size No. 1 Left Hand was initiated. In May 1961 NYU Child Prosthetic Studies reported the results of a preliminary examination of two units manufactured by the Sierra Engineering Company (7). The hands appeared to be of excellent quality and workmanship with minor exceptions, and in June 1961 the manufacture of 55 additional left hands was authorized for field-test purposes.

During September and October 1961, NYU Child Prosthetic Studies received two shipments totaling 40 hands from the manufacturer. These were found to be unacceptable because of engineering deficiencies, and all were returned for modification. In February 1962, 37 hands were finally accepted for use in the field study. Another 14 hands submitted later were also found to be acceptable, making a total of 51.

Another Interim Report *(6)* on the status of the field study was submitted at the October 1962 meeting of the Subcommittee on Child Prosthetics Problems. It was reported that the APRL-Sierra Child-Size No. 1 Left Hand was considered to be essentially satisfactory both mechanically and functionally, although more rigid quality control in manufacture and assembly was desirable. The recommendation of this report that the hand and cosmetic glove be approved for commercial distribution was accepted by the Subcommittee and the study was terminated in January 1963.

## PURPOSES OF THE STUDIES

The APRL-Sierra Child-Size Mo. 1 Hand (both right and left) was developed to provide the juvenile amputee with a cosmetically

acceptable terminal device which would closely resemble the normal hand in size, shape, and coloring. Maximum function—commensurate with cosmesis, simplicity of operation, adequate strength, and reasonable cost—was a concomitant objective.

Since the field study of the left hand was essentially an extension of the study of the right hand, the general goals of both evaluations were identical:

1. To introduce the hand into clinical use.
2. To corroborate findings of laboratory studies.
3. To determine the acceptability, utility, application, and durability of the production-model hand and glove.
4. To investigate indications and contraindications for prescription.

In the light of the experience gained in the study of the right hand, three considerations were given closer attention in the study of the left hand:

1. Performance differences between the experimental hand and the hooks previously worn were investigated in greater detail than was the case in the study of the right hand.
2. The short wear-life of the cosmetic gloves used in the study of the right hand presented a definite and challenging problem. In the course of the study, the exterior of the experimental hand was extensively modified to eliminate sharp edges which might contribute to glove damage. The effectiveness of these changes was of particular interest in the study of the left hand.
3. The effect of wearing the hand on the child's school behavior was a planned aspect of the study of the right hand. Data secured on this significant subject were limited, however, since the study overlapped two school years. With the earlier commencement of the study of the left hand (February 1962), these data were obtained for some children fitted during March and April 1962.

## DESCRIPTION OF THE HAND

The APRL-Sierra Child-Size No. 1 Hand (both right and left) consists of a monocoque hand shell of cast aluminum, articulated index and middle fingers, a "two-position" thumb, and nonarticulated but flexible ring and little fingers. A voluntary-opening type of mechanism is housed within the hand shell and the entire unit is covered with a thin plastic glove that can be replaced as warranted (Fig. 2).

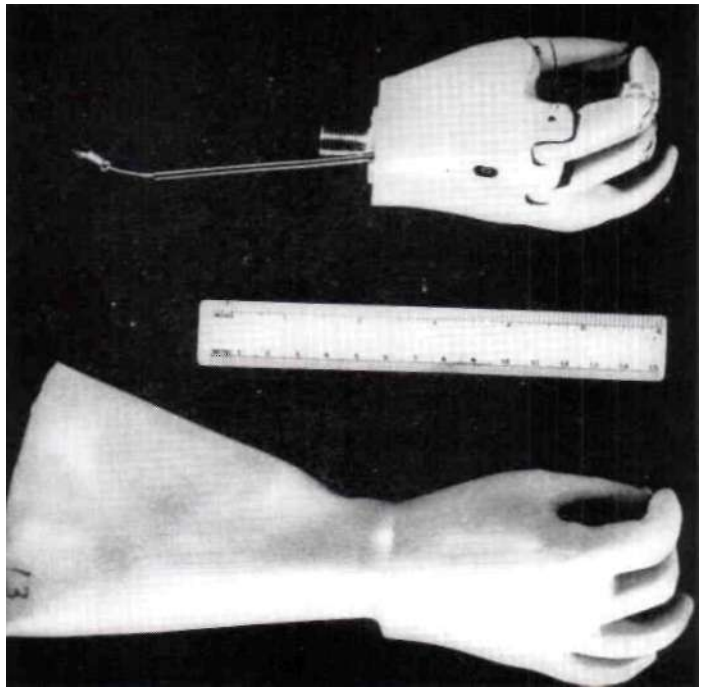


Fig. 2. APRL-Sierra Child Size Model No. 1 Hand.

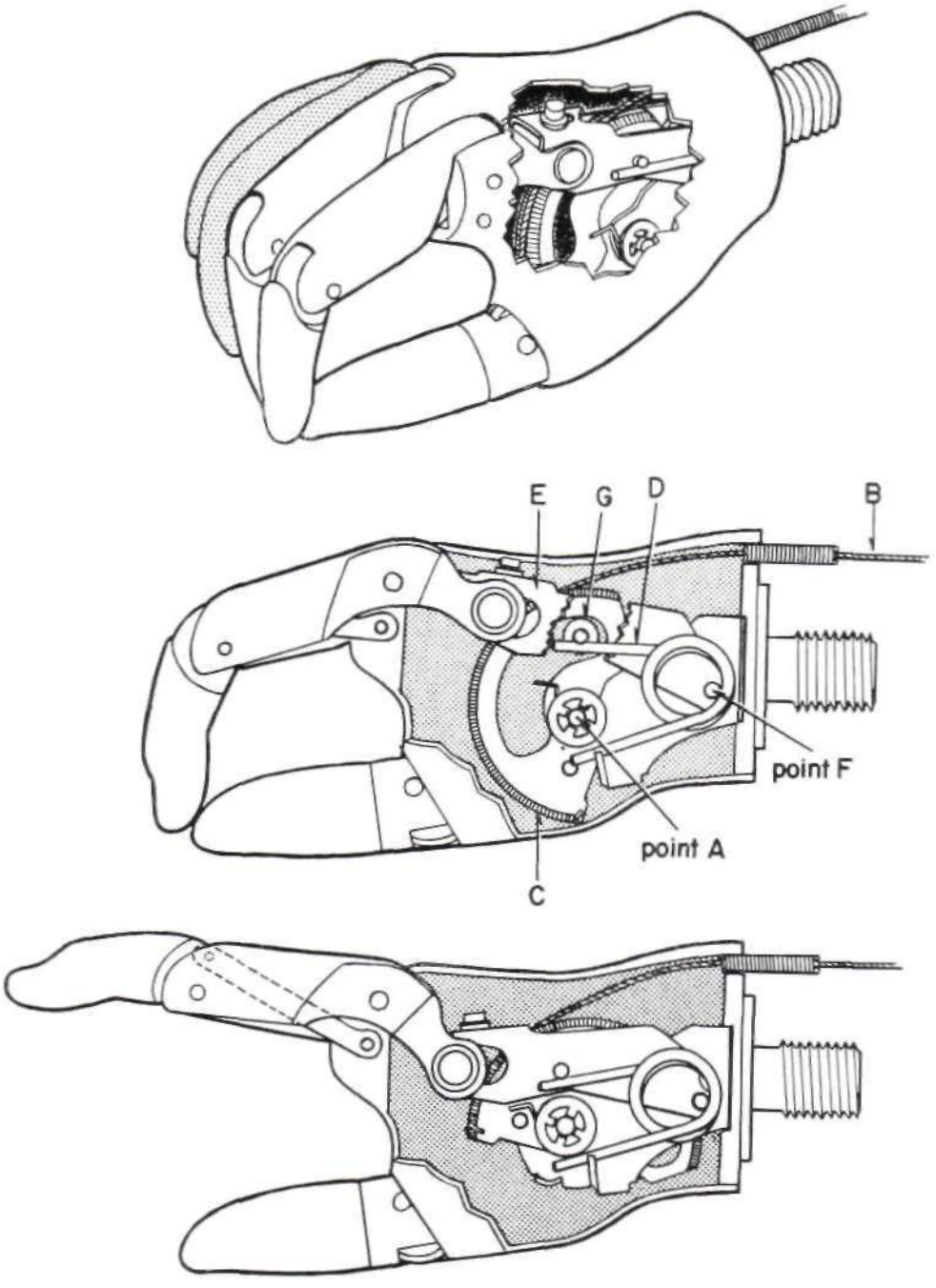



Fig. 3. Cutaway views of the APRL-Sierra Model No. 1 Hand *(3).* When no tension is applied to the control cable *B,* spring *D* forces the index and middle fingers toward the thumb to provide prehension of the three-jaw-chuck type. Tension in the control cable *B* causes the quadrant C to rotate about point *A,* a point displaced from the true center of quadrant *C.* The cam action thus provided by the outer edge of the slot in quadrant *C* against roller *G* forces lever *E* to rotate counterclockwise about point *F,* in turn causing the index and middle fingers to open. A small brass plate is mounted within lever *E* in such a fashion that, when little or no tension is applied to the control cable, the plate wedges against the periphery of the quadrant C. The wedging action, known as "Bac-Loc," resists opening of the fingers when force is introduced through the finger linkage but has no effect on the system when force is applied through the control cable.

The index and middle fingers each consist oi three aluminum castings which, along with a portion of the hand shell, form a four-bar linkage to provide coordinated articulation at points corresponding to the metacarpophalangeal and the proximal interphalangeal joints (Fig. 3). This arrangement results in a minimum amount of glove distortion through the range of motion required.

The thumb is an aluminum casting mounted to the hand shell through a locking mechanism that permits it to be held in either of two positions—one for maximum opening between fingers and thumb, the other for a smaller opening for conservation of excursion.

The ring and little fingers, the two consisting of a one-piece casting of foam rubber, are simply fastened to the hand shell and left to move with the cosmetic glove.

A threaded stud (1/2 x 20) attached to the wrist section of the hand is provided for use with currently available wrist units.

Maximum allowable weight is 6 3/4 oz. (without the glove). Less than 9 lb. of tension in the control cable (measured at the point of entry into the hand) is needed to open the fingers and a minimum of 2 lb. of prehension force is provided.

Cosmetic gloves for the hand are available in a minimum of seven Caucasian and six Negroid shades from each manufacturer.

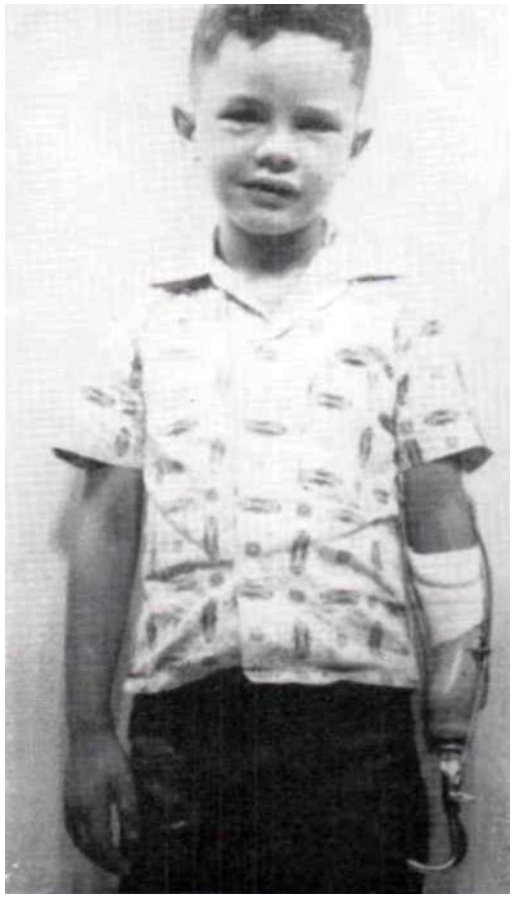


Fig. 4. Boy wearing Dorrance hook.

## SAMPLE

The sample, which included a variety of upper-extremity types, consisted of 77 subjects, one of whom was fitted with hands bilaterally. All the children in the study, except two, had previously worn Dorrance-type hooks (Fig. 4).

A total of 39 children, of whom 36 were unilateral arm amputees, were fitted with the right hand (Table 1). Of the three remaining subjects one (with bilateral shoulder-disarticulation amputations) was fitted with a right hand only and continued to wear a hook on the left side; one (with right above-elbow and left short below-elbow amputations) was also fitted with a right hand and retained a hook on the left; and a triple amputee (with bilateral long below-elbow and left knee-disarticulation amputations) was given hands on both sides. This last subject was included in both the right- and left-hand samples.

Thirty-nine children, of whom 36 were also unilateral arm amputees, were fitted with the left hand (Table 2). Of the three remaining subjects one amputee (with bilateral shoulder-disarticulation amputations) was given a left hand only; a triple amputee (with bilateral long below-elbow and right below-knee amputations) received a left hand and kept a hook on the right; and the third subject was the aforementioned triple amputee who was included in both samples.

## PROCEDURES

The fittings in both the Right- and Left-Hand Studies were conducted through the clinics participating in the Child Amputee

TABLE 1. SAMPLE: APRL-SIERRA NO. 1 RIGHT-HAND STUDY.

(N = 39)

| Age | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | | 10 | | 11 | | 12 | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sex | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F |
| Partial Hand, Wrist-Disarticulation, or Long Below-Elbow | — | — | 1 | 1 | 1 | 1 | — | 1 | — | — | — | — | 1 | — | — | — | 1 | — | 4 | 3 |
| Medium or Short Below-Elbow | — | 1 | 2 | 1 | 3 | 2 | 1 | 3 | 1 | — | 1 | — | — | — | — | — | — | — | 8 | 7 |
| Very Short Below-Elbow | — | 2 | — | 1 | — | 1 | 1 | — | — | 1 | — | — | — | — | — | — | — | — | 1 | 5 |
| Elbow Disarticulation or Standard Above-Elbow | — | — | — | 1 | — | 1 | — | 2 | — | — | — | 2 | — | — | — | — | — | — | 0 | 6 |
| Shoulder-Disarticulation | — | — | — | — | — | — | — | — | 1 | — | — | — | — | — | — | — | — | — | 1 | 0 |
| Bilateral | — | — | — | — | — | — | — | 1[a] | — | — | — | — | — | — | — | 1[b] | — | — | 0 | 2 |
| Triple | — | — | — | — | — | — | — | — | 2[c] | — | — | — | — | — | — | — | — | — | 2 | 0 |
| Total | — | 3 | 3 | 4 | 4 | 5 | 2 | 7 | 4 | 1 | 1 | 2 | 1 | — | — | 1 | 1 | — | 16 | 23 |

[a] Bilateral Shoulder-Disarticulation Amputations.

[b] Right Standard Above-Elbow, Left Short Below-Elbow Amputations.

[c] One boy had Right Short Below-Elbow, Left Syme, and Right Above-Knee amputations, and was the only child in the sample who had not worn an arm prosthesis before. The other boy had a Left Knee-Disarticulation and Bilateral Long Below-Elbow amputations and was fitted with hands on right and left sides.

TABLE 2. SAMPLE: APRL-SIERRA NO. 1 LEFT-HAND STUDY.

(N = 39)

| Age | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | | 10 | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sex | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F |
| Partial Hand, Wrist-Disarticulation, or Long Below-Elbow | 2 | 2 | — | 1 | 2 | — | 1 | — | 2 | — | — | — | — | — | 7 | 3 |
| Medium or Short Below-Elbow | 3 | 2 | 1 | 1 | — | 3 | 1 | 1 | — | 2 | — | — | — | 1 | 5 | 10 |
| Very Short Below-Elbow | — | 1 | 1 | — | — | 2 | — | 1 | — | — | — | 1 | — | — | 1 | 5 |
| Elbow-Disarticulation or Standard Above-Elbow | 1 | — | — | 1[a] | — | — | — | 1 | — | — | — | 1 | — | — | 1 | 3 |
| Shoulder-Disarticulation | — | — | — | — | — | — | 1 | — | — | — | — | — | — | — | 1 | 0 |
| Bilateral | — | — | 1[b] | — | — | — | — | — | — | — | — | — | — | — | 1 | 0 |
| Triple | — | — | — | — | — | — | — | — | 2[c] | — | — | — | — | — | 2 | 0 |
| Total | 6 | 5 | 3 | 3 | 2 | 5 | 3 | 3 | 4 | 2 | — | 2 | — | 1 | 18 | 21 |

[a] Plus Right Anomalous Hand and Foot.

[b] Left Standard Above-Elbow Amputation and Right Paraxial Hemimelia (Ulnar). He wears no prosthesis on the right side.

[c] One boy had Right Below-Knee and Bilateral Long Below-Elbow amputations, and was fitted with the experimental hand on the left side. He continued to wear a hook on the right side. The other was the Bilateral Long Below-Elbow and Left Knee-Disarticulation amputee who was fitted with experimental hands on both sides and is included in both Right- and Left-Hand Study samples.

Research Program.[7] In order that wearers of the hand might secure the longest possible wear period before growth of the child caused an objectionable size discrepancy, it was recommended that the clinics select candidates whose nonamputated hand size was such that they should be able to wear the experimental hand for at least a year.

The experiences of the clinics were evaluated on the basis of: first, the reactions of the children, their parents, and others to the experimental hand and to other previously worn terminal devices; second, observations of classroom behavior during the treatment period; third, ratings of the children's performance of standard prehensile tasks using the experimental and old terminal devices; and fourth, maintenance.

In the course of the studies the children were required to make four visits to the clinic servicing them during a minimum period of five months.

### FIRST CLINIC VISIT: SCREENING

A screening session was conducted during the first visit. The children and their parents were oriented to the purpose of the survey, the number of visits required, and the need to follow through with experimental procedures. Parents and children expressing a willingness to participate selected glove shades from shade guides provided by both manufacturers. Neither the experimental hand nor a complete cosmetic glove was shown to the patients or their parents during the first visit. A selection form, recommending the child as a participant in the study and furnishing information concerning him, was completed and sent to the NYU Child Prosthetic Studies.

The candidates were evaluated on the basis of information provided on the selection form and sampling requirements. Upon approving a candidate NYU sent the clinic a hand and glove for the child and a questionnaire to be completed by the child's classroom teacher prior to fitting the experimental hand.

The questionnaire pertained primarily to the child's psychosocial adjustment to the school environment. The teacher was asked to fill out the questionnaire before the experimental hand was fitted and to fill out a similar form at the conclusion of the study. The purpose of this procedure was to determine whether the child's behavior or performance with a prosthesis in school was affected as a result of wearing the experimental hand. In order to provide comparability of data, it was important that the same teacher provide both pre- and post-fitting observations.

### SECOND CLINIC VISIT: FITTING

At the second clinic visit a prosthetic performance test utilizing the old terminal device was administered and the reactions of children and parents to the old device were ascertained. The child was fitted with an experimental hand and initial reactions to the new component were secured from child and parents. The child and parents were then given instructions that the experimental hand was to be worn exclusively until the next clinic visit two months later.

### THIRD CLINIC VISIT: TWO-MONTHS POST-FITTING EVALUATION

Two months after the fitting the reactions of child and parents to the new component were again recorded at the clinic. Comparisons between old and new terminal devices with respect to weight, ease of operation, and usefulness were noted, and a prosthetic per-

[7] Area Child Amputee Center, Michigan Crippled Children Commission, Grand Rapids, Mich.; Amputee Clinic, Children's Division, Institute of Physical Medicine and Rehabilitation, New York, N. Y.; Amputee Clinic, Newington Hospital for Crippled Children, Newington, Conn.; University of Illinois Amputee Clinic, Chicago, Ill.; Birmingham Child Amputee Clinic, Birmingham, Ala.; Duke Orthopedic Amputee Clinic, Duke Medical Center, Durham, N. C; Georgia Juvenile Amputee Clinic, Crippled Children's Service, Emory University Branch, Atlanta, Ga.; Amputee Clinic, Children's Rehabilitation Center, Buffalo, N. Y.; Child Amputee Prosthetics Project, University of California Medical Center, Los Angeles, Calif.; Amputation Clinic, Kernan Hospital, Baltimore, Md.; Child Amputee Prosthetic and Congenital Deficiency Clinic, Children's Orthopedic Hospital, Seattle, Wash.; Juvenile Amputee Clinic, Florida Crippled Children's Commission, Orlando, Fla.; Amputee Clinic, Home for Crippled Children, Pittsburgh, Pa.; Child Amputee Clinic, State Hospital for Crippled Children, Elizabethtown, Pa.; Juvenile Amputee Clinic, Crippled Children's Hospital, New Orleans, La.

formance test, in which first the new hand and then the old terminal device were evaluated, was also conducted. The parents were then told to permit the wearing of either the old or the new terminal device as the child desired and were scheduled for a further clinic visit two months later.

### FOURTH CLINIC VISIT: FINAL EVALUATION

The final evaluation was conducted four months after the initial fitting. The reactions of child and parent to the new hand were again obtained, and the old and new devices were compared in the same manner as earlier. The clinic summarized its data on a form provided for the purpose, and the child's classroom teacher was asked to complete another questionnaire.

## RESULTS—SUBJECTIVE REACTIONS

### PARENT AND CHILD PREFERENCES

At the conclusion of the test period, the 77 children participating in the study and their parents decided almost unanimously in favor of retaining the experimental hand with only seven rejecting it completely. In contrast to these seven rejections, 21 children expressed a desire to wear the hand exclusively. The remaining 49 children took intermediate positions ranging from a predominantly-hand to a predominantly-hook preference. All in all 42 children and their parents clearly preferred the hand; 15 were ambivalent or offered contradictory opinions; 20 preferred the hook.

### HAND USED EXCLUSIVELY

Of the 21 children (13 girls and 8 boys) who chose to wear the hand exclusively, 20 were prior hook wearers, one had previously worn a Becker Plylite hand, and one had never worn a prosthesis before because his parents had refused to accept a hook. Cosmesis was extremely important to this group and was often the only factor mentioned by the child.

JM, a long below-elbow amputee who was 6 years and 11 months old at the initiation of the study, is typical of the children in this category. When asked what he liked about the hand after four months' wear, he replied, "I like it—the way it looks." He disliked the appearance of the hook and could think of nothing favorable to say about it or anything unfavorable to say about the hand. The hand functioned better, he said, and was important to him for use at school. Schoolmates stared at first, but liked it. JM's mother thought he had better function with the hook, but only because he had not had the new hand very long. She also remarked that he should wear the hand all the time because "it gave him more confidence." The hook's only contribution was that it prepared the child for the hand, she said.

Sandra, a short below-elbow amputee, was 5 years and 9 months old at the beginning of the study. She cited better function as the reason for preferring the hand: "... can move things better—holds lots of things better." She disliked nothing about the hand, liked nothing about the hook, and said she wanted to wear the former all the time. Her mother preferred the hand for reasons both of appearance and grasp; schoolmates found it easier to hold on to when playing games, and it didn't slip when the child tied her shoes. Sandra should not wear a hook at her age, her mother declared.

### HAND USED PREDOMINANTLY

The hand was the terminal device of choice for an additional 21 children (15 girls and 6 boys). The hook was preferred for rough outdoor activities in which hook function was superior.

Typical of the group was Curtis, age 5, a very short below-elbow amputee, who liked "everything" about the hand: it resembled his other hand, held paper when he wrote, and grasped a baseball bat better. However, he felt that the hook was lighter, was easier to open, and superior for playing with certain toys. His mother was pleased with the appearance of the hand, Curtis's attitude toward it, and the fact that other children were willing to hold it in games. However, she thought he should wear the hook at home for activities that might damage the glove. During the last two months of experimental wear, when parents and children could choose which device would be worn, Curtis used the hand exclusively, except when repairs were required.

Diana, age 5, a short below-elbow amputee, expressed a desire to wear the hand most of the time and the hook only for swimming *(sic!).* The reason for her preference was that "it looks like my other hand." Earlier she had found the hand somewhat harder to operate and had experienced difficulty releasing it from bicycle handles. Her mother was concerned about tears on the glove fingers, but Diana said, "It doesn't matter what the glove looks like." Her mother agreed that the hand should be worn in most circumstances, but thought the hook could be used for swimming and as a replacement in case the hand broke.

### HAND AND GLOVE USED ABOUT EQUALLY

Seven children (5 girls and 2 boys) and their parents desired to retain both hook and hand and to use them on an approximately 50-50 basis. For example, Carol, an 8-year-old short below-elbow amputee who lived on a farm, preferred the appearance of the hand: "It gives me another hand and people don't stare"; and the function of the hook: "I don't drop things with the hook or worry that someone might bump into me and knock them out of my grasp." She also was concerned about tearing the glove. Carol chose to wear the hand both to regular and Sunday school and the hook for farm chores and play. Her father agreed with the child's viewpoint. He thought the glove not rugged enough, but the hook handy and sturdy.

### PARENT AND CHILD DISAGREEMENT

There were eight children (6 boys and 2 girls) whose primary choice of terminal device differed from that of their parents. In five instances, the child chose the hand and the parent the hook; in the other three cases, the positions were reversed. The basis for disagreement was usually a relative emphasis upon appearance and function.

Michael, age 6, whose partial hand amputation was fitted as a wrist disarticulation, was pleased that the hand "looked like my other one," but acknowledged that the hook was lighter and easier to use. If he could retain only one device, he would choose the hook, since he could do much more with it; however, his mother and friends preferred the hand. The latter were sometimes afraid of the hook. Michael's father preferred the hand for cosmetic reasons and cited other advantages: "... more chance to play cowboy and wrestling . . . children not afraid . . . danger of bumping into others when playing with the hook."

### HOOK USED PREDOMINANTLY

Six boys and seven girls preferred the hook for daily use and the hand for dress occasions. Five of the children were under 5 years of age (one, age 3 and four, age 4), and four of these had not yet attended primary school, kindergarten, or play school. Eleven of these children rated the hook function better and ten specifically said the hand was heavy or hard to operate; one older boy complained that the hand did not afford a tight grasp and a younger girl said the hook held things in a better position. Parents of twelve of these children declared hook function was better; the other parent expressed no preference.

Danny, with an elbow disarticulation and split-ray hand, was the youngest child in the study—barely 4 years of age when fitted with the hand. To open it, he had to hold his elbow completely extended with maximum tension on the cable. Even in this position, full opening required more effort than he typically cared to exert, although he was pleased that the hand looked like his natural one. Danny stated that the artificial hand was heavier and harder to operate than the hook and did not pick up objects as well. The hook was better for grasping a swing chain and for holding his bread to push food. The child's mother hoped that his skill with the hand would improve, but after four months she reported that he wore it only for "going visiting." She thought the hand would be of greater use when he was older.

### HAND REJECTIONS

In view of the fact that complete rejection of the experimental hand was rare, it is interesting to note the instances when it occurred. Seven children rejected the hand completely; four of these were 4- or 5-year-old boys, one was a 7-year-old girl with bilateral shoulder disarticulations, and the other two were a boy

and a girl, both 9 years old, who were excellent users of their hooks and apparently were not concerned with the appearance of this device.

Various factors contributed to these rejections. Several of the younger boys and the 9-year-old boy and girl obtained better function with the hook and seemed relatively unmindful of appearance. The bilateral shoulder-disarticulation amputee was a marginal user of any prosthesis and found the increase in operating forces and the difficulty of positioning the hand without a wrist-flexion unit intolerable. Three children experienced excessive hand malfunctions and two others, because of frequency of glove damage or difficulty in getting replacements, wore unsightly gloves for prolonged periods.

### AGE AND SEX IN RELATION TO ACCEPTANCE LEVEL

The data contained in the last two categories of acceptance level (Hook Used Predominantly and Hand Rejections) suggest that age is a strong consideration governing hand or hook preference. Such a relationship would not be surprising, since younger children may be expected to: first, experience difficulty with hand weight and operating forces because of limited physical development, and second, be more careless in their use of a device, less concerned with the niceties of appearance, and would not be subject to the social pressures of the school environment.

Age, however, cannot be regarded as an absolute criterion, since several of the children in the study who selected the hand as their primary choice were 4-year-olds. In fact, when the age and sex of the children are tabulated against indicated levels of preference (Table 3), sex appears to be more significantly related to choice of device than does age. Thus, girls of all ages for whom the hand is of appropriate size appear to be potentially the best candidates for the No. 1 Hand, while younger boys would seem to be less likely to accept the device.

### EFFECTS ON SCHOOL ADJUSTMENT

The questionnaire to be completed by the classroom teacher was designed to secure pertinent information concerning the behavior of the child in school while wearing the old terminal device and the experimental hand respectively. It was hypothesized that the child's classmates and teacher might react more positively to a hand than they had to a hook and as a result adjustment of the child to the school situation would show discernible changes. This type of improved behavior had been noted previously when a child who had been a nonprosthesis wearer was fitted for the first time *(8)*.

Historically, two significant problems frequently encountered by juvenile amputees wearing hooks to school have been the indignity of being called "Captain Hook" and

TABLE 3. RIGHT- AND LEFT-HAND WEAR PATTERNS.

| Girls (N = 44) | | | | | | | | | | Boys (N = 33) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Age When Fitted with Hand | | | | | | | | | | Age When Fitted with Hand | | | | | | | | | |
| Total | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Total |
| 13 | 1 | 4 | 4 | 2[a] | — | 1 | 1 | — | Hand Used Exclusively | — | 1 | 1 | 2 | 2 | 2[b] | — | — | — | 8 |
| 15 | 4 | 1 | 2 | 4 | 2 | 1 | — | 1 | Hand Used Predominantly | — | — | 1 | 1 | 1 | 2 | — | 1 | — | 6 |
| 5 | — | 1 | 1 | 1 | 1 | 1 | — | — | Hand and Hook Used About Equally | — | — | — | 1 | — | 1 | — | — | — | 2 |
| 2 | 1 | — | 1 | — | — | — | — | — | Child-Parent Disagreement | — | 1 | 1 | 1 | 1 | 2 | — | — | — | 6 |
| 7 | 2 | 1 | 2 | 2 | — | — | — | — | Hook Used Predominantly | 1 | 2 | — | 1 | 1 | — | — | — | 1 | 6 |
| 2 | — | — | — | 1 | — | 1 | — | — | Hand Rejections | — | 1 | 3 | — | — | — | 1 | — | — | 5 |
| 44 | 8 | 7 | 10 | 10 | 3 | 4 | 1 | 1 | Total | 1 | 5 | 6 | 6 | 5 | 7 | 1 | 1 | 1 | 33 |

[a] Previous terminal device was Becker Hand; became a 100% No. 1 Hand wearer.

[b] No prosthesis used prior to hand; became full-time (or at least school-time) hand wearer.

similar names by classmates and refusal by other children to hold their hooks in hand-holding games. Elimination or reduction of these difficulties was anticipated when the child was fitted with a functional terminal device that closely resembled a normal hand.

The teacher's opinion was obtained concerning various aspects of the child's school behavior: attendance, homework, conduct, friendships, social participation and leadership, and extent of use of the prosthesis. As provided in the study plan, the teacher's questionnaires were to be completed twice: once while the child was still wearing a hook, and again after four months of hand wear when the child would presumably have acquired sufficient skill in the use of the hand, and changes in school behavior would have had an opportunity to develop.

When it became apparent that a majority of the children in the Left-Hand Study would not have worn the hand for four months before the end of the 1961-1962 school year, the original plan was modified to provide for completion of the second questionnaire just prior to the end of the academic year regardless of length of time the hand had been worn.

Unfortunately, comparable hook-and-hand questionnaires (that is, both completed by the same teacher) are available for only 16 of the 77 children in the sample. The majority of the remaining 61 children were of pre-school age or were fitted with the hand toward the end of the school year or during the summer, so that they did not have the same teacher at the beginning and the end of the study. The data from the teachers' questionnaires were, therefore, supplemented by information concerning school and personal adjustment from other sources wherever available.

## REACTIONS AND REPRESENTATIVE COMMENTS

Of the 29 boys and 21 girls in the sample who were 6 years of age or over, 26 boys and 21 girls were either wearing the hand in school at the termination of the experiment or stated that they intended to do so when the fall term began. Included in this group were four of the children whose preferred device was the hook. Nevertheless, they wore the hand to school. One boy, age 8, summarized the opinion of these four children when he said, "I wear it because the kids like it better."

As mentioned previously, a number of children reported that prior to using the hand they had been called "Captain Hook" by other children and that this had disturbed them. There is considerable evidence that the effects of this name-calling can be quite destructive to social relations among children. One girl, in fact, refused to wear the prosthesis to school after such an incident. When the hand was worn these difficulties tended to disappear. The essence of the reaction to and acceptance of the hand may be gathered from the large number of favorable comments made by playmates, schoolmates, teachers, and others.

Representative statements *reported by the children* included the following:

"My schoolmates were excited about the hand because I have five fingers on the left hand now."

"It smells nice, looks nice, and works nicer than the hook."

"I like the feel of the hand; it looks real."

"One little girl thought my hand had grown back."

"They said it was prettv. The girls aren't scared of it."

"I wanted to look at it. I always wanted to know when I was going to get it. It drives me out of my mind."

"My school friends stared at first; they liked it."

"At school they all liked the looks, especially how real it looked, including the fingernails."

"Kids like to see the way I can bend the fingers (floaters) all the way back. They like to feel it. One boy bit it to see what it would do."

Representative reactions *reported by the parents* included these remarks:

"They were surprised when they found out he could move the fingers and thumb."

"Children in school were not aware of his prosthesis until he wore a short-sleeved shirt. They displayed curiosity and then seemed to be very casual."

"In many cases the fact that it is not a natural hand has had to be brought to their attention, even when it was worn without long sleeves."

"Danny will start school this fall and the principal was amazed to see the hand. He said he had to look twice to make sure it was the same child. Danny's playmates were sure he had gotten a 'real' hand."

"His friends are afraid of the hook. But with the hand, they will take hold of it and play games."

"The child said she used to like the hook and wore it all the time, but now some of her friends don't like it and are afraid of it."

"Her schoolmates noticed the change and they completely accepted it. Her sisters were quite proud and anxious for their friends to see she had a new hand."

"When he played games with other children, most of them were afraid to hold his hook. Since he's worn the hand they aren't afraid."

"Cindy is happy about the better attitude of the children around her, especially in school."

"She said that one of her best friends 'almost fainted,' she was so delighted to see her with two hands."

"The appearance has done wonders for her at school."

"The children at school crowded around him and asked to see how it worked."

"Her friends had called her 'Captain Hook' (when she wore the hook). Little ones cried and would run away from her, afraid. We actually had to *bribe* her to wear the hook to school. Now we have no difficulty getting her to wear her arm with the hand all the time."

"Children don't call him names ('Captain Hook')."

"School children are delighted and fascinated with the hand."

". . . interested because it is different; want to see how it works. Betsy will show it."

"It is easier to hold on to when playing games."

"The change from the hook to the hand caused a lot of questions to be asked at first. But it was soon accepted."

"Danny wore the hand every day for two weeks and some of his classmates were not aware that it was not his own hand."

Only a few *children* volunteered negative remarks:

"His brother got scared of the hand, but later liked it."

"Sister afraid of it at first."

"Pammy (sister) thought it was a 'weirdy.' "

### ATTENDANCE, PREPARATION, AND CONDUCT IN CLASS

The teachers' reports concerning the children's attendance, preparation, and conduct in class yielded very little information of significance. Only one child (a triple amputee) was considered below average in attendance as a result of absences related to his prosthesis. The factors of preparation for class and conduct showed slight changes in ratings from the first to the second questionnaire, but there were no differences specifically attributable to hand wear.

### FRIENDSHIPS, PARTICIPATION, AND LEADERSHIP

Ten of the 16 children for whom teachers' questionnaires were available appeared to have achieved excellent to adequate adjustment and participation in class with both the hook and the experimental hand. Despite these satisfactory relationships, these children still found the appearance of the hand advantageous in the school setting as a means of decreasing social prejudice. Several of these 10 children remarked that their classmates were now more willing to hold hands in games and seemed friendlier. This pattern of increased acceptance tended to enhance the self-concept of the children in the study.

Five children were reported as improved in class participation or friendships after being fitted with the artificial hand, although the prosthetic performance of two of this group was considered to have deteriorated. However, the improvement in appearance was obviously more important than the decrease in function. For this small group of children regardless of their skill in or amount of hand usage there was a discernible change in the type and extent of their social interactions. This took the form either of an increased number of social contacts with various children or of an improved relationship with one or two selected classmates.

An example of the personal importance attached to the hand is apparent in the report of one child's physical therapist which describes his behavior after being fitted:

"On the way back on the train, Randy patted his hand against his face and scratched the tip of his nose several times before settling down to sleep. Until then, he couldn't keep his eyes off it, and when he lay down he put the hand on his chest 'for all the world to see.' As we neared Bloomington, he wondered if we shouldn't go by the school because 'perhaps Mrs. Sheveland (the teacher) will still be there.'

"After dinner he put his prosthesis on and toured the neighborhood to show everyone his hand. His mother reportedly was greatly pleased; so much so that she could not hold back the tears on more than one occasion during the evening, so that when Randy said his prayers, she had to leave the room. He wanted to wear his hand to bed but when his mother explained that it had to be put into the plastic bag, he accepted the explanation.

"This morning he arrived at school in 'clam-digger' pants and a long-sleeved shirt. He had told his father yesterday that if he wore long-sleeved shirts no one would ever know his hand was not real."

Other examples of the significance of the hand follow:

"The teacher said the boy is actually using the hand more than he had ever used the hook. (This was in spite of the fact that all reports indicated that his functional capabilities with the hook were greatly superior.) His mother said, 'We were very pleased that he had the hand for his first Holy Communion.'

"The nun said Randy did not need to hold hands in prayers or going to and from the altar, since she thought this might be a difficult thing to do, but he did as the other children were doing and was very proud."

Another child, Sheila, had reconciled herself to the reluctance of other children to hold the hook:

"Some children don't like to touch it (the hook), but I know a girl who has long fingernails and I don't like to touch her hands, either. When I first got it, I thought the kids in school will be surprised. They will think I don't belong in a crippled children's school!"

Another child, Philip, used his artificial hand to shake hands.

The last of the 16 children for whom data were available, a girl of 6, did not have a good relationship with her teacher or with the other children. There was no discernible improvement in the situation after she was fitted with a hand. Still, by the time of the second questionnaire report, she was somewhat more willing to display her prosthesis in public and make use of it.

## CONCLUSION

Although there was no clear-cut evidence of widespread, dramatic changes in behavior attributable to the use of the APRL-Sierra Hand, the data all point in the direction of improved self-perceptions as well as better social attitudes and relationships. With the exception of the 10 per cent of the sample who rejected the hand for a variety of reasons, the remaining amputee children and their parents, teachers, and classmates reported a variety of positive social consequences related to hand wear. For the most part these reports referred to improved *feelings, opinions, and attitudes* of the subjects, although a small number of positive *behavioral* changes could also be documented. In general, the children themselves as well as their classmates and parents were socially more comfortable as a result of the introduction of the hand.

The functional limitations of the hand in comparison to a hook will be documented in a subsequent article in *Artificial Limbs.* In contrast, the evidence concerning the cosmetic benefits of the device, particularly its concomitant psychosocial implications, is most impressive.

## RESULTS—PRESCRIPTION CONSIDERATIONS

### SIZE of SOUND HAND AND AGE

For the purposes of the Right-Hand Study, the No. 1 Hand was hypothesized as being appropriate for child amputees between the ages of 4 and 10. Consequently, experimental wearers were selected on the basis of this age range rather than of size. In the course of the study, however, it became apparent that the hand was undersized for many of the children selected.

The clinics were then requested to report the following dimensions in all cases of noticeable discrepancy: circumference at the metacarpophalangeal knuckles, excluding the thumb, with hand in closed position *(5%* in, on the No. 1 Hand); and the length from the styloid process of the radius to the tip of the thumb (3 5/8 in. on the No. 1 Hand). Several clinics also reported hand dimensions of children for whom the No. 1 Hand was considered of appropriate size.

Table 4 presents the measurements of sound hands of children in the Right-Hand Study for whom the No. 1 Hand was too small; small, but acceptable; and well matched, according to the opinion of clinic personnel.

It would appear difficult to derive a precise range of sound-hand sizes or ages for which the No. 1 Hand provides an acceptable match. In one case, where the sound hand was 6 5/8 in. in circumference and 4 1/2 in. in length, the clinic rated the hand as unacceptably small, but in another instance it was considered suitable for a child whose hand was 7 1/4 in. in circumference and 4 1/2 in. in length. It should also be noted that while the majority of the

TABLE 4. SAMPLE: ADEQUACY OF NO. 1 HAND IN RELATION TO NATURAL-HAND SIZE
(N = 21)

| | Size of Sound Hand | | Age When Measured | | Sex |
|---|---|---|---|---|---|
| | Circumference (In Inches) | Length | Years | Months | |
| No. 1 Hand too small; prescription contra-indicated. | * | * | 12 | 7 | M |
| | (bilateral) | | 11 | 7 | F |
| | 7 5/8 | 4 3/4 | 11 | 1 | M |
| | 7 1/2 | 4 1/2 | 10 | | F |
| | 6 7/8 | 4 3/8 | 6 | | F |
| | 6 5/8 | 4 | 8 | 1 | F |
| No. 1 Hand smaller than sound hand, but acceptable. | 7 1/4 | 4 1/2 | 9 | 9 | M |
| | 6 5/8 | 5 | 9 | 4 | F |
| | 6 1/2 | 4 3/8 | 9 | | F |
| | 6 1/2 | 4 | 6 | 11 | F |
| | 6 1/4 | 4 | 9 | 1 | F |
| | 6 1/8 | 3 7/8 | 5 | 10 | M |
| | | 3 3/4 | 9 | 5 | F |
| | 6 1/2 | | 7 | 7 | F |
| | 6 | | 9 | 3 | M |
| | 6 | | 8 | 9 | M |
| | 6 | | 7 | 5 | M |
| No. 1 Hand "matches" sound hand. | 6 1/4 | 3 1/2 | 6 | | M |
| | 5 1/2 | 3 7/8 | 5 | 7 | M |
| | 5 3/4 | 3 1/4 | 7 | 8 | F |
| | | | 4 | 4 | F |

* Data not reported.

"oversized" children were 8 years of age or older several younger children fell into this category. Furthermore, even hands regarded as unacceptably small by the clinics were retained by the children and worn, at least for dress, for several months longer.

In the selection of candidates for the Left-Hand Study dimensions of the children's sound hands were taken into consideration. In general, an effort was made to accept as wearers only those children with a sound-hand circumference of not over 6 1/4 in. and a length up to 3 7/8 in. It was also anticipated that the majority of such children would fall into the age range of 4 to 8 years. As a consequence, there were few complaints about size in the Left-Hand Study.

Christine, age 10, had sound-hand dimensions of 6 3/8 in. circumference and 3 7/8 in. length at the time of selection. These became 6 1/2 in. and 4 1/2 in. by the time of the four months' check and the clinic was then of the opinion that the hand was too small. Christine and her parents agreed, but strongly preferred even a poorly matched hand to the alternative of a hook. There were six other children in the sample with sound hands of excessive circumference or length, i.e., larger than 6 1/4 in. in circumference and 3 7/8 in. in length. There was indication that all the children in this group were not completely satisfied with the size of the No. 1 Hand, but their lack of enthusiasm was generally expressed in the comment, "a little small, but still all right."

Thus, as a general guide in considering the prescription of a No. 1 Hand, it is possible to state:

1. For children whose remaining hand dimensions do not exceed 6 1/4 in. in circumference and 3 7/8 in. in

length, the No. 1 Hand can probably be fitted without objectionable size disparity. Naturally the closer the children are to this level when fitted the faster they will outgrow the No. 1 Hand.

2. Children with these hand dimensions will typically fall into the age range from large 3-year-olds to small 8-year-olds, with a predominance of 4- to 6-year-olds. However, considerations of hand weight and operating forces may exclude some children at the lower end of this age range.

## CLINIC OPINIONS

Clinic opinions concerning various aspects of the No. 1 Hand were obtained in both phases of the study. Clinic personnel were also asked to express themselves on the question: "Are there any contraindications to prescribing this hand (age, sex, performance, etc.)?" Responses, however, were confined primarily to the experiences of the particular child under observation as each questionnaire was completed. Hence the comments made were essentially confirmatory of information gathered from other sources.

Expressions of a general attitude toward prescription and use of the No. 1 Hand were relatively rare. Thus, it is possible that the typical reaction of the clinics participating in the study was one of reservation concerning the experimental item—of not wishing to take a strongly positive or negative position until more experience had been acquired and "all the returns were in."

This situation reflects the fact that the majority of the clinics participating in the program appeared to be "functionally oriented," some of them strongly so. Hence, a device which historically and in fact provides lesser function was likely to be viewed with skepticism. Some clinics were also concerned about the initial cost of the hand and glove and the expense of repairs and replacements particularly of the glove.

If this interpretation of the prevailing frame of reference is correct, such comments as were made concerning "contraindications to prescription" take on added significance by their infrequent occurrence. To cite the Left-Hand Study data again: For only nine of the 36 children discussed was dissatisfaction with some aspect of the hand strong enough to be mentioned as a possible contraindication to use. These instances were:

| No. OF CHILDREN | CONTRAINDICATIONS |
|---|---|
| 2 | Discrepancy in size |
| 2 | Frequent breakage or malfunction |
| 2 | Force requirements excessive for particular child |
| 1 | Functional limitation as compared with hook |
| 1 | Rapid wear of glove a possible contraindication for a *wry* active child |
| 1[8] | Emotional difficulty |

Excerpts from a letter written by one of the clinic chiefs might be appropriate as a summary statement of prescription considerations. His comments not only reaffirm reactions to the hand which appear to have been fairly typical, but also express an approach to prescription which seems to be conservative yet reasonable:

"The mother's comment with regard to cosmesis is that the hand is 'beautiful.' She is perfectly willing to go to all extremes in cosmetic appreciation. The mother feels that the child's reaction to the appearance of the hand was one of 'being proud of it.' This was exemplified by the child's desire to always wear the hand at school. It was interesting to me that, after approximately six months of wear, Debra was anxious to wear the hand all the time and not to wear the hook any more. However, in the recent episode, when the hand became no longer functional, she was perfectly agreeable to return to the use of the hook. This is particularly interesting to me, because the mother feels that Debra actually lost no function in the transition from the hook to the hand.

"At age 6, Debra learned to operate the thumb adjustment and, as a consequence, was able to continue with the prosthetic hand as the assisting side at school in such functions as holding a book while reading so that she could turn the pages with her normal hand; holding papers while writing; and holding papers while cutting. At home, she was able to hold fork and knife with the prosthetic hand but, at age 7, is still able to cut only soft meat, such as a hamburger. She uses the hand in all bi-manual activity.

"Our own opinion here is that we will prescribe this hand for children who are already using a hook. In the unilateral case where there is reasonable dexterity, I feel that with the prosthetic side being the assisting side we can sacrifice the minimal loss of function which one

[8] One clinic felt strongly that prescription would be a dubious practice where cosmesis was highly important for child and parent if the next larger hand size was unavailable later.

probably gets in the transition from hook to hand. The only criticism is the amount of force necessary to operate the hand."


## ACKNOWLEDGMENTS

The late Dr. Carleton Dean, former Director of the Michigan Crippled Children Commission, played a prominent role in the early stages of the child's hand program, particularly in the procurement of the experimental units. Colonel Maurice J. Fletcher, Dr. Fred Leonard, Colonel John Butchkosky, and Victor T. Riblett, of the Army Prosthetics Research Laboratory, were responsible for the development of the hand and assisted in the resolution of problems encountered in the study. To all these gentlemen, we express our appreciation.

We also acknowledge the valuable cooperation and assistance of the children and personnel associated with the clinics participating in the Child Amputee Research Program.

Roberta Bernstein, Alfred Brooks, Herbert Bursky, Bertram Litt, Deborah Osborne, and Dr. Edward Peizer, staff members of New York University Child Prosthetic Studies, have also made significant contributions at various stages during the development and testing of the APRL-Sierra Child Size No. 1 Hand and in the preparation of the report upon which this article and a subsequent article to appear in the Autumn 1964 issue of *Artificial Limbs* are based.


## LITERATURE CITED


1. Fishman, Sidney, and Hector VV. Kay, *Acceptability of a functional-cosmetic artificial hand for young children,* Child Prosthetic Studies, Research Division, College of Engineering, New York University, January 1964.
2. Fletcher, M. J., and Fred Leonard, *The principles of artificial-hand design,* Artificial Limbs, May 1955, p. 78.
3. National Academy of Sciences—National Research Council, *Final summary report, APRL-Sierra Child-Size Hand, Size 1, Model A,* March 1961.
4. New York University, Child Prosthetic Studies, Research Division, College of Engineering, *Interim report, field test—APRL-Sierra Child Size No. 1 Hand {right),* October 1960.
5. New York University, Child Prosthetic Studies, Research Division, College of Engineering, *Interim report, field test—APRL-Sierra Chili Size Model 1 hand {right),* May 1961.
6. New York University, Child Prosthetic Studies, Research Division, College of Engineering, *Interim report, APRL-Sierra No. 1 Hand {left),* October 1962.
7. New York University, Child Prosthetic Studies, Research Division, College of Engineering, *Memorandum report: preliminary considerations of the APRL-Sierra Child Size Model 1A Hand (left),* May 1961.
8. Peizer, Edward, *The clinical treatment of juvenile amputees, 1953-1956,* Report No. 115.26C, Child Prosthetic Studies, Research Division, College of Engineering, New York University, August 1958.

# Body Segment Parameters[1]

## A Survey of Measurement Techniques

Rudolfs Drillis, PH.D.,[2]
Renato Contini, B.S.,[3] AND
Maurice Bluestein, M.M.E.[4]

Human motor activity is determined by the response of the subject to constantly changing external and internal stimuli. The motor response has a definite pattern which can be analyzed on the basis of temporal, kinematic and kinetic factors.

Temporal factors are those related to time: cadence (tempo) or the number of movements per unit time (minute or second), the variability of successive durations of motion, and temporal pattern. The temporal pattern of each movement consists of two or more phases. The relative duration of these phases and their interrelationships are indicative characteristics of the movement under consideration. For example, in walking, two basic time phases may be noted, the stance phase when the leg is in contact with the ground and the swing phase. The ratio of swing-phase time to stance-phase time is one of the basic characteristics of gait.

The kinematic analysis of movement can be accomplished by studying the linear and angular displacements of the entire body, the joints (neck, shoulder, elbow, wrist, hip, knee, ankle) and the segments (head, upper arm, forearm, hand, thigh, shank, foot). For the purpose of investigation, the most important kinematic characteristics are: the paths of motion, linear and angular displacement curves, amplitudes or ranges of motion, the instantaneous and average velocities and their directions, and finally the linear and angular accelerations of the body segments under investigation. Information on these criteria can be obtained readily from objective (optical or electrical) recordings of the movements of a subject.

The kinetic analysis is concerned with the influence of different forces and moments acting on the body or a body segment during the performance of a given activity. To determine these forces and moments, accurate data on the mass (weight), location of mass centers (centers of gravity), and the mass moments of inertia of the subject's body segments are required.

At present there are limited data on body segment parameters, especially those for American subjects. Such data available are based on studies made on a limited number of dissected male cadavers. This cannot be regarded as a representative sample for our normal population with its wide range of age and difference of body build. There are no data available on female subjects in the United States.

A precise knowledge of these body segment parameters has many applications, such as in the design of work activities or the improvement of athletic performances. It has particular value in understanding orthopedic and prosthetic problems. It would result in a better design of braces and prosthetic devices and more reliable methods for their adjustment. From these data it would also be possible to develop more precise and effective procedures for

[1] The investigation on which this article was based is supported in part by a Research Special Project grant from the Vocational Rehabilitation Administration, Department of Health, Education, and Welfare.

[2] Senior Research Scientist, Research Division, School of Engineering and Science, New York University, New York City.

[3] Senior Research Scientist, Research Division, School of Engineering and Science, New York University, New York City.

[4] Assistant Research Scientist, Research Division, School of Engineering and Science, New York University, New York City.

the evaluation of braces and artificial limbs. These procedures would replace the use of subjective ratings on performance by an amputee or a disabled person.

The information on body segment parameters obtained by simple clinical methods can be very useful in general medical practice. It would provide a tool for the determination of:

1. body segment growth and decay in normal and abnormal conditions;
2. body segment density changes in normal and pathological cases;
3. body mass distribution asymmetry;
4. more precise body composition (fat, bones, muscles).

The aim of this article is to give a brief review of the methods used by different investigators for the determination of body segment parameters. Since some of the first treatises and papers are no longer available, we include some tables and figures which summarize the data obtained by some of the earlier researchers.

## EARLY EFFORTS

Since ancient times there has existed an intense curiosity about the mass distribution of the human body and the relative proportions of its various segments. Those professions which had to select or classify subjects of varying body build were particularly interested in the problem. In spite of individual differences between particular subjects there are many characteristics which are common to all normal human beings. Thus the lower extremities are longer and heavier than the upper extremities, the upper arm is larger than the forearm, the thigh is larger than the shank, and other similar relationships.

Historically this interest was first directed to the length relationships between the body segments. To characterize these relationships certain rules and canons were promulgated. Each canon has its own standard unit of measure or module. Sometimes the dimension of a body segment or component parts of a body segment were used as modules and occasionally the module was based on some abstract deduction.

The oldest known module is the distance measured between the floor (sole) and the ankle joint. This module was used in Egypt some time around the period 3000 B.C. On this basis, the height of the human figure was set equal to 21.25 units. Several centuries later in Egypt a new module, the length of the middle finger, was introduced. In this instance body height was set equal to 19 units. This standard was in use up until the time of Cleopatra.

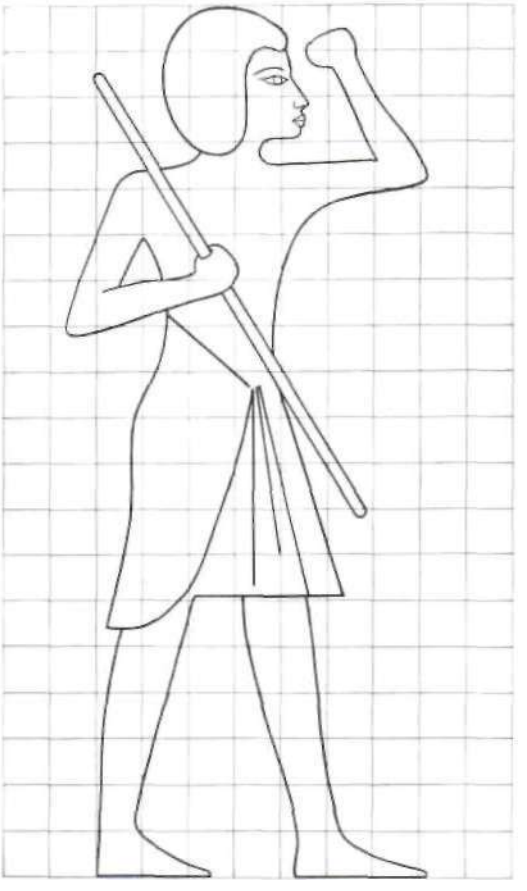


Fig. 1. Egyptian middle finger canon.

In the fifth century B.C., Polyclitus, a Greek sculptor, introduced as a module the width of the palm at the base of the fingers. He established the height of the body from the sole of the foot to the top of the head as 20 units, and on this basis the face was 1/10 of the total body height, the head 1/8, and the head and neck together 1/6 of the total body height. In the first century B.C., Vitruvius, a Roman architect, in his research on body proportions found that body height was equal to the arm spread—the distance between the tips of the middle fingers

with arms outstretched. The horizontal lines tangent to the apex of the head and the sole of the foot and the two vertical lines at the finger tips formed the "square of the ancients." This square was adopted by Leonardo da Vinci. He later modified the square by changing the position of the extremities and scribing a circle around the human figure.

Diirer (1470-1528) and Zeising (1810-1876) based their canons on mathematical abstracts which were not in accordance with any actual relationships.

At the beginning of the twentieth century, Kollmann tried to introduce a decimal standard by dividing the body height into ten equal parts. Each of these in turn could be subdivided into ten subunits. According to this standard, the head height is equal to 13 of these smaller units: seated height, 52-53; leg length, 47; and the whole arm, 44 units.

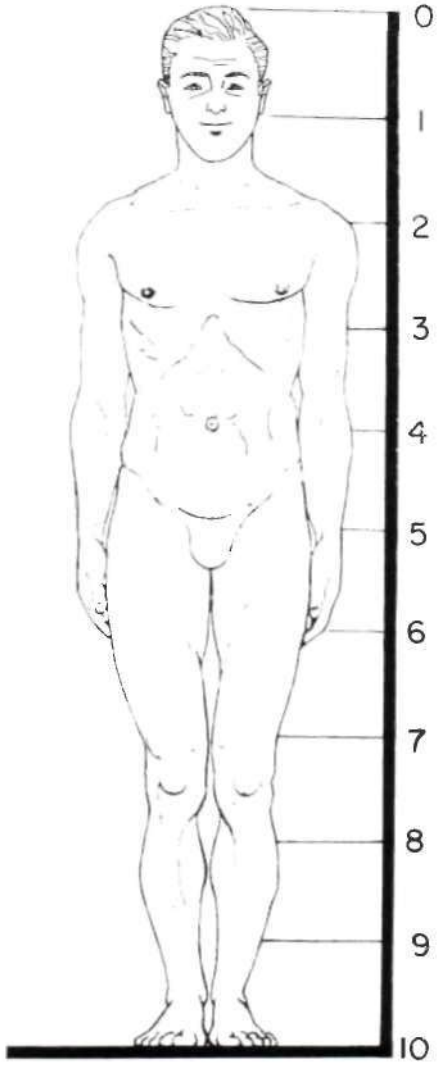


Fig. 2. Kollmann's decimal canon.

## PREVIOUS STUDIES IN BODY PARAMETERS

Starting with the early investigators, the idea has prevailed that volumetric methods are best for determining relationships between body segments. There were basically two methods which were used for the determination of the volume of the body segments: (1) body segment immersion, and (2) segment zone measurement or component method. In these methods it is assumed that the density or specific gravity of any one body segment is homogeneous along its length. Hence the mass of the segment can be found by multiplying its volume by its density.

## IMMERSION METHOD

Harless in Germany first used the immersion method. In 1858 he published a text book on *Plastic Anatomy,* and in 1860 a treatise, *The Static Moments of the Human Body Limbs.* In his investigations, Harless dissected five male cadavers and three female cadavers. For his final report, however, he used only the data gathered on two of the subjects.

The immersion method involves determining how much water is displaced by the submerged segment. Previous researchers, including Harless, have relied on the measurement of the overflow of a water tank to find the volume of water displaced.

Harless started his studies with the determination of the absolute and relative lengths of the body and its segments. The absolute lengths were measured in centimeters. For determining the relative lengths, Harless used the hand as a standard unit. The standard hand measurement was equal to the distance from the wrist joint to the tip of the middle finger of the right hand. Later Harless also used the total height of the body as a relative unit of length. In the more recent studies on body parameters, this unit is accepted as the basis for the proportions of the various segment lengths. The results of Harless' studies are shown in Table 1.

For obtaining the absolute weights of the body segments, Harless used the gram as the standard. As a unit for relative weights, he first decided to use the weight of the right hand, but later established as his unit the one thousandth part of the total body weight. His results are given in Table 2.

In a very careful way Harless determined the volume and density (specific gravity) of the body segments. The results of these measurements are presented in Table 3.

To determine the location of mass centers (centers of gravity), Harless used a well-balanced board on which the segment was moved until it was in balance. The line coincident with the fulcrum axis of the board was marked on the segment and its distance from proximal and distal joints determined. The location of the mass center was then expressed as a ratio assuming the segment length to be equal to one. Harless also tried to determine the location of segment mass center from the apex of the head by assuming that the body height is equal to 1,000. The data for one subject are shown in Table 4. From the table, the asymmetry of the subject becomes evident.

To visualize the mass distribution of the human body, Harless constructed the model shown in Figure 3. The linear dimensions of the links of the model are proportional to the segment lengths; the volumes of the spheres are proportional to segment masses. The centers of

TABLE 1. ABSOLUTE AND RELATIVE LENGTHS OF BODY SEGMENTS (AFTER HARLESS)

| | Absolute Lengths in cm. | | Relative Lengths | | | |
|---|---|---|---|---|---|---|
| | | | Hand Length = 1,000 | | Body Height = 1,000 | |
| | G | K | G | K | G | K |
| Head and neck | 21.2 | 20.2 | 1.275 | 1.08 | 122.7 | 120.0 |
| Upper trunk | 41.0 | 40.0 | 1.900 | 2.14 | 225.8 | 238.5 |
| Lower trunk | 13.5 | 17.5 | 0.690 | 0.94 | 81.1 | 104.5 |
| Upper arm | 36.4 | 30.3 | 1.792 | 1.62 | 211.1 | 180.7 |
| Forearm | 29.9 | 26.2 | 1.471 | 1.40 | 173.1 | 156.5 |
| Hand | 20.3 | 18.7 | 1.000 | 1.00 | 117.6 | 111.7 |
| Thigh | 44.9 | 42.3 | 2.210 | 2.26 | 260.0 | 252.0 |
| Shank | 42.9 | 38.1 | 2.111 | 2.03 | 248.4 | 227.0 |
| Foot | 6.0 | 9.7 | 0.295 | 0.52 | 34.7 | 58.0 |
| Whole body | 172.68 | 167.7 | 8.500 | 8.97 | 1,000 | 1,000 |

TABLE 2. ABSOLUTE AND RELATIVE WEIGHTS OF BODY SEGMENTS (AFTER HARLESS)

| | Absolute Weights in grams | | Relative Weights | | | |
|---|---|---|---|---|---|---|
| | | | Hand = 1,000 | | Body Weight = 1,000.00 | |
| | Cadaver 1 | Cadaver 2 | Cadaver 1 | Cadaver 2 | Cadaver 1 | Cadaver 2 |
| Head | 4,555 | 3,747 | 8.435 | 9.529 | 71.20 | 75.11 |
| Upper trunk | 23,055 | 17,779 | 42.694 | 45.209 | 360.40 | 356.43 |
| Lower trunk | 6,553 | 4,868 | 12.145 | 12.380 | 102.43 | 97.56 |
| Upper arm | 2,070 | 1,448 | 3.833 | 3.682 | 32.35 | 29.04 |
| Forearm | 1,160 | 795.5 | 2.148 | 2.023 | 18.13 | 15.94 |
| Hand | 540 | 383.6 | 1.000 | 1.000 | 8.44 | 7.69 |
| Thigh | 7,165 | 5,887 | 13.252 | 14.972 | 112.00 | 118.00 |
| Shank | 2,800 | 2,247.5 | 5.185 | 5.716 | 43.77 | 45.04 |
| Foot | 1,170 | 985.2 | 2.167 | 2.505 | 18.28 | 19.74 |
| Both upper extremities | 7,540 | 5,254 | | | 117.86 | 105.34 |
| Both lower extremities | 22,270 | 18,239.4 | | | 348.11 | 365.56 |
| Whole body | 63,970 | 49,895 | 118.4 | 126.9 | 1,000.00 | 1,000.00 |

TABLE 3. DENSITY OF THE BODY SEGMENTS (IN GR PER CM³) (AFTER HARLESS)

| Segment | Male (3 Cadavers) | Female (2 Cadavers) | Mean |
|---|---|---|---|
| Upper arm | 1.0880 | 1.0596 | 1.0766 |
| Forearm | 1.1086 | 1.0714 | 1.0937 |
| Hand | 1.1126 | 1.1130 | 1.1128 |
| Thigh | 1.0686 | 1.0541 | 1.0628 |
| Shank | 1.1002 | 1.0822 | 1.0930 |
| Foot | 1.0893 | 1.1006 | 1.0922 |
| Head | 1.0851* | 1.1300* | 1.1107 |

* Data on one subject only.

TABLE 4. LOCATION OF THE MASS CENTERS (FOR ONE SUBJECT) (AFTER HARLESS)

| Segment | Distance from Proximal Joint Segment Length = 1.000 | Distance from Apex of Head to Sole = 1,000 |
|---|---|---|
| Head (from apex) | 0.361 | 43.530 |
| Upper trunk | 0.497 | 276.585 |
| Lower trunk | 0.518 | 413.000 |
| R. upper arm | 0.427 | 235.245 |
| L. upper arm | 0.432 | 235.245 |
| R. Forearm | 0.417 | 404.290 |
| L. Forearm | 0.402 | 402.805 |
| R. hand | 0.361 | 608.230 |
| L. hand | 0.357 | 605.245 |
| R. thigh | 0.430 | 571.850 |
| L. thigh | 0.569 | 568.875 |
| R. shank | 0.443 | 841.680 |
| L. shank | 0.494 | 841.680 |
| R. foot (from heel) | 0.436 | 974.955 |
| L. foot | 0.436 | 974.955 |
| Mean for all segments | 0.432 | |

the spheres indicate the location of mass centers (centers of gravity) of the segments.

Modified models of the mass distribution of the human body and mass center location of the segments have been made by several other investigators. It is unfortunate that up to now a unified and universally accepted subdivision of the human body into segments does not exist.

In 1884, C. Meeh investigated the body segment volumes of ten living subjects (8 males and 2 females), ranging in age from 12 to 56 years. In order to approximate the mass of the segments, he determined the specific gravity of the whole body. This was measured during quiet respiration and was found to vary between 0.946 and 1.071 and showed no definite variation with age. The segment subdivision used by Meeh is shown in Figure 4 and the

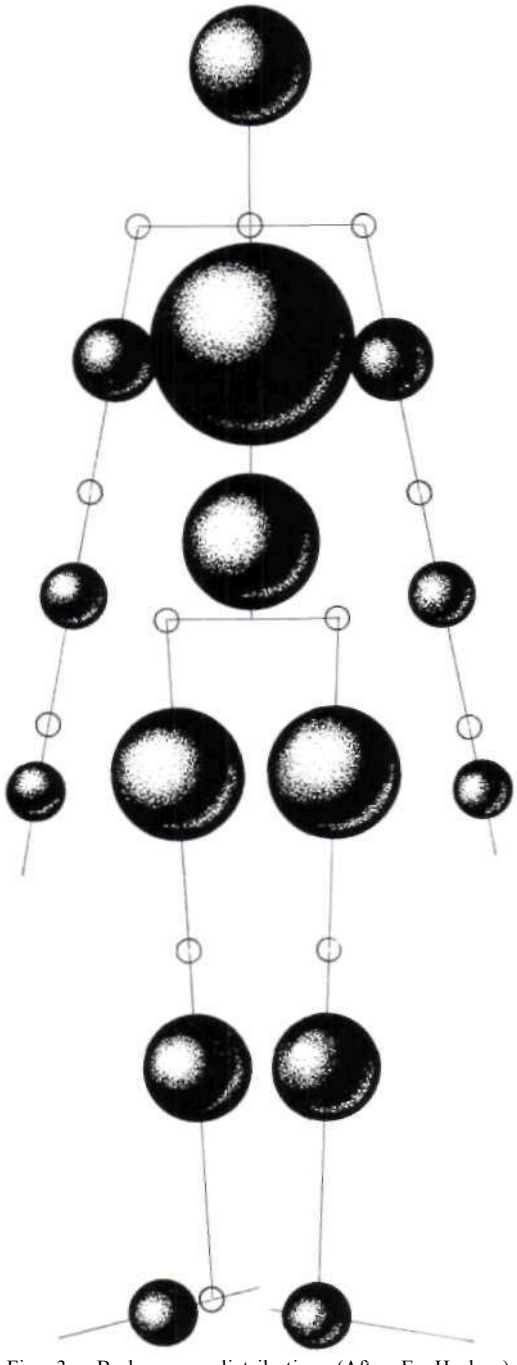


Fig. 3. Body mass distribution (After E. Harless).

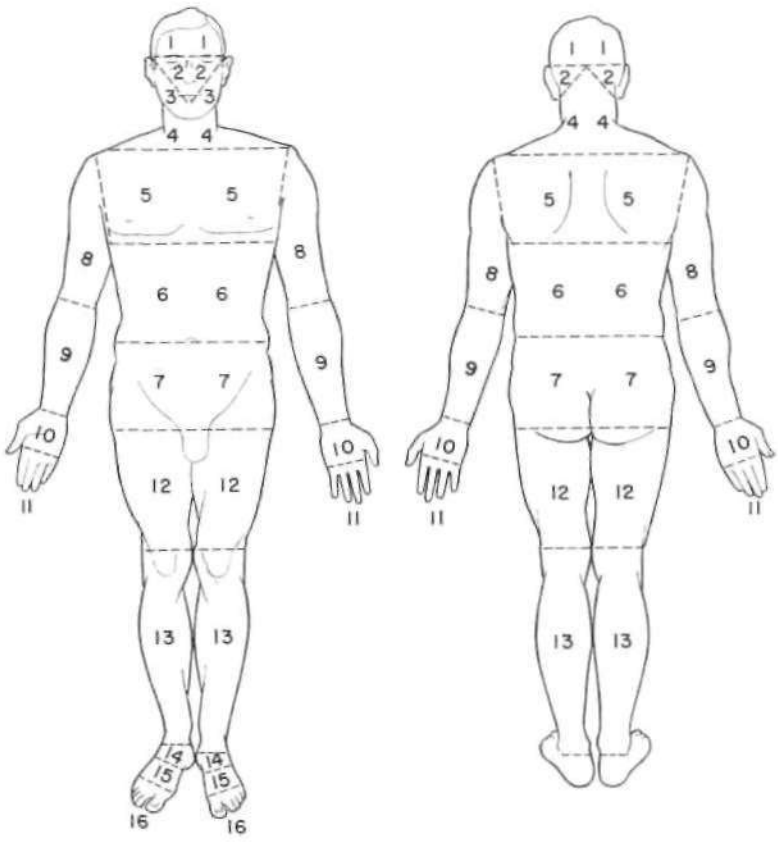



Fig. 4. Body segments (After C. Meeh).

TABLE 5. BODY SEGMENT VOLUME. TOTAL BODY VOLUME = 1,000 (AFTER MEEH)

| Segment | Males (8 Subjects) | | Females (2 Subjects) | |
|---|---|---|---|---|
| Cranium (1)* and upper jaw (2) | 71.64 | | 57.67 | |
| Lower jaw (3) and neck (4) | 38.32 | | 29.83 | |
| Head and neck (1 + 2 + 3 + 4) | | 109.96 | | 87.50 |
| Chest (5) | 186.10 | | 137.76 | |
| Abdomen (6) | 137.47 | | 144.68 | |
| Pelvis (7) | 182.95 | | 215.83 | |
| Whole trunk (5 + 6 + 7) | | 506.52 | | 498.27 |
| Upper arm (8) | 28.04 | | 27.56 | |
| Forearm (9) | 14.90 | | 13.51 | |
| Palm and thumb (10) | 5.20 | | 3.72 | |
| The four fingers (11) | 1.95 | | 2.07 | |
| The whole hand (10 + 11) | 7.15 | | 5.79 | |
| Both upper extremities | | 100.19 | | 93.73 |
| Thigh (12) | 81.63 | | 100.42 | |
| Shank (13) | 43.56 | | 46.51 | |
| Base of foot (14)<br>Middle foot (15) | 13.77 | | 10.92 | |
| The five toes (16) | 2.70 | | 2.40 | |
| The whole foot (14 + 15 + 16) | 16.47 | | 13.32 | |
| Both lower extremities | | 283.33 | | 320.50 |
| Total body | | 1,000.00 | | 1,000.00 |

* The numbers indicate the segments in Figure 4.

results of the segment volume measurements are presented in Table 5.

C. Spivak, in 1915, in the United States, measured the volumes of various segments and the whole body for 15 males. He found that the value of specific gravity of the whole body ranged from 0.916 to 1.049.

D. Zook, in 1930, made a thorough study of how body segment volume changes with age. In making this study, he used the immersion method for determining segment volumes. These were expressed in per cent of whole body volume. His sample consisted of youngsters between the ages of 5 and 19 years. His immersion technique was unique, but his claim that it permitted the direct determination of the specific gravity of any particular body segment does not seem to have been established. Some of his results are shown in Figures 5 and 6.

In the period from 1952 to 1954, W. Dempster at the University of Michigan made a very thorough study of human body segment measurements. His investigations were based on values obtained on eight cadavers. Besides volumes, he obtained values for mass, density, location of mass center, and mass moments of inertia. The immersion method was used to determine volume. However, these data have limited application since all of Dempster's subjects were over 50 years of age (52-83) and their average weight was only 131.4 lb. The

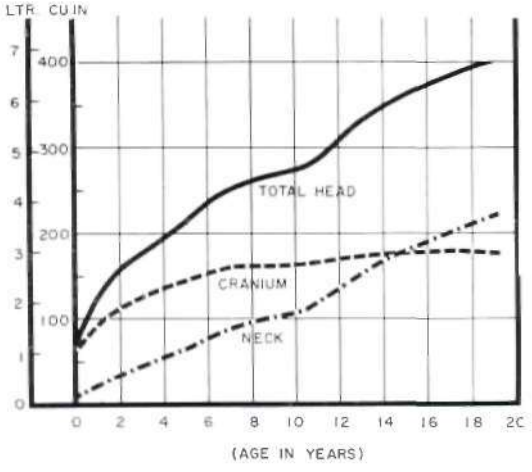



Fig. 5. Mean head volume change with age (After D. Zook)

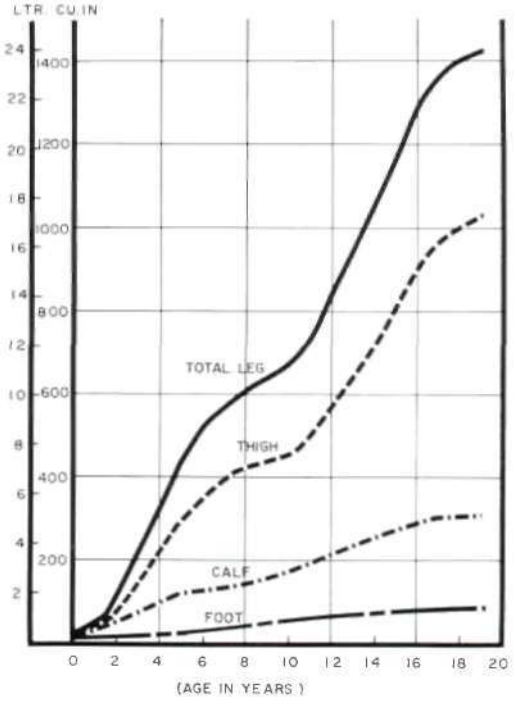



Fig. 6. Mean leg volume change with age (After D. Zook and others).

immersion method was used in Russia by Ivanitzkiy (1956) and Salzgeber (1949).

The immersion technique can be applied for the determination of the total segment volume or any portion thereof in a step-by-step sequence. It can be applied as well on living subjects as on cadavers. In this respect it is a useful technique.

There is some evidence that for most practical purposes the density may be considered constant along the full length of a segment. According to O. Salzgeber (1949), this problem was studied by N. Bernstein in the 1930's before he started his extensive investigations on body segment parameters. By dividing the extremities of a frozen cadaver into zones of 2 cm. height, it was established that the volume centers and mass centers of the extremities were practically coincident. It would seem therefore that the density along the segment was fairly constant for the case studied. Accepting this, it follows that the extremity mass, center of mass, and mass moment of inertia

may be determined from the volume data obtained by immersion. However, it should be noted that for the whole body, according to an investigation by Ivanitzkiy (1956), the mass center does not coincide with the volume center, due to the smaller density of the trunk.

## COMPUTATIONAL METHODS

Harless was the first to introduce computational methods as alternatives to the immersion method for determining body volume and mass. He suggested that this would be better for specific trunk segments since no definite marks or anatomical limits need be applied.

He considered the upper part of the trunk down to the iliac crest as the frustum of a right circular cone. The volume (*V1*) is then determined by the formula:

$$V_1 = \frac{\pi h}{3}(r_1^2 + r_1 r_2 + r_2^2), \text{ where}$$

$h$ is the height of the cone, $r_1$ is the greater radius, and $r_2$ is the lesser radius of the cone.

He assumed that the volume of the lower (abdomino-pelvic) part of the trunk (*V2*) can be approximated as a body between two parallel, nonsimilar elliptical bases with a distance $h$ between them. The volume *V2* is determined by the formula:

$$V_2 = \frac{\pi h}{6}[2(ab + a_1 b_1) + ab_1 + a_1 b] \text{ where}$$

$a$ and $b$ are the half axes of the greater, and $a_1$ and $b_1$ are the half axes of the lesser elliptical area, and $h$ is the distance between them.

On the basis of dimensions taken on one subject, using these formulas he arrived at a value for *V1* of 21,000 cm cubed and 5,769 cm subed for *V2*. Using a value of 1.066 gr/cm cubed as the appropriate specific gravity of these parts, the total trunk weight was computed to be 28.515 kg. The actual weight of the trunk was determined (by weighing) to be 29.608 kg. The computed weight thus differed from the actual weight by 1.093 kg, or 3.69 per cent.

Several subsequent investigators used this method subdividing the body into segments of equal height. For increased accuracy these zones should be as small as practically possible —a height of 2 cm is the practical lower limit. The zone markings are measured starting usually from the proximal joint of the body segment. The circumference of the zone is measured and it is assumed that the cross-section is circular. The volume may be computed and on the basis of accepted specific gravity values the mass may be found. From these values one may compute the center of mass and mass moment of inertia.

Amar (1914) in order to compute the mass moment of inertia of various body segments made a number of assumptions. He assumed the trunk to be a cylinder, and that the extremities have the form of a frustum of a cone. The mass moment of inertia for the trunk about a lateral axis through the neck is determined from the formula:

$I = M/12\ (3r^2 + 4h^2)$ where $r$ and $h$ are the radius and height of the cylinder, respectively,

and for the extremities by the formula:

$$I = M\left[\frac{1^2}{9}\left(l + \frac{d}{r + r_1}\right) + \frac{(r + r_1)^2 - 2d^2}{16}\right] \text{ where}$$

$I$ is the mass moment of inertia about a lateral axis through the proximal joint;
$M$ is the mass of the segment;
$l$ is the length of the segment or height of the frustum;
$r$ is the radius of the larger cone base;
$r_1$ is the radius of the smaller cone base;
$d$ is the quantity $(r - r_1)$.

Weinbach (1938) proposed a modified zone method based on two assumptions: (1) that any cross-section of a human body segment is elliptical, and (2) that the specific gravity of the human body is uniform in all its segments and equal to 1.000 gr/cm cubed. The area *(A)* at any cross section is expressed by the equation:

$A = \pi ab$ where $a$ and $b$ are the half axes of the ellipse.

Plotting a graph showing how the equidistant cross-sectional areas change relative to their location from the proximal joint, it is possible to determine the total volume of the segment and hence its mass and location of center of mass. The mass moment of inertia (/) may be obtained by summing the products of the distances from the proximal joint to the zone center squared *(r squred)* and the corresponding zone mass:

$$I = \sum mr^2$$

Unfortunately both of Weinbach's assumptions are questionable since the cross sections of human body segments are not elliptical and the specific gravities of the different segments are not equal to 1.000 gr/cm cubed nor is density truly uniform in all segments.

Bashkirew (1958) determined the specific gravity of the human body for the Russian population to be 1.044 gr/cm cubed with a standard deviation of ±0.0131 gr/cm cubed and the limits from 0.978 minimum to 1.109 maximum. Boyd (1933) determined further that specific gravity generally increases with age. Dempster (1955) showed that Weinbach's method was good for determining the volume of the head, neck, and trunk but not good for other body parts.

It is evident that the determination of body segment parameters, based on the assumption that the segments can be represented by geometric solids, should not be used when great accuracy is desired. This method is useful only when an approximate value is adequate.

Fischer introduced another approximate method of determining human body parameters by computation known as the "coefficient method." According to this procedure, it is assumed that fixed relations exist between body weight, segment length, and the segment parameters which we intend to find. There are three such relationships or ratios expressed as coefficients. For the body segment mass, the coefficient is identified as *C1* and represents the ratio of the segment mass to the total body mass. The second coefficient *C2* is the ratio of the distance of the mass center from the proximal joint to the total length of the segment. The third coefficient *C3* is the ratio of the radius of gyration of the segment about the mediolateral centroidal axis to the total segment length. Thus to determine the mass of a given segment for a new subject, it would be sufficient to multiply his total body mass by coefficient *C1* corresponding segment mass. Similarly the location of mass center and radius of gyration can be determined by multiplying the segment length by the coefficients *C2* and *C3* respectively.

Table 6 compares the values of coefficient *C1* obtained by different investigators.

Table 6 shows that the differences between the coefficients obtained by different investigators for particular segment masses are great. The difference is highest for the trunk and head mass where the coefficients vary from 49.68 to 56.50 per cent of body mass. Next highest difference is in the thigh coefficients from 19.30 to 24.43 per cent of body mass. Since the number of subjects used in the studies, with the exception of that of Bernstein, is small and no anthropological information on body build is given, it is difficult to draw any definite conclusions about the scientific and practical value of these coefficients for body segment mass determination.

As already mentioned, the data obtained by Harless are based on two decapitated male cadavers, and since the blood had been removed some errors are possible. The data of Meeh are based on volume measurements of eight living subjects. The large coefficient for the trunk is influenced by the assumption that all body segments have the same average density, where actually it is less for the trunk.

Braune and Fischer (1889) made a very careful study of several cadavers. Their coefficients are based on data taken on three male cadavers whose weight and height were close to the data for the average German soldier. The relative masses (coefficients) of the segments were expressed in thousandths of the whole body mass. The positions of the mass center and radius of gyration (for determination of the segment mass moments of inertia) were expressed as

Table 6. Body Segment Mass as per cent of Total Mass (Males Only)

| Segment | Investigator | | | |
|---|---|---|---|---|
| | Harless | Braune and Fischer | Bernstein | Dempster |
| Head, neck, and trunk less limbs | 53.42 | 49.68 | 52.98 | 56.50 |
| Upper arms | 6.48 | 6.72 | 5.31 | 5.30 |
| Forearms | 3.62 | 4.56 | 3.64 | 3.10 |
| Hands | 1.68 | 1.68 | 1.41 | 1.20 |
| Thighs | 22.36 | 23.16 | 24.43 | 19.30 |
| Shanks | 8.78 | 10.54 | 9.31 | 9.00 |
| Feet | 3.66 | 3.66 | 2.92 | 2.80 |

proportional parts of the segment's total length. Fischer's coefficients have been accepted and used in most subsequent investigations to date.

N. Bernstein and his co-workers (1936) at the Russian All-Union Institute of Experimental Medicine in Moscow carried out an extensive investigation on body segment parameters of living subjects. The study took care of anthropological typology of body build. The results of this investigation were published in a monograph, *Determination of Location of the Centers of Gravity and Mass (weight) of the Limbs of the Living Human Body* (in Russian). At present the monograph is not available in the United States. Excerpts of this investigation, which cover 76 male and 76 female subjects, 12 to 75 years old, were published by N. Bernstein in 1935 in his chapters on movement in the book, *Physiology of Work* (in Russian), by G. P. Konradi, A. D. Slonim, and V. C. Farfel.

Table 7 shows data for the comparison of segment masses of living male and female subjects as established by Bernstein's investigation. The data are self-explanatory.

TABLE 7. BODY SEGMENT AS PER CENT OF TOTAL BODY MASS (= 100.00)

| Segment | Bernstein (Living Subjects) | | | Fischer |
|---|---|---|---|---|
| | 76 Males | 76 Females | Average | 3 Male Cadavers |
| Upper arms | 5.31 | 5.20 | 5.26 | 6.72 |
| Forearms | 3.64 | 3.64 | 3.64 | 4.56 |
| Hands | 1.41 | 1.10 | 1.26 | 1.68 |
| Thighs | 24.43 | 25.78 | 25.11 | 23.16 |
| Shanks | 9.31 | 9.68 | 9.49 | 10.54 |
| Feet | 2.92 | 2.58 | 2.75 | 3.66 |

## DETERMINATION OF MASS CENTER LOCATION

In the biomechanical analysis of movements it is necessary to know the location of the segment mass center which represents the point of application of the resultant force of gravity acting on the segment. The mass center location of a segment system such as an arm or a leg or the whole body determines the characteristics of the motion.

TABLE 8. DISTANCE OF MASS CENTER FROM THE PROXIMAL JOINT. SEGMENT LENGTH = 1.000

| Segment | Investigator | | | |
|---|---|---|---|---|
| | Harless | Braune and Fischer | Bernstein | Dempster |
| Upper arm | 0.485 | 0.470 | 0.466 | 0.436 |
| Forearm | 0.440 | 0.420 | 0.412 | 0.430 |
| Thigh | 0.467 | 0.440 | 0.386 | 0.433 |
| Shank | 0.360 | 0.420 | 0.413 | 0.433 |

TABLE 9. DISTANCE OF FOREARM MASS CENTER FROM THE PROXIMAL JOINT. FOREARM LENGTH = 1.000 (AFTER BERNSTEIN)

| Age | Male | | Female | |
|---|---|---|---|---|
| | Mean M | Range M $\pm \sigma$ | Mean M | Range M $\pm \sigma$ |
| 12–15 | 0.383 | 0.359–0.407 | 0.415 | 0.392–0.441 |
| 16–25 | 0.419 | 0.388–0.450 | 0.417 | 0.383–0.451 |
| 26–35 | 0.409 | 0.383–0.435 | 0.425 | 0.388–0.462 |
| 36–45 | 0.403 | 0.384–0.422 | 0.405 | 0.370–0.440 |
| 46–75 | 0.428 | 0.402–0.454 | 0.411 | 0.381–0.441 |

Table 8 shows the relative location of the mass center for different segments. It is evident that the assumption that mass center of all segments is located 45 per cent from the proximal and 55 per cent from the distal end of the segment is not valid. Since the mass distribution of the body is related to body build it seems that the mass center location also depends on it.

Bernstein claims that he was able to locate the mass centers with an accuracy of ±1 mm. Hence the data of Table 9 represent the result of very careful measurements. An analysis of these data shows that there is no definite trend of the coefficients differing with age or sex. The variance of the coefficients is very high and reaches nine per cent as maximum. Thus the use of the same coefficients for subjects with a wide range of body build is highly questionable.

Figures 7 and 8 represent, in modification, Fischer's schemes for the indication of the mass center location of the extremities. The letters of the alphabet indicate the location levels of the mass centers on the human figure. The

corresponding cross sections through the segments are shown separately. The letters designate the following:

*A*—mass center of upper arm
*B*—mass center of whole arm
C—mass center of forearm
*D*—mass center of forearm and hand
*E*—mass center of hand
*F*—mass center of thigh
*G*—mass center of whole leg
*H*—mass center of shank
*I*—mass center of shank and foot
*J*—mass center of foot

The location of mass centers with respect to the proximal and distal joints as determined by W. Dempster (1955) is shown in Figure 9.

It is easy to find the equations for the determination of the coordinates of the mass center when the coordinates of the segment's proximal and distal joints are given.

By using Fischer's coefficients for mass center of a particular segment the following

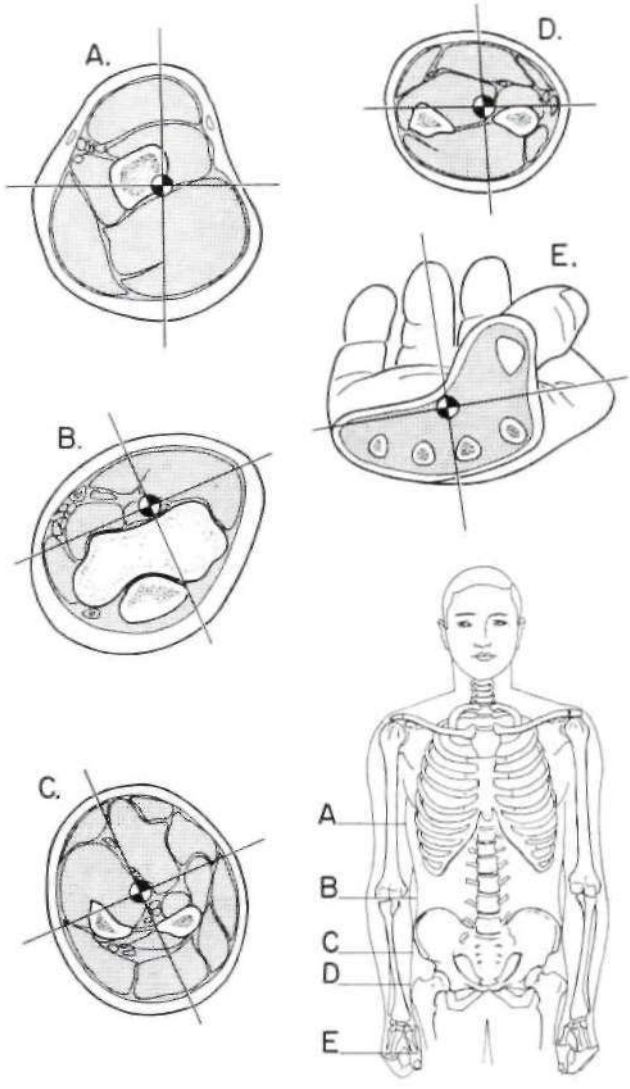



Fig. 7. Location of mass centers of the upper extremity (Redrawn from 0. Fischer).

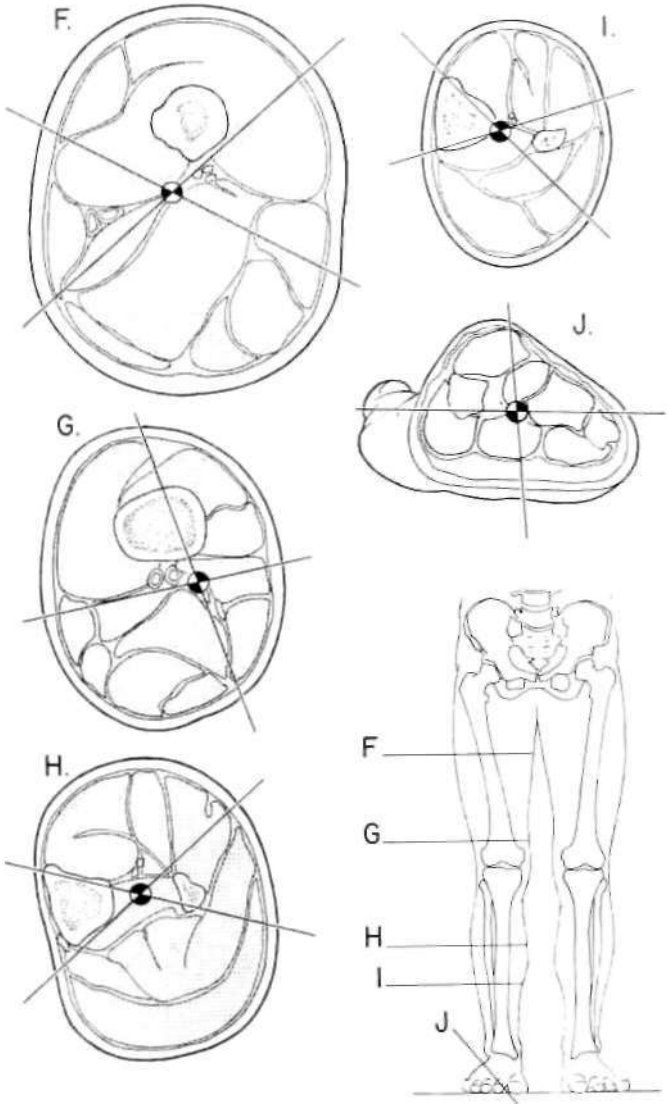



Fig. 8. Location of mass centers of the lower extremity (Redrawn from O. Fischer).

formulas were developed:

Coordinates of mass center of the:

a. forearm:

$x = 0.42xd + 0.58xp$

$y = 0.42yd + 0.58yp$

where $xd$, $yd$ are coordinates of the distal (wrist) joint and $xp$, $yp$ are coordinates of the proximal (elbow) joint.

b. upper arm:

$x = 0.47xd + 0.53xp$

$y = 0.47yd + 0.53xp$

where $xd$, $yd$ are coordinates of the elbow joint and $xp$, $yp$ are coordinates of the shoulder joint.

c. shank:

$x = 0.42dx + 0.58xp$

$y = 0.42yd + 0.58yp$

where $xd$, $yd$ are coordinates of the ankle joint and $xp$, $yp$ are coordinates of the knee joint.

d. thigh:

$x = 0.44xd + 0.56xp$

$y = 0.44yd + 0.56yp$

where *xd, yd* are coordinates of the knee joint and *xp*, *yp* are coordinates of the hip joint.

For the case of three-dimensional recordings of motion, similar equations for *z* are used. The coordinates of the mass center of trunk *(t)* are:

$xt = 0.235\ (xfr + xfl) + 0.265\ (xbr + xbl)$,
with similar equations for the *yt* and *zt* coordinates.

Here *xfr* is the coordinate of the right hip and *xfl* is the coordinate of the left hip, and *xbr* is the coordinate of the right shoulder and *xbl* is the coordinate of the left shoulder.

In the same manner the equations for segment systems are developed:

a. entire arm:
mass center *x* coordinate given by:
$xac = 0.130\,xgm + 0.148\,xm + 0.448\,xa + 0.27\,xb$, where
*xac*—entire arm mass center *x* coordinate
*xgm*—mass center of the hand
*xm*—wrist joint
*xa*—elbow joint
*xb*—shoulder joint

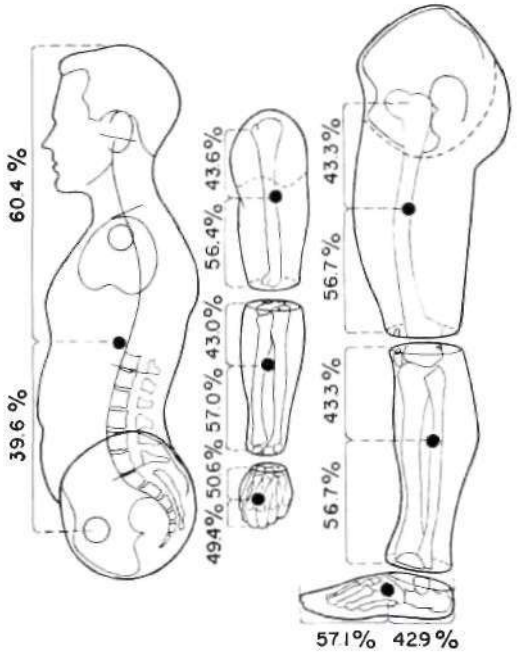



Fig. 9. Location of mass centers of body segments (After W. Dempster).

Similar equations for *y* and *z* coordinates are used:

b. entire leg:
mass center *x* coordinate given by:
$xlc = 0.096\ xgp + 0.119\ xp + 0.437\ xs + 0.348\ xf$, where
*xlc*—entire leg mass center *x* coordinate
*xgp*—mass center of foot
*xp*—ankle joint
*xs*—knee joint
*xf*—hip joint

Similar equations are developed by the *y* and *z* coordinates.

By analogy the formulas for coordinates determining the location of the mass center of the entire body in two or three dimensions can be developed.

As regards the coefficient *C3*, it is known that the mass moment of inertia (*I*) is proportional to the segment's mass and to the square of the segment's radius of gyration *(p)*. Fischer found that the radius of gyration for rotation about the axis through the mass center and perpendicular to the longitudinal axis of the segment can be established by multiplying the segment's length *(l)* by the coefficient *C3* = 0.3. Hence the mass moment of inertia with respect to the mass center is *Ig = mpp = m(0.3l)(0.31) = 0.09ml squred.*

For the rotation of the segment about its longitudinal axis, Fischer found the coefficient *C4* = 0.35, so that the radius of gyration *p* = 0.35 *d,* where *d* is the diameter of the segment.

Since for living subjects the segment rotates about the proximal or distal joint and not the mass center, the mass moment of inertia that we are interested in is greater than *Ig* by the term *mee,* where *e* is the distance of mass center from the joint. It follows that the mass moment of inertia for segment rotation about the joint is equal to *Ij = mpp + mee = m(pp + ee).*

## NEW YORK UNIVERSITY STUDIES

At present the Biomechanics group of the Research Division of the School of Engineering and Science, New York University, is engaged in the determination of volume, mass, center of mass, and mass moment of inertia of living body segments. The methods employed will

now be discussed. Some of these techniques are extensions of the methods used by previous researchers; others are procedures introduced by New York University.

## DETERMINATION OF VOLUME

The two methods being investigated by New York University to determine segment volumes are (1) immersion and (2) mono- and stereophotogrammetry.

### IMMERSION METHOD

The Biomechanics group at New York University uses water displacement as the basis for segment volume determination. However, the procedure differs from that used by previous researchers in that the subject does not submerge his segment into a full tank of water and have the overflow measured. Instead his segment is placed initially in an empty tank which is subsequently filled with water. In this way, the subject is more comfortable during the test, and the segment remains stationary to ensure the proper results.

A variety of tanks for the various segments—hand, arm, foot, and leg—has been fabricated. It is desirable that the tank into which the segment is to be immersed be adequate for the extreme limits which may be encountered and yet not so large as to impair the accuracy of the experiments. A typical setup is shown in Figure 10.

The arm is suspended into the lower tank and set in a fixed position for the duration of the test. The tank is then filled to successive predetermined levels at two-centimeter increments from the supply tank of water above. At each level, readings are taken of the height of the water in each tank, using the meter sticks shown. The volume occupied by water between any two levels is found by taking the difference between heights of water levels and applying suitable area factors. Thus to find the volume of the forearm the displacement volume is found for the wrist to elbow levels in the lower tank and between the corresponding levels in the upper tank. The difference between these two volumes is the desired forearm volume.

To find the center of volume obtain volumes in the same manner of consecutive two-centimeter sections of the limb. Assuming the volume center of each section as one centimeter from each face, sum the products of section volume and section moment arm about the desired axis of rotation. The net volume center for the body segment is then this sum divided by the total volume of the segment. In a similar fashion, using the appropriate combination of tanks, we find the volumes of other segments, hand, foot, and leg. The use of an immersion tank to find hand volume is shown in Figure 11. The data on volume and volume centers can also be used along with density as a check against methods of obtaining mass and center of mass.

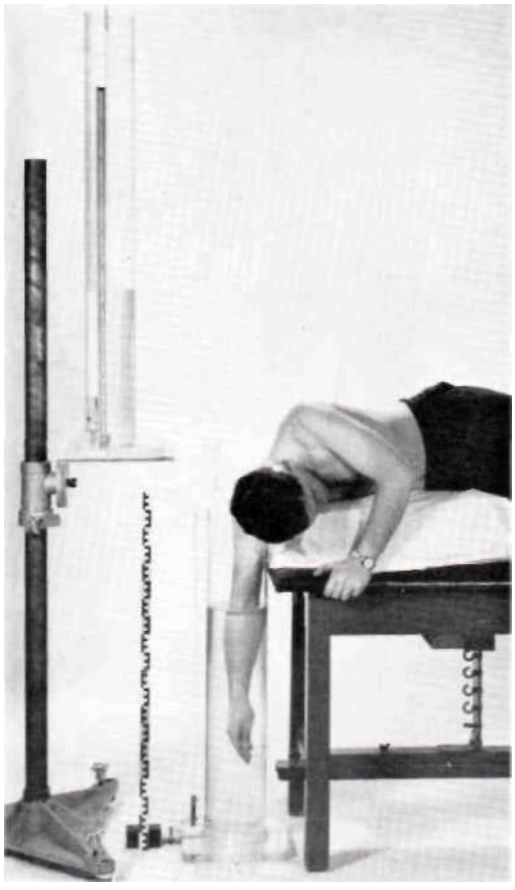


Fig. 10. Determination of the arm volume.

### PHOTOGRAMMETRY METHOD

In order to find the volume of an irregularly shaped body part such as the head or face a

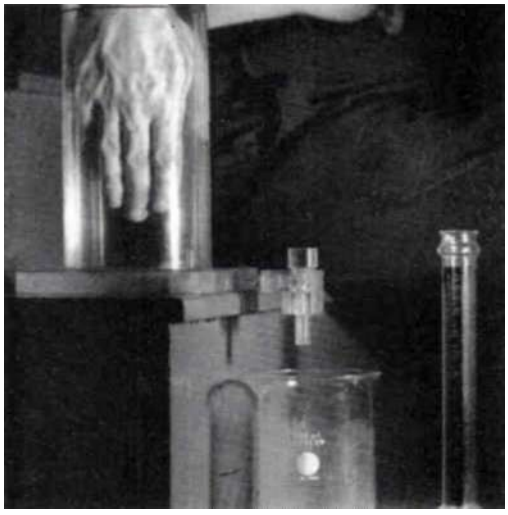


Fig. 11. Determination of the hand volume.

photographic method may be employed. Such a procedure, called photogrammetry, allows not only the volume to be found, but a visual picture of the surface irregularity to be recorded as well. The two types of this technique are mono- and stereophotogrammetry. The principles are the same for each, except that in the latter procedure two cameras are used side by side to give the illusion of depth when the two photographs are juxtaposed. The segment of interest is photographed and the resulting picture is treated as an aerial photograph of terrain upon which contour levels are applied. The portions of the body part between successive contour levels form segments whose volumes can be found by use of a polar planimeter on the photograph as described by Wild (1954). By summing the segmental volumes, the total body segment volume can be found. A controlled experiment by Pierson (1959) using a basketball verified the accuracy of such a procedure. Hertzberg, Dupertuis, and Emanuel (1957) applied the technique to the measurement of the living with great success. The reliability of the photographic technique was proven by Tanner and Weiner (1949). For a more detailed discussion of the photogrammetric method, refer to the paper by Contini, Drillis, and Bluestein (1963).

METHOD OF REACTION CHANGE

In searching for a method which will determine the segment mass of a living subject with sufficient accuracy, the principle of moments or of the lever has been utilized. The use of this method was suggested by Hebestreit in a letter to Steinhausen (1926). This procedure was later used by Drillis (1959) of New York University. Essentially it consists of the determination of reaction forces of a board while the subject lies at rest on it. The board is supported by a fixed base at one end *(A)* and a very sensitive weighing scale at the other end *(B).* The location of the segment center of mass can be found by the methods described elsewhere in this paper. The segment mass is *m,* the mass of the rest of the body is *M.* The reaction force (measured on the scale) due to the board only should be subtracted from the reaction force due to the subject and board. First the reaction force *(S0)* is determined when the segment (say the arm) is in the horizontal position and rests alongside the body; second, the reaction force *(S)* is determined when the segment is flexed vertically to 90 deg. with the horizontal. The distance between the board support points *A* and *B* is constant and equal to *D.* The distance *(d)* of the segment mass center from the proximal joint is known and the distance *b* from the proximal joint to support axis *A* can be measured. From the data it is possible to write the corresponding moment equations about *A.* The solution of these equations gives the magnitude of the segment's mass as

$$m = \frac{(S - S_0)D}{d}$$

To check the test results, the segment is placed in a middle position, approximately at an angle that is 45 deg. to the horizontal, in which it is held by a special adjustable supporting frame shown at the right in Figure 13.

The magnitude of the segment mass in this case will be determined by the formula:

$$m = \frac{(S_m - S_0)D}{d(l - \cos\varphi)}$$

where $S_m$ is the measured reaction force for this position, and $\varphi$ the angle with the horizontal.

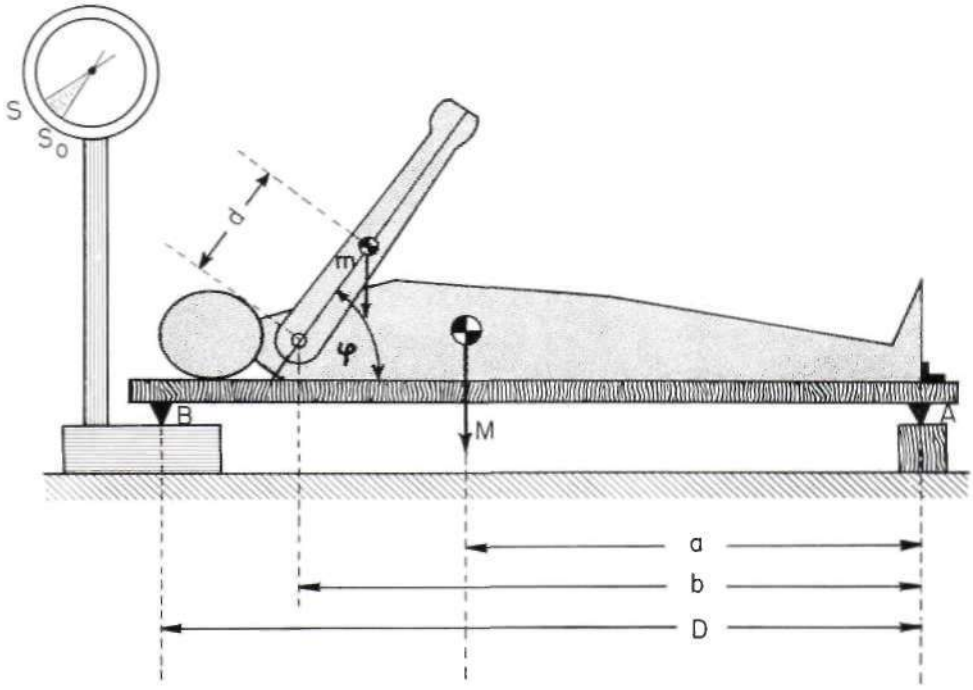



Fig. 12. Determination of the arm mass (reaction board method).

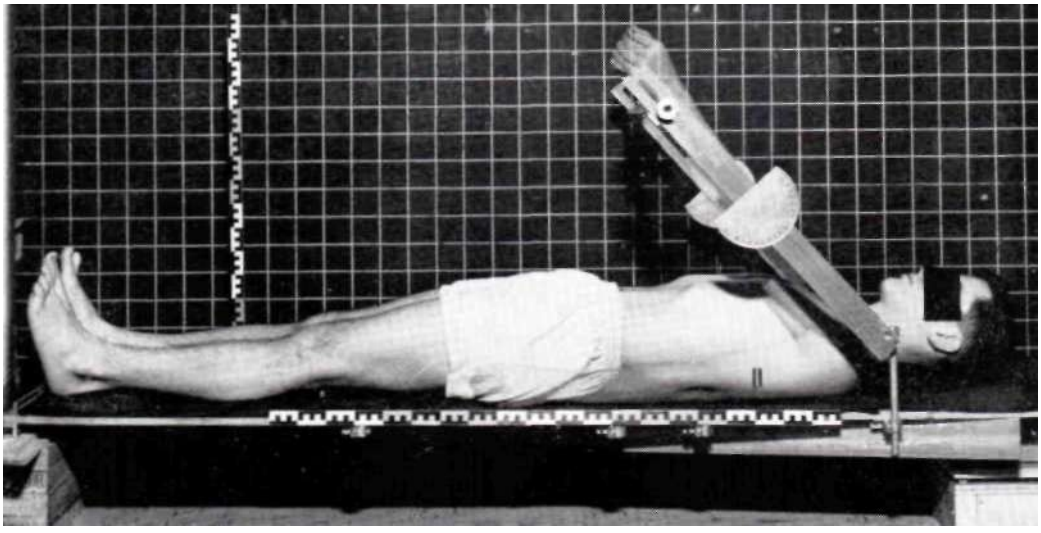


Fig. 13. Reaction board with supporting frame.

By replacing the sensitive scale with an electrical pressure cell or using one force plate, it is also possible to record the changing reaction forces. If the subsequent positions of the whole arm or forearm in flexion are optically fixed as in Stick Diagrams, the corresponding changing reaction forces can be recorded by electrical oscillograph.

It is assumed that in flexion the elbow ioint has only one degree of freedom, *i.e.,* it is uniaxial; hence the mass determination of forearm and hand is comparatively simple. The shoulder joint has several degrees of freedom and for each arm position the center of rotation changes its location so that the successive loci describe a path of the instantaneous centers. If the displacement *(e)* of the instantaneous center in the horizontal direction is known from the Slick Diagram, the magnitude of the segment mass will be

$$m = \frac{(S_m - S_c)D}{d(1 - \cos\varphi) + e}$$

where $S_m$ is the corresponding reaction force for the given position of the segment.

QUICK RELEASE METHOJD

This technique for the determination of segment moments of inertia is based on Newton's Law for rotation. This law states that the

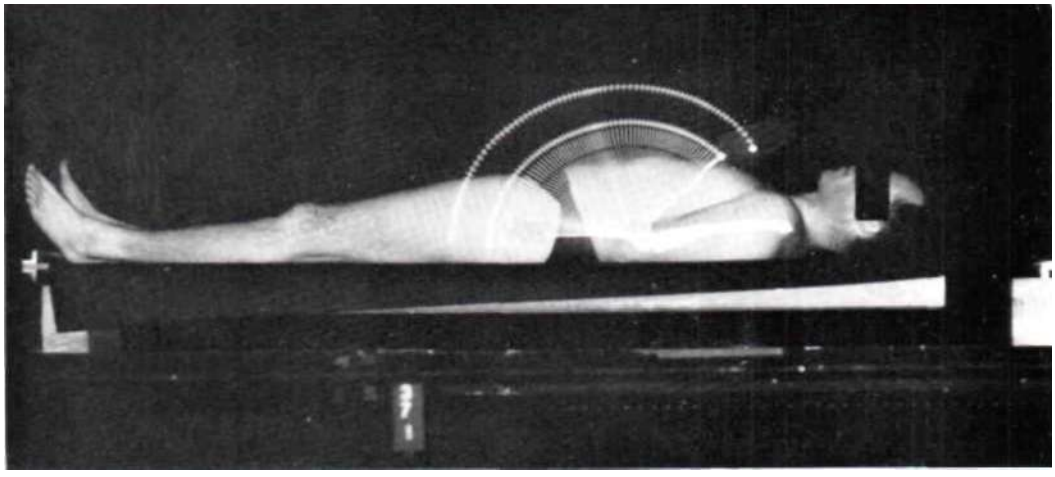


Fig. 14. Stick diagram of forearm flexion.

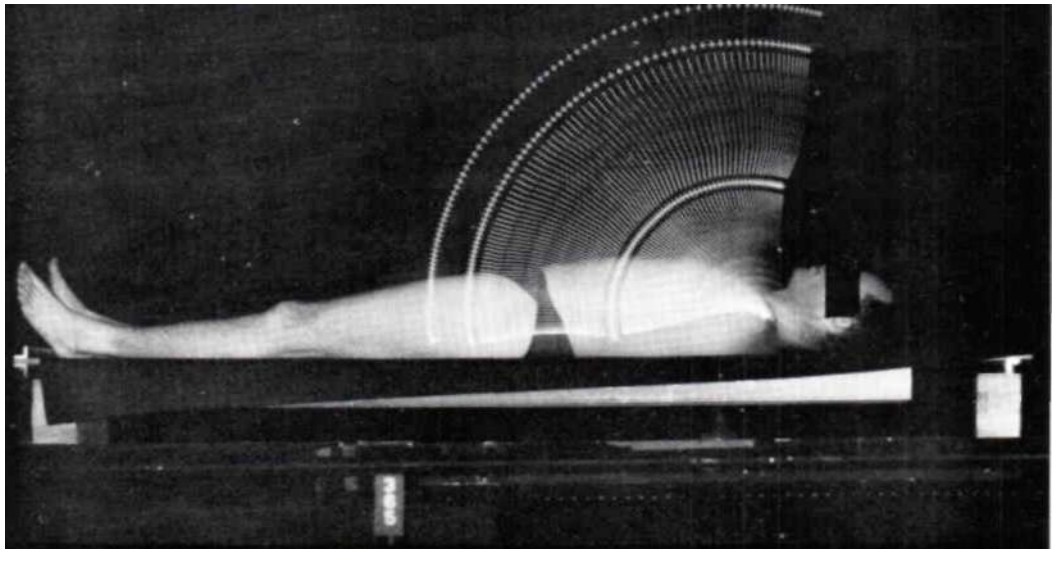


Fig. 15. Stick diagram **of** arm **flexion.**

torque acting on a body is proportional to its angular acceleration, the proportionality constant being the mass moment of inertia. Thus if the body segment, say the arm, can be made to move at a known acceleration by a torque which can be evaluated by applying a known force at a given distance, its moment of inertia could be determined. Such a procedure is the basis for the so-called "quick release" method.

To determine the mass moment of inertia of a body segment, the limb is placed so that its proximal joint does not move. At a known distance from the proximal joint at the distal end of the limb, a band with an attached cord or cable is fixed. The subject pulls the cord against a restraint of known force, such as a spring whose force can be found by measuring *its deflection.* The activating torque about the proximal joint is thus proportional to the force and the distance between the joint and the band (moment arm). The acceleration of the limb is produced by sharply cutting the cord or cable. This instantaneous acceleration may be measured by optical or electrical means and the mass moment of inertia about the proximal joint determined.

This technique is illustrated in Figure 16. The subject rotates his forearm about the elbow, thereby pulling against the spring shown at the right through a cord wrapped around a pulley. The mechanism on the platform to the right contains the cutter mechanism with an engagement switch which activates the circuit of the two accelerometers mounted on the subject's forearm. The potentiometer at the base of the spring records the force by measuring the spring's deflection. The accelerometers in tandem give the angular acceleration of the forearm and hand at the instant of cutting. A scale is used to determine the moment arm of the force. This method is further discussed by Drillis (1959).

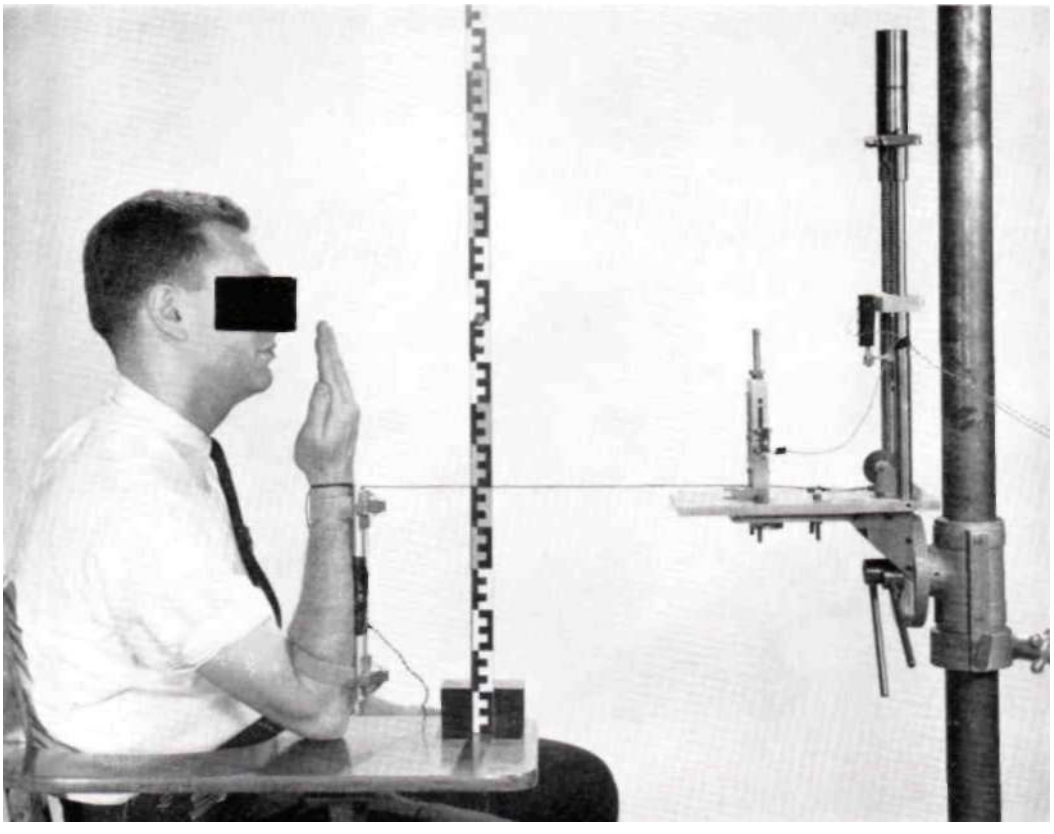


Fig. 16. Quick release method.

COMPOUND PENDULUM METHOD

This technique for finding both mass moment of inertia of the segment and center of mass may be used in one of two ways: (1) considering the segment as a compound pendulum and oscillating it about the proximal joint, and (2) making a casting of plaster of Paris or dental stone and swinging this casting about a fixed point.

Using the first method, it is necessary to find the moment of inertia, the effective point of suspension of the segment, and the mass center; thus, there are three unknown quantities.

A study by Nubar (1960) showed that these unknowns may be obtained if it is assumed that the restraining moment generated by the individual is negligible. In order to simplify the calculations, any damping moment (resulting from the skin and the ligaments at the joint) is also neglected. The segment is then allowed to oscillate, and its period, or time for a complete cycle, is measured for three cases: (1) body segment alone, (2) segment with a known weight fixed to it at a known point, (3) segment with another known weight fixed at that point. Knowing these three periods and the masses, one can find the effective point of suspension, the center of mass, and the mass moment of inertia from the three equations of motion. If the damping moment at the joint is not negligible, it may be included in the problem as a viscous moment. The above procedure is then extended by the measurement of the decrement in the succeeding oscillations.

In the second procedure, the casting is oscillated about the fixed suspension point. The moment of inertia of the casting is found from the measurement of the period. The mass center can also be determined by oscillating the segment casting consecutively about two suspension points. This method is described in detail by Drillis *el al.* (1963). Since the weight of both the actual segment and cast replica can be found, the measured period can be corrected on the basis of the relative weights to represent the desired parameter (mass center or mass moment of inertia) of the actual segment. The setup for the determination of the period of oscillation is shown in Figure 17.

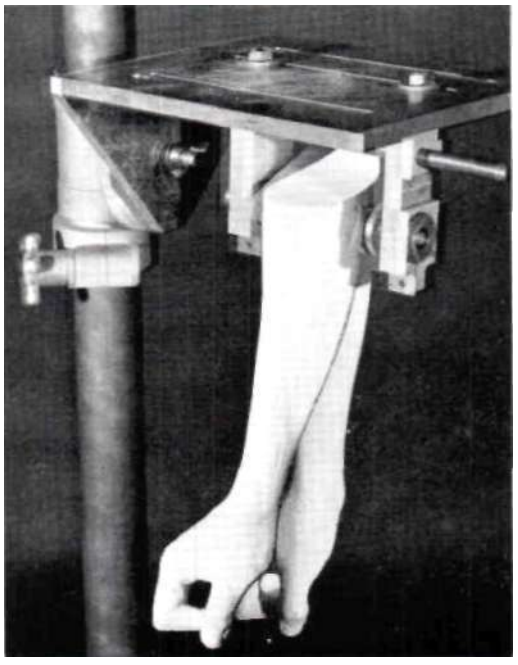


Fig. 17. Compound pendulum method.

The photograph in Figure 17 has been double-exposed to illustrate the plane of oscillation.

TORSIONAL PENDULUM METHOD

The torsional pendulum may be used to obtain moments of inertia of body segments and of the entire body. The pendulum is merely a platform upon which the subject is placed. Together they oscillate about a vertical axis. The platform is restrained by a torsion bar fastened to the platform at one end and to the ground at the other. Knowing the physical constants of the pendulum, *i.e.,* of the supporting platform and of the spring or torsion bar, the measurement of the period gives the mass moment of inertia of the whole body. The principle of the torsional pendulum is illustrated schematically in Figure 18.

Figures 19 and 20 describe the setup in use. There are two platforms available: a larger one for studying the supine subject and a smaller one for obtaining data on the erect or crouching subject. In this way, the moments of inertia for both mutually perpendicular axes of the body can be found.

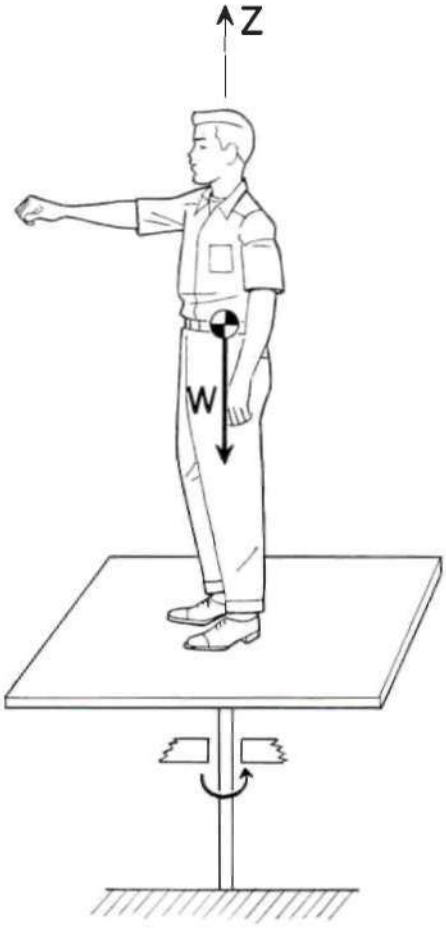



Fig. 18. Torsional pendulum method.

Figure 19 shows a schematic top view of the subject lying supine on the large table. Recording the period of oscillation gives the mass moment of inertia of the body about the sagittal axis for the body position indicated. Figure 20 is a side view of the small table used for the standing and crouching positions. This view shows the torsion bar in the lower center of the picture encased in the supporting structure.

This method can also be used to find mass moments of inertia of body segments. Nubar (1962) describes the necessary procedure and equations. Basically it entails holding the rest of the body in the same position while oscillating the system for two different positions of the segment in question. Knowing the location of the segment in each of these positions, together

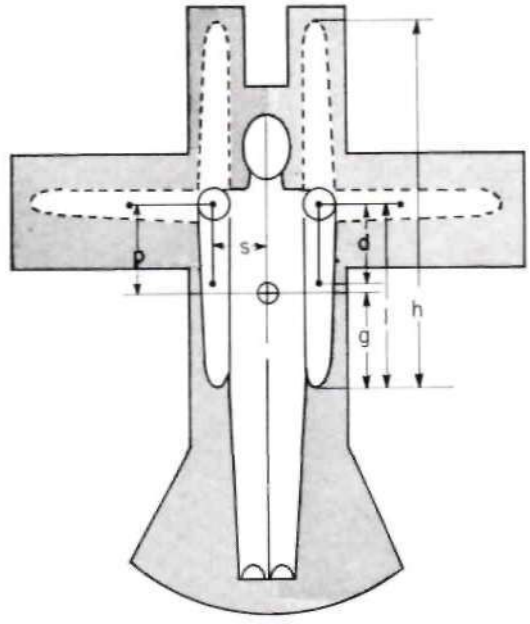



Fig. 19. Body dimensions on torsion table.

with the periods of oscillation of the pendulum, the segment moment of inertia with respect to the mediolateral centroidal axis may be found. This technique is illustrated by the schematic Figure 19 for the case of the arm. The extended position is shown; the period would then be obtained for the case where the arm is placed down at the subject's side.

Both the mass and center of mass of the arm can be determined using the large torsion table. The table and supine subject are rotated for three arm positions—arms at sides, arms outstretched, and arms overhead—and respective total moments of inertia are found from the three periods of oscillation. Assuming that the position of the longitudinal axis of the arm can be defined, *i.e.,* the axis upon which the mass center lies can be clearly positioned, the following equations may be applied:

$$d = \frac{I_2[h(2g + 2l - h) - 4lg] - I_1[p^2 - (h - l - g)^2] - I_3[(l - g)^2 - p^2]}{2I_1(l + g + s - h) + 2I_2(h - 2g) + 2I_3(g - l - s)}$$

$$\text{arm mass} = \frac{I_2 - I_1}{2[p^2 - (l - g)^2 - 2d(g - l - s)]}$$

where *I1, I2, I3* are the total moments of inertia of table, supports, and subject, found from

Fig. 20. Mass moment of inertia determination (squatting position).

the periods of oscillation, for the subject with arms at sides, outstretched, and overhead, respectively.

$h$ is the distance from middle fingertip when arms are at the sides to the tip when arms are overhead.

$l$ is the total arm length (fingertip to shoulder joint).

$g$ is the distance from middle fingertip to the lateral center line of the table when the arms are at the sides.

$p$ is the distance from middle fingertip to the lateral center line when the arms are outstretched.

$s$ is the distance between the longitudinal center line of the table and the longitudinal axis of the arm when the arms are at the sides.

$d$ is the distance between the mass center of the arm and the shoulder joint.

In this case, the subject is placed so that his total body mass center coincides with the table's fixed point of rotation and there are no initial imbalances. The explanation of the above symbols may be clarified by reference to Figure 19.

## DIFFICULTIES IN OBTAINING PROPER. DATA

In the commonplace technical area, where it has been necessary to evaluate the volume, mass, center of mass, etc., of an inanimate object, this object is usually one of fixed dimensions; that is, there is no involuntary movement of parts. The living human organism, on the other hand, is totally different in that none of its properties is constant for any significant period of time. There are differences in standing erect and in lying down, in inhaling and in exhaling, in closing and in opening the hand. It is necessary, therefore, to develop a procedure of measurement which can contend with these changes, and to evaluate data with particular reference to a specified orientation of the body.

One ever-present problem in dealing with the body is the location of joints. When a segment changes its attitude with respect to adjacent segments (such as the flexion of the elbow), the joint center or center of rotation shifts its position as well. Thus, in obtaining measurements on body segments, it is necessary to specify exactly what the boundaries are. As yet there is no generally accepted method of dividing the body into segments.

When an attempt is made to delineate the boundary between segments for purposes of experimental measurement, one cannot avoid the method of placing a mark on the subject at the joint. This mark will have to serve as the segment boundary throughout the experiment. Unfortunately an error is introduced here when the elasticity of the skin causes the mark to shift as the subject moves. This shift does not correspond to a shift in the actual joint.

In an analysis of a particular body segment involving movement of the segment, such as the quick release, reaction, and torsional pendulum methods which have been described, one must take care to ensure that only the segment moves. Usually this involves both physical and mental preparations on the part of the subject.

Finally, the greatest error in obtaining results on body parameters is due to variations in body build. As can be seen from the previous data brought forth, different researchers using identical techniques have gotten quite dissimilar data on the same body segment due to the use of subjects with greatly varying body types.

In an effort to resolve this conflict, the Biomechanics group at New York University is endeavoring to relate their data on body segment parameters to a standard system of body typology.

## ANTHROPOMETRIC STUDIES

In order to develop a means of classifying the subjects according to body build, the method of somatotyping is utilized. Here the body build is designated according to relative amounts of "endomorphy, ectomorphy, and mesomorphy" as described by W. H. Sheldon *et al.* (1940, 1954) in the classic works in the field. In order to determine the subject's somatotype, photographs are taken of three views: front, side, and back. These are illustrated in Figure 21.

The Biomechanics group of New York University has obtained the services of an authority in the field, Dr. C. W. Dupertuis, to establish the somatotype of the subjects. The photographs also will be used to obtain certain body measurements.

The aim of the study is to develop relationships between body parameters and body build or important anthropometric dimensions so that a pattern will be established enabling body parameters to be accurately found for all body types.

If sufficient subjects are measured it should be possible to obtain a set of parameter coefficients which take into consideration the effect of the particular body type. When these coefficients are applied to some set of easily measurable body dimensions on any new subject, the appropriate body parameters could easily be determined.

It is planned to prepare tables of these body parameter coefficients (when their validity has been established) for some future edition of *Artificial Limbs.*

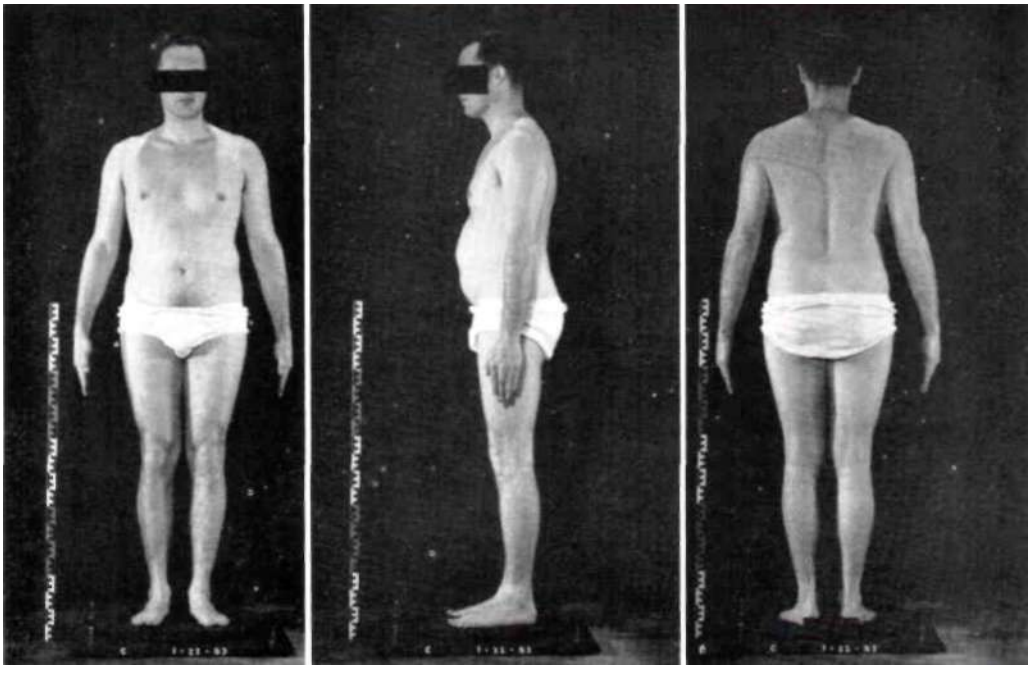


Fig. 21. Photographs for somatotyping.

## BIBLIOGRAPHY


1. Amar, J., *Le moteur humain,* Paris, 1914.
2. Bashkirew, P. N., *Human specific gravity in the light of its practical importance to anthropology and medicine* (in Russian). Soviet Anthropology, 2 (2): 95-102, Moscow, 1958.
3. Bernstein, N. A., O. A. Salzgeber, P. P. Pavlenko, and N. A. Gurvich, *Determination of location of the centers of gravity and mass of the limbs of the living human body* (in Russian), All-Union Institute of Experimental Medicine, Moscow, 1936.
4. Boyd, E., *The specific gravity of the human body,* Human Biology, 5: 646-672, 1933
5. Braune, W., and O. Fischer, *The center of gravity of the human body as related to the equipment of the German infantryman* (in German), Treat. of the Math.-Phys. Class of the Royal Acad. of Sc. of Saxony, 26: 1889.
6. Contini, R., R. Drillis, and M. Bluestein, *Determination of body segment parameters,* Human Factors, 5 (5): 1963.
7. Dempster, W. T., *Space requirements of the seated operator,* USAF, WADC, Tech. Rep. 55-159, Wright-Patterson Air Force Base, Ohio, 1955.
8. Drillis, R., *The use of gliding cyclograms in the biomechanical analysis of movement,* Human Factors, 1 (2): 1959.
9. Du Bois, J., and W. R. Santschi, *The determination of the moment of inertia of the living human organism,* paper read at the International Congress on Human Factors in Electronics, Institute of Radio Engineers, Long Beach, Calif., May 1962.
10. Fischer, 0., *Theoretical fundamentals of the mechanics of living bodies* (in German), Berlin, 1906.
11. Harless, E., *Textbook of plastic anatomy, Part III* (in German), Stuttgart, 1858.
12. Harless, E., *The static moments of human limbs* (in German), Treatises of the Math.-Phys. Class of the Royal Acad. of Sc. of Bavaria, 8: 69-96 and 257-294, 1860.
13. Hertzberg, H. T., C. W. Dupertuis, and I. Emanuel, *Stereophotogrammetry as an anthropometric tool,* Photogrammetric Engineering, 24: 942-947, 1957.
14. Ivanitzkiy, M. F., *Human anatomy* (in Russian); Part I, 3rd ed., Moscow, 1956.
15. Meeh, C, *Volummessungen des menschlichen Korpers und seiner einzelner Teile in der verg-chiedenen Altersstufen,* Ztschr. fur Biologie, 13: 125-147, 1895.
16. Nubar, Y., *Determination of characteristics of the compound pendulum by observing oscillations,* unpublished report, Research Division, College of Engineering, New York University, 1960.
17. Nubar, Y., *Rotating platform method of determining moments of inertia of body segments,* unpublished report, Research Division, College of Engineering, New York University, 1962.
18. Pierson, W. F., *The validity of stereophotogrammetry in volume determination,* Photogrammetric Engineering, 25: 83-85, 1959.
19. Salzgeber, O. A., *Method of determination masses and location of mass centers of stumps* (in Russian), Transact. Scient. Research Inst. of Prosthetics in Moscow, 3: Moscow, 1949.
20. Sheldon, W. H., S. S. Stevens, and W. B. Tucker, *The varieties of human physique,* New York, 1940.
21. Sheldon, W. H., C. W. Dupertuis, and C. McDermott, *Atlas of men,* New York, 1954.
22. Steinhausen, W., *Mechanik d. menschlichen Korpers,* in Handbuch d. Normalen n. pathologischen Physiologie, 14: 1926-1927.
23. Tanner, J. M., and J. S. Weiner, *The reliability of the photogrammetric method of anthropometry, with a description of a miniature camera technique,* Am. J. Phys. Anthrop., 7: 145-186, 1949.
24. Weinbach, A. P., *Contour maps, center of gravity, moment of inertia, and surface area of the human body,* Human Biology, 10 (3): 356-371, 1938.
25. Wild, T., *Simplified volume measurement with the polar planimeter,* Surveying and Mapping, 14: 218-222, 1954.
26. Zook, D. E., *The physical growth of boys,* Am. J. Dis. Children, 1930.
27. Zook, D. E., *A new method of studying physical growth,* Junior-Senior High-School Clearing House, 5: 1932.

# The Status of Limb Prosthetics as a Part of Orthopedic Residency Training

## A Report on a Questionnaire Survey

HAROLD W. GLATTLY, M.D.[1]

At the time the Committee on Prosthetics Education and Information (now the Committee on Prosthetic-Orthotic Education) of the National Academy of Sciences was organized in the spring of 1958, relatively few orthopedic residency programs included training in limb prosthetics. Although prosthetics had always been associated with medicine, it is only in very recent times that this subject has become a part of the medical education process. As a result of a number of factors, in the past five years a radical change has come about in the attitude of organized orthopedics toward amputation as a form of disability for which that specialty is responsible. With each passing year, more questions relating to prosthetics have been included in the orthopedic specialty board examinations.

In the interest of determining the present status of amputee care and management as a part of orthopedic residency programs, the Committee on Prosthetic-Orthotic Education (CPOE), in cooperation with the American Board of Orthopaedic Surgery, conducted a questionnaire survey of all the orthopedic residency programs in the United States. A cover note, signed by Doctor Charles Herndon as President of the Board, with an enclosed form, was sent to all training chiefs who are listed in the Directory of Approved Internships and Residencies, published annually as a supplement to the education number of the *Journal of the American Medical Association.* The results of this survey are presented here in tabular form:

| | |
|---|---|
| Total Forms Distributed | 286 |
| Questionnaires Returned | 257 (90 per cent) |

QUESTION # 1:

Do your residents receive training in limb prosthetics?

Yes 224 (88 per cent of returned forms)

No 33

(21 chiefs who answered "No" outlined plans for initiating prosthetics training in their programs in the near future.)

QUESTION #2:

In what year was training in prosthetics made a part of your residency program?

(This question was misinterpreted by two thirds of the respondents as referring to the first-, second-, or third-year level of training. A high percentage who answered correctly indicated that they had initiated this training during the past three years.)

QUESTION #3:

Does training in prosthetics include:

a. Attendance by your residents at an organized prosthetics clinic?

Yes 189 (84 per cent of the 224 programs that conduct prosthetics training)

No 35

(7 chiefs who answered "No" are organizing prosthetics teaching clinics.)

If "Yes," is the clinic organized within the Department of Orthopedic Surgery Yes 139

Department of Physical Medicine Yes 23

Jintly operated Yes 27

b. Attendance by your residents at the prosthetics courses for physicians available at the University of California at Los Angeles, New York University, and Northwestern University?

Yes 115

No 109

[1] Executive Secretary, Committee on Prosthetic-Orthotic Education, Division of Medical Sciences, National Academy of Sciences—National Research Council. This Committee is jointly supported by the Training Division, Vocational Rehabilitation Administration, Department of Health, Education, and Welfare, and the Prosthetic and Sensory Aids Service, Veterans Administration.

(59 chiefs who answered "No" indicated a desire to send their residents to these courses if funds were available. The number of residents they desire to send annually for a course totaled 410. This is about 90 per cent of the 450 third-year residents now in training throughout the country.)

## COMMENTS

Two hundred seven of the chiefs, or 80 per cent of those who returned the questionnaire, submitted comments bearing upon the subject of the form. Their remarks related to the following items, and typical quotations are included here.

1. *The essentiality of training orthopedic residents in the modern concepts of amputee care and management.*

"I am enthusiastically behind the Board of Orthopaedic Surgery actively participating in and developing the prosthetics field in every training program."

*2. The importance of having a teaching prosthetics clinic available.*

"Unless there is an active prosthetics clinic within the hospital, proper training cannot be conducted. The university short courses are excellent, but the resident should have continuous exposure."

"Large centers with good amputee clinics should invite residents of other hospitals to attend on a regular basis."

3. *Value of the university short prosthetics courses.* (The comments emphasized the fact that these courses systematized the resident's knowledge.)

"It is my firm opinion that residents who have been able to have the experience of attending one of the courses at New York or Chicago have gained considerably in their understanding, attention, and interest. Some of our residents have already attended one of these courses prior to coming to us, and those that have not are encouraged to attend."

"We insure that our staff members are checked out through the university prosthetics courses."

"While it is a problem to get the men away, I feel that the limb courses have provided a vital part of our prosthetics training program."

4. *The problem of financinq the attendance of their residents at the university courses.*

"At present we cannot afford to send our residents to the established courses at UCLA, NYU, or Northwestern. We are striving to train our staff to initiate a local prosthetics program."

5. *Intramural prosthetics courses.*

"We are initiating a three-day program in prosthetics including surgical management. This course will be given twice yearly by our attending staff."

"We have set up an organized program in prosthetics for residents each year. The subject matter rotates on a four-year basis so that each resident will get at least four of these intramural courses. The faculty consists of our staff and a local prosthetist."

6. A few chiefs preferred the two-week combined upper- and lower-extremity course, such as is now given at UCLA.

7. *Expedients for residents who cannot attend the university courses.*

"The three prosthetics schools cannot handle all orthopedic residents. As an alternate for those who cannot attend, perhaps some type of course given regionally should be considered."

"Instructional courses for residents at the annual American Academy of Orthopaedic Surgeons meeting would be valuable."

8. *Miscellaneous Comments.*

"It is our belief that orthopedic surgeons should make the diagnosis of the condition that would require amputation; then do the surgery at the correct level, after having the patient on a pre-amputation program, and then place the patient on a pre-prosthetics program. The orthopedic surgeon should order the prosthesis and work with the brace and limbmaker and supervise the training of the patient after he has his prosthesis."

"One of the great fallacies in this program arises from the fact that probably 95 per cent of all amputations are performed by general surgeons whose interest in rehabilitation is ever so slight or lacking. I would look forward to the time when everyone who is knowledgeable will alter this sad situation."

9. There were only three of the 257 forms that contained remarks that were critical concerning the prosthetics training of residents.

"Prosthetics is important! So are hand surgery and physical medicine. They are all important! How much should the Board cover?"

"Judging by my experience in private practice, it appears to me that the emphasis on prosthetics training is greater than the amount of work one encounters justifies."

"I do not feel that intensive training in prosthetics is necessary. I would have difficulty in finding time for it in view of the great amount of other subjects that must be covered during the residency."

(All three of the above-quoted chiefs are sending or plan to send residents to the university courses.)

This survey documents the fact that limb prosthetics is now an integral part of medical education. Organized orthopedics can therefore be depended upon to conduct an effective "grass-roots" type of prosthetics education program to familiarize the surgeons throughout the country concerning the modern concepts of amputee care and management. The many newly organized prosthetics clinics will be an effective instrument in this endeavor.

# News and Notes

### Twelfth Meeting of CPRD

The Twelfth Meeting of the Committee on Prosthetics Research and Development was held in the National Academy of Sciences Building in Washington, D. C, on December 12 and 13, 1963.

Guests attending the meeting included representatives from the leading orthotics development centers in the United States invited for the purpose of assisting in the initiation of a pilot evaluation program for orthotic devices and procedures. The proposed evaluation program was discussed at length. It was the consensus of the Committee that NYU should proceed with the orthotics evaluation program, using the following items: the VAPC PTB brace, the UCSF shoe inserts, and the Baylor University and the University of Michigan hand splints.

There were reports from liaison representatives: Dr. Harold W. Glattly, for the Committee on Prosthetic-Orthotic Education (formerly the Committee on Prosthetics Education and Information); Dr. Eugene F. Murphy, for the Veterans Administration; and Dr. Philip L. Williams, for the Vocational Rehabilitation Administration.

Dr. J. Warren Perry, of VRA, made a presentation on the University Council on Orthotic-Prosthetic Education, explaining that its members are the Educational Directors and the Medical Directors (three of each) of the Prosthetics-Orthotics Education Schools at UCLA, NU, and NYU, and that he serves as secretary of the Council.

Dr. Perry said that the first standardized test for physicians in prosthetics and orthotics has just been completed. He also said that UCOPE is concerned because problems related to total-contact sockets and techniques are still unresolved.

One problem in the evaluation of total-contact sockets has been the lack of means to obtain accurate measurement of pressures between socket and stump. There were indications at this meeting of CPRD that a solution for this problem may be forthcoming. Mr. Anthony Staros said that the VA Prosthetics Center hopes to have available in the near future a simple hydraulic method for measurement that may be useful as a clinical instrument. Dr. James B. Reswick demonstrated a pressure-measuring device developed at Case Institute which he believes utilizes a technique applicable to the measurement of pressures inside a socket.

Reports were received from the three standing Subcommittees: the Subcommittee on Child Prosthetics Problems, the Subcommittee on Design and Development, and the Subcommittee on -Evaluation.

Despite its increasing activities in orthotics, CPRD decided to retain its name for the time being. Because of growing interest in bioengineering on the part of the Division of Engineering and Industrial Research, it was thought that a change in name at this time might be premature.

At the instigation of the Chairman, there was considerable discussion of whether CPRD is doing all that is within its capabilities. Two questions were discussed rather fully: *First,* should the Committee be more inclusive in nature; that is, should it become a Committee on Bioengineering? *Second,* can the Committee clarify its function as it exists at present?

Concerning the first question, there was a keen awareness that, now that infectious diseases have been largely overcome, there will be an increasing need for assistive devices of various kinds (in addition to limb prosthetics and orthopedic braces). There obviously is a real need for national leadership—such as NAS—NRC is capable of giving—in the bioengineering effort to develop such devices.

Concerning the second question, it was believed that, to some extent, a clarification of function has been undertaken by the Subcommittee on Evaluation by the establishment of a task force on currently acceptable prosthetic and orthotic devices and techniques and another task force to devise a numerical system for rating prosthetic and orthotic devices.

It was decided that the next meeting of CPRD would be coordinated with Government agencies so as to give timely recommendations on various proposals.

### Thirteenth Meeting of CPRD

The Thirteenth Meeting of the Committee on Prosthetics Research and Development

was held at Case Institute of Technology in Cleveland, Ohio, on April 23 and 24, 1964.

The members of CPRD were welcomed to Case Institute by Dr. John A. Hrones, the Institute's Vice President for Academic Affairs, and Dr. Ray Bolz, Head of Engineering Research at the Institute. A number of faculty members attended the meeting.

The entire morning of April 24 was devoted to a presentation on current research projects in bioengineering being conducted at Highland View Hospital under the auspices of Case Institute of Technology. The projects, which are being conducted in the Department of Physical Medicine and Rehabilitation and the Metabolic Research Facility of Highland View Hospital, include engineering analysis of motor activities as a cybernetic system, telemetric devices for activation of paralyzed muscles, kinesiophysiological studies of muscles, and clinical evaluation. Following the presentation by members of the Case Institute faculty and the staff of Highland View Hospital, the members of CPRD were conducted on a tour to see many of the projects, including the Case Research Arm-Aid, at first hand.

Dr. Sidney Fishman, in the absence of Dr. J. Warren Perry, spoke briefly on the University Council on Orthotic-Prosthetic Education. He emphasized the uniqueness of the instruction offered at each of the three Prosthetics-Orthotics Education Schools: Northwestern University offers special courses in spinal orthotics and business administration; the University of California at Los Angeles offers a two-week survey course for physicians and surgeons and a six-month program for young prosthetists and orthotists; and New York University offers a B.S. program in prosthetics and orthotics, in addition to emphasizing lower-extremity orthotics.

Dr. Harold W. Glattly, Executive Secretary of the Committee on Prosthetic-Orthotic Education, reviewed the changing mission of CPOE since it was organized in 1958. At that time, prosthetics was not considered an area for which orthopedics was responsible. Now, however, prosthetics is a part of medical education and is included in orthopedic residency training. Consequently, CPOE can devote its energies to clinical studies throughout the country, to follow-up studies, and to such projects as the so-called Amputee Census.

Mr. Victor T. Riblett briefly reviewed the history of the Army Medical Biomechanical Research Laboratory and described its organization into two major divisions: mechanical and chemical. He mentioned the progress of current projects and described their wide diversity.

Mr. Charles Asbelle described some of the projects currently in progress at the Navy Prosthetics Research Laboratory. One recent development at NPRL is an accelerated procedure for brace production which consists of three parts: a tracing method, utilizing a tilting table and diazo paper; a forming method, utilizing a hydraulic unit; and a finishing method, utilizing dipping into a liquid plastic. Other recent developments include a variable-cadence knee unit, an inexpensively molded artificial foot, and an air-escape valve for total-contact, above-knee sockets.

The immediate postsurgical fitting of lower-extremity amputees was a subject of major interest. Dr. Thomas M. Hart, of the Department of Orthopedic Surgery at the University of California at San Francisco, described the application of immediate postoperative fitting techniques at the San Francisco General Hospital. Commander Frank Golbranson, Medical-Officer-in-Charge, Navy Prosthetics Research Laboratory, showed a motion-picture film in color depicting his handling of patients on whom immediate postoperative fitting techniques were employed. He said that four patients had been treated at NPRL, and the results are most encouraging, from both the physiological and the psychological standpoints. Postoperative fitting techniques have also been employed with some success at the Hospital for Joint Diseases in New York City. The Veterans Administration Hospital in Seattle, Wash., intends to embark on an extensive study of the procedure. To coordinate all these studies, CPRD is forming an *ad hoc* committee with Dr. Verne T. Inman as Chairman. One of the first tasks of the *ad hoc* group will be to devise a checklist and data-collecting instruments so that results from all centers participating can be correlated properly. Another goal is the development of criteria for the

design of the temporary prostheses that will be required.

Mr. Colin A. McLaurin, Chairman of the Subcommittee on Design and Development, reported that since the Twelfth Meeting of CPRD there had been two meetings of the Subcommittee and meetings of three workshop panels (Lower-Extremity Fitting, Lower-Extremity Components, and Upper-Extremity Fitting, Harnessing, and Power Transmission). Altogether, Mr. McLaurin said, some 50 persons have participated in workshop panel meetings. In summarizing the work of the Subcommittee on Design and Development, Mr. McLaurin said the Subcommittee fosters communication, offers guidance to persons engaged in prosthetics design, and submits specific recommendations for the consideration of CPRD.

Professor Herbert R. Lissner, Chairman of the Subcommittee on Evaluation, reported that since the Twelfth Meeting of CPRD two task forces of the Subcommittee have been active. One task force is charged with listing currently acceptable prosthetic and orthotic devices. The other task force is concerned with the development of a numerical system for rating prosthetic and orthotic devices.

In the absence of Dr. Charles H. Frantz, Dr. Fishman gave an informational report on the activities of the Subcommittee on Child Prosthetics Problems.

In its executive session, CPRD reviewed proposals made to the Veterans Administration for research contracts, upon which the Committee's recommendations were desired by VA. Also, it was decided that, pursuant to a request from VA that the National Academy of Sciences give advisory assistance in the field of sensory aids for the blind and deaf, CPRD will create, commencing July 1, 1964, a Subcommittee on Sensory Aids which will have representatives on it from the Division of Behavorial Sciences, NAS—NRC.

**Annual Meeting for 1963 of CPEI and the Subcommittee Activities**

The annual meeting of the Committee on Prosthetics Education and Information [now the Committee on Prosthetic-Orthotic Education (CPOE)] was held in the National Academy of Sciences Building in Washington, D. C, on October 26, 1963. In addition to the members of CPEI, there were present some 15 guests, representing federal and nonfederal agencies and organizations with which CPEI has overlapping interests. Dr. C. Leslie Mitchell, Chairman of CPEI, greeted the group and introduced Dr. R. Keith Cannan, Chairman of the Division of Medical Sciences. NAS—NRC, who counseled the group to review their program critically in the light of present prosthetics educational needs, pointing out that a purely educational or informational program is not normally a proper function of an NAS—NRC committee. When CPEI was organized in 1958, a need existed for a neutral group, such as characterizes an NAS—NRC committee, to work with other agencies and organizations in a national effort to inform medical and paramedical groups concerning the results of the prosthetics research program. As organized medicine, especially orthopedics, assumes responsibility for the dissemination of this knowledge, the efforts of CPEI can very well undergo a transition in which increased emphasis will be given to collecting basic data and recording clinical experience—a true function of an NAS—NRC committee.

The meeting proceeded with the reports of the chairmen of the three subcommittees and a detailed discussion of their activities and projects. The discussion included the following items that have general interest:

1. Although the prosthetics teaching needs in undergraduate and postgraduate education have verv materially lessened in the past five years, the efforts of the Subcommittee on Prosthetics in Medical Education, chairmanned by Dr. J. Hamilton Allan, should continue to develop teaching material. Items already available are in demand by instructors in medical schools, residency programs, and schools of physical and occupational therapy. New teaching aids being developed by Dr. Allan's group include sets of slides, brochures, and films.
2. The Subcommittee on Prosthetics in Paramedical Education, chairmanned by Miss Dorothy Baethke, is presently interested in improving the prosthetics

training of physical therapists, occupational therapists, rehabilitation nurses, and social workers. Recognizing the important role in amputee rehabilitation that is played by vocational rehabilitation counselors, CPEI, in approving the program of this Subcommittee, voted to add the prosthetics educational needs of this discipline to the interests of Miss Baethke's group.

3. Dr. Roy M. Hoover, Chairman of the Subcommittee on Prosthetics Clinical Studies, discussed the value of the basic data collected on more than 12,000 new amputees in a two-year period from some 200 prosthetics facilities that participated in the Amputee Census. A preliminary report on this project ippeared in the Spring 1963 issue of *Artificial Limbs.* The data brought to light certain problem areas that need further study. Of special significance is the fact that this project demonstrated that the prosthetics facilities of this country offer a practical source for certain categories of prosthetics information that can be collected in a relatively short period of time and be based upon a large number of amputees. The Conference of Prosthetists, now being formed within the organizational framework of the American Orthotics and Prosthetics Association, will provide a group to work with CPEI. In approving the program of the Subcommittee on Prosthetics Clinical Studies, CPEI recommended that an effort be made to study the results of amputations at a number of hospitals, such as the study recently completed at the Massachusetts General Hospital.
4. The educational needs in the field of orthotics were explored by CPEI with respect to areas wherein the Committee could be of assistance. Although nothing specific was decided upon, the interest of the members in orthotics was evidenced by their unanimous decision to change the name of the Committee from the Committee on Prosthetics Education and Information (CPEI) to the Committee on Prosthetic-Orthotic Education (CPOE).

During the Annual Assembly of the American Academy of Orthopaedic Surgeons at the Palmer House in Chicago, Ill., eight members of the CPOE Subcommittee on Prosthetics Clinical Studies were present at an informal meeting called by the Subcommittee Chairman, Dr. Hoover, on January 20, 1964. Various items in the study data forms were discussed by the group and recommendations were made for their clarification and completion. Mrs. Barbara Friz reported on the current status of the study. New members attending the meeting included: Dr. Robert Mazet, Jr., Los Angeles, Calif.; Dr. Edward T. Haslam, Tulane University; Dr. Herbert E. Pederson, Wayne University; and Dr. Garth E. Russell, University of Missouri.

The annual meeting of the CPOE Subcommittee on Prosthetics in Paramedical Education was held at the University of California, Los Angeles, Calif., April 27-28, 1964, under the chairmanship of Miss Dorothy Baethke. All members were present and reports were received from each paramedical group, as follows: Colonel Ruth A. Robinson, occupational therapy; Mrs. Florence Linduff, physical therapy; Mrs. Barbara Madden, rehabilitation nursing; and Mrs. Enolia Archinard, social work. Miss Martha Matthews and Miss Margaret Kohli, *ex officio* members, represented the Education Council of the American Occupational Therapy Association and the Council on Physical Therapy School Directors, respectively.

Considerable time was devoted to discussing the educational needs of the paramedical professions in the field of orthotics. Dr. Jacquelin Perry, of the Rancho Los Amigos Hospital, discussed the current status of spinal orthotics and the principles of lower- and upper-extremity bracing. Modern teaching methods were discussed by Dr. Miles Anderson, Director of UCLA Prosthetics-Orthotics Education. The application of programmed instruction to prosthetics and orthotics subjects was considered by members of the Subcommittee.

Miss Jeannine Dennis, an occupational therapist, presented a new progress film, *Infant to School Age Child with Unilateral*

*Below-Elbow Prosthesis,* produced by the UCLA Child Amputee Prosthetics Project. The film was well received by members of the Subcommittee who recommended its reproduction for use as a teaching aid. Recognizing a continuing need for visual aids and other instructional materials which would keep members of the various professions informed on the latest developments in research and clinical experience, the Subcommittee made several recommendations toward fulfilling this need.

Miss Dorothy Baethke completes her term of office as Chairman of the Subcommittee on Prosthetics in Paramedical Education at the end of the Fiscal Year 1963-1964. Miss Baethke, who has served as Chairman since the establishment of the Subcommittee three years ago, will be replaced by Colonel Ruth A. Robinson, Chief of the Occupational Therapy Section at Walter Reed General Hospital in Washington, D. C, and former Chief of the Army Medical Specialist Corps.

**Annual Assembly for 1963** of **AOPA**

The annual assembly of the American Orthotics and Prosthetics Association was held in New Orleans, La., during the period November 3-6, 1963. The President of the Association, Mr. Carlton Fillauer, of Chattanooga, Tenn., presided. Registered attendance numbered more than 500.

Professional and technical matters considered during the meetings included orthotic devices proposed for evaluation by a formal CPRD evaluation program, the use of silicones in prosthetics and orthotics, splinting the rheumatoid hand, principles of total contact in prostheses, a comparison of German and American principles for the alignment of above-knee prostheses, the latest developments in porous laminates, and teaching techniques in prosthetics and orthotics. Exhibitors were well represented.

The assembly concluded with a banquet at which Dr. George T. Aitken, Chairman of CPRD, was the principal speaker. In his address, Dr. Aitken described the increasing emphasis on orthotics research, development, and evaluation by CPRD. He congratulated the members of AOPA for being among the pioneers in the development of the interdisciplinary "team" approach to the solution of medical problems and pointed out that much remains to be done. Mr. Robert C. Gruman, of Minneapolis, Minn., was installed as the new President of the Association for 1963-1964. Serving with him are President-Elect Herbert J. Hart, of Oakland, Calif.; Vice-President David C. McGraw, of Shreveport, La.; and Secretary-Treasurer M. P. Cestaro, of Washington, D. C.

**AOPA** Conference of Prosthetists

A new organization known as the Conference of Prosthetists has recently been formed by the American Orthotics and Prosthetics Association. The members of the new group will devote themselves exclusively to professional matters pertaining to the practice of prosthetics.

Over the years, AOPA has endeavored to serve two purposes: to meet the needs of the brace and limb industry on a national level, and to improve the professions of orthotics and prosthetics. The founding fathers recognized that this latter objective could best be achieved by working with existing medical organizations and groups, and this cooperative relationship has been very productive. The newly formed Conference of Prosthetists will provide an organization of professionally dedicated individuals to work with other organizations on projects and activities of mutual interest. The Amputee Census is an example of what can be accomplished by the united efforts of the prosthetists of this country.

The activities and projects of the Conference of Prosthetists are controlled by a small working group designated as the Executive Committee. With the view toward the future collection of comparable prosthetics data, the initial effort of the Executive Committee is the development of a uniform limbshop record form to be used by the members of the Conference.

**Prosthetics-Orthotics Education**

The University Council on Orthotic-Prosthetic Education (UCOPE) met on January 31, 1964, in the Prosthetic-Orthotic Education facilities at the University of California at Los Angeles. Attending this meeting were

liaison representatives of the American Orthotics and Prosthetics Association—American Board for Certification, the Committee on Prosthetics Research and Development, and the Committee on Prosthetic-Orthotic Education. Progress reports were presented by the representatives in attendance, and there were summaries of recent activities of the university programs in Prosthetics-Orthotics Education in the semester courses, undergraduate programs, and short-term courses.

The annual Vocational Rehabilitation Administration Conference on Prosthetics and Orthotics is scheduled to be held in Washington, D. C, on May 15, 1964, under the chairmanship of Dr. J. Warren Perry. On the evening before this all-day meeting, the American Orthotics and Prosthetics Association will hold a reception for conference participants at the Lafayette Hotel.

The Prosthetics-Orthotics Education Program is supported partly by funds from educational grants from the Vocational Rehabilitation Administration of the Department of Health, Education, and Welfare, and partly by the universities concerned. National coordination of the Prosthetics-Orthotics Education Program is accomplished through the Committee on Prosthetic-Orthotic Education of the Division of Medical Sciences, NAS—NRC, and the University Council on Orthotic-Prosthetic Education. In addition, close relations are maintained with the American Board for Certification in Prosthetics and Orthotics, the American Orthotics and Prosthetics Association, the American Congress of Physical Medicine, the American Academy of Orthopaedic Surgeons, the American Physical Therapy Association, the American Occupational Therapy Association, the Veterans Administration, and other interested groups and organizations.

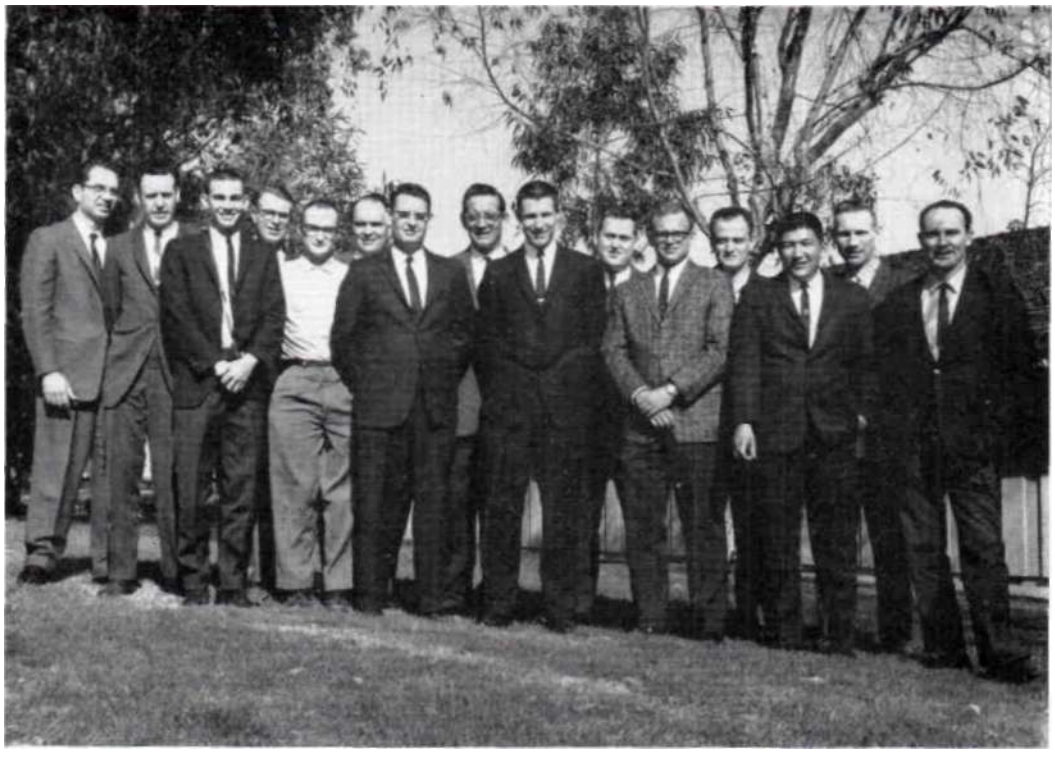
*Prosthetics-Orthotics Education at UCLA*

The first class in child amputee prosthetics at UCLA, based on the results of ten years of research in the Child Amputee Prosthetics Project, scheduled for April 24 and 25, 1964, was oversubscribed, with 14 prosthetists, 15 therapists, and 18 physicians enrolled, a total of 47 students. Since a number of applicants had to be turned away, two classes have been scheduled for the 1964-1965 academic year: one in December and another in June. The classes are sponsored by the UCLA Prosthetics-Orthotics Education Program, and the members of the Child Amputee Prosthetics Project staff do the teaching.

Textbook for the course is the comprehensive summary recently published by the Child Amputee Prosthetics Project, *The Limb-Deficient Child* (reviewed in the Autumn 1963 issue of *Artificial Limbs).* Supplementing the text are lesson sheets with drawings by Carl Sumida, of the Project staff. The teaching staff is led by Dr. Milo B. Brooks, Medical Director of the Project, and Dr. Cameron B. Hall. Assisting them are Jeannine Dennis, O.T.R.; Lorraine Ogg, R.P.T.; Carl Sumida, C.P.O.; Richard Lee, C.P.; Harry Campbell, C.P.; Lila Beal, M.S.W.; and other members of the Child Amputee Prosthetics Project staff.

Construction of the new Physical Rehabilitation Center building on the UCLA West Medical Campus is proceeding rapidly, with the completion date set for January 17, 1965. It is planned that the UCLA Prosthetics-Orthotics Education Program will move into its new quarters in February 1965. Fred Sanders, Senior Mechanician, has developed detailed plans for the move which should be accomplished with a minimum of lost time. Mr, Sanders has also coordinated the redesign of the entire prosthetics-orthotics laboratory area, which was originally planned around the fabrication of wood as well as plastic prostheses. In the new design, emphasis is placed on plaster, plastic, and plastic-foam procedures, with very little use of wood.

The certificate program in UCLA Prosthetics-Orthotics Education during the 1964-1965 academic year will be lengthened to two full semesters, for a total of nine months, during which the students will take 12 three-week courses and one course of four weeks' duration. Experience with this program during the past three years has shown that more time is required to do a thorough job; hence the increase from seven to nine months. Not more than six students will be enrolled in the pro-



Participants in class in Below-Knee Prosthetics at UCLA, January 6-24, 1964. Asterisks indicate full-time certificate students. Left to right: Eugene C. Fleishauer, Ray E. Moore, Anthony W. Burns*, Leonard E. Mumaugh, Larry A. Rose*, Leigh A. Wilson, Cecil E. McMorris, William D. Weisgerber, Jerrell R. Ballard, Gregory F. Scott*, Mark E. Schultz*, Earl V. Shields*, Mike M. Martinez, Delbert L. Clark, John J. Bray, Associate Director, UCLA Prosthetics-Orthotics Education.

gram, and priority will be given to applicants who have a B.A. or B.S. degree.

During the 1963-1964 academic year, UCLA Prosthetics-Orthotics Education has offered an experimental program for physicians and therapists in which all aspects of both upper- and lower-extremity prosthetics and orthotics were covered. A two-week, 80-hour course, the program was originally conceived with the needs of residents in orthopedics and physical medicine particularly in mind. In previous years, a one-week course in each of the major areas of prosthetics and orthotics was offered, making it necessary for students to make repeated visits to UCLA to cover the entire field. With the new program, a physician or therapist can accomplish this with one trip. In addition to residents, the course has appealed to many attending physicians and a substantial number of them have enrolled in the classes.

The number of therapists enrolled in the program was less than the number of physicians. The class size was not allowed to exceed a total of 40 because of space limitations. Each class was filled to capacity and many applicants had to be turned away. A total of **160** students completed the four courses offered.

Information concerning UCLA instructional offerings in prosthetics and orthotics, together with application forms, can be obtained from Dr. Miles H. Anderson, Director, Prosthetics-Orthotics Education Program, Medical Center B4-229, University of California, Los Angeles, Calif. 90024.

Listed below is a tentative schedule of the courses offered during the 1964-1965 academic year:

Participants in class in Above-Knee Prosthetics at UCLA, February 10-March 6, 1964. Asterisks indicate full-time certificate students Back row: John J Bray, Associate Director, UCLA Prosthetics-Orthotics Education, Walter H. Willis, Eugene C. Fleishauer, Gregory F. Scott*, Louis F. Jansen, Walter S. Smith, Riley H. Hindman, Larry A. Rose*, Donald F. Colwell, Instructor. Front row: Bernard C. Simons, Leonard E. Mumaugh, Anthony W. Bums*, Earl V. Shields*, Mark E. Schultz*.

*Prosthetists*

Total-Contact Above-Knee Socket Technique—Sept. 14-18.
Above-Knee Prosthetics—Oct. 5-30.
Special Problems in Above-Knee Prosthetics—Nov 2-27.
Below-Knee Prosthetics—Nov, 30-Dec. 18.
Special Problems in Below-Knee Prosthetics—Dec. 21-Jan. 8.
Hip-Disarticulation and Syme Prostheses—Feb. 22-Mar. 12.
Special Problems in Hip-Disarticulation and Syme Prostheses—Mar. 15-Apr. 2.
Upper-Extremity Prosthetics—Apr. 5-23.
Special Problems in Upper-Extremity Prosthetics—Apr. 26-May 14.

*Orthotists*

Functional Long Leg Bracing—Jan. 11-29.
Special Problems in Functional Long Leg Bracing—Feb 1-19.
Functional Bracing of the Upper Extremities—May 17-June 4.
Special Problems in Functional Bracing of the Upper Extremities—June 7-11; June 21-30.

*Therapists*

Prosthetics-Orthotics—Oct. 5-16; Nov. 30-Dec. 11; Apr 5-16; May 31-June 11.

*Physicians*

Prosthetics-Orthotics—Oct. 5-16; Nov. 30-Dec. 11; Apr. 5-16; May 31-June 11.

*Prosthelists, Therapists, and Physicians*

Child-Amputee Prosthetics—Dec. 14-18; June 14-18.

*Rehabilitation Personnel*

Prosthetics-Orthotics Rehabilitation—Nov. 16-20; Mar. 15-19; May 17-21.

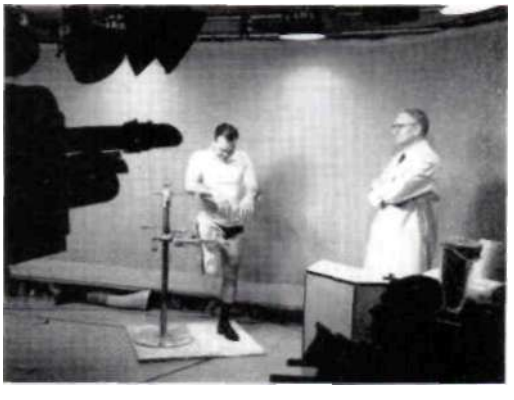
In addition to their regular teaching duties, members of the UCLA Prosthetics-Orthotics

Education faculty have been engaged in a number of related activities.

A lecture-demonstration entitled *Modern Teaching Modalities* was presented before the Orthopedic Research and Education Seminar in Dallas, Tex., on March 12, 1964, by Dr. Miles H. Anderson, Director of the UCLA Prosthetics-Orthotics Education Program. The seminar is sponsored annually by the Committee on the Skeletal System of the National Academy of Sciences—National Research Council, in conjunction with the American Academy of Orthopaedic Surgeons, for orthopedic personnel in medical schools.

Dr. Anderson also lectured on the subject *Teaching Techniques in Prosthetic and Orthotic Laboratory Instruction* before the annual assembly of Region VIII of the American Orthotics and Prosthetics Association in San Antonio, Tex., and before the annual assembly of Region X in Sacramento, Calif.

A lecture-demonstration on the *UCLA Functional Long Leg Brace* was given by John J. Bray, C.P.O., Associate Director of the UCLA Prosthetics-Orthotics Education Program, before the annual assembly of Region X of AOPA in Sacramento on April 5, 1964. This presentation was followed by one entitled *Functional Bracing of the Upper Extremities,* by Lee Roy Snelson, Orthotics Instructor in the UCLA Prosthetics-Orthotics Education Program.



Dr. Charles O. Bechtol and Donald *V.* Colwell, C.P., demonstrate the VAPC casting machine on closed-circuit television program for California Medical Association.

Dr. Cameron B. Hall, Assistant Clinical Professor of Surgery (Orthopedics), and Dr. Miles H. Anderson, Director of Prosthetics-Orthotics Education, both of the UCLA Medical School, have been appointed to three-year terms as members of the U. S. Subcommittee of the Committee on Prostheses, Braces, and Technical Aids of the International Society for Rehabilitation of the Disabled.

Physicians from all parts of California assembled for the annual meeting of the California Medical Association at the Biltmore Hotel in Los Angeles, Calif., saw a closed-cir-

Donald F. Colwell, C.P., demonstrates the total-contact, plastic, above-knee socket with Hydra-Cadence, under the direction of Dr. Charles 0. Bechtol.

cuit, color television program presented from the UCLA Medical School by Dr. Charles O. Bechtol, Professor of Orthopedics, and Donald F. Colwell, of the UCLA Prosthetics-Orthotics Education faculty.

The 90-minute program featured the use of the VAPC casting jig, the total-contact, above-knee socket, the Hydra-Cadence and the Hydra-Knee hydraulic units, the PTB below-knee prosthesis, the Canadian hip-disarticulation and Syme prostheses, and various upper-extremity prostheses ranging from those for partial-hand amputations to shoulder-disarticulation prostheses.

*Prosthetics-Orthotics Education at NYU*

A number of courses specific to prosthetics and orthotics were offered for the first time as part of New York University's undergraduate

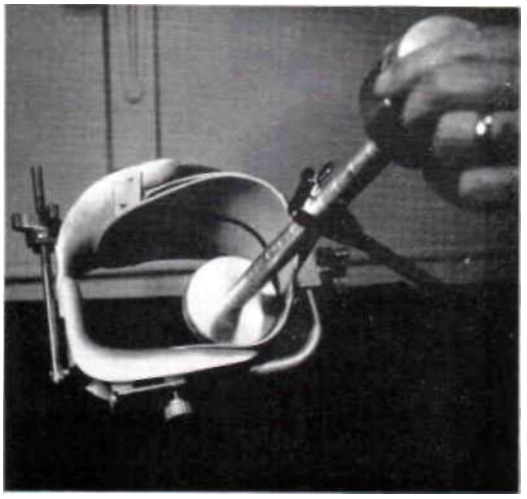
four-year course of study leading to the degree of Bachelor of Science in Prosthetics and Orthotics. During the fall of 1963, students completed courses in *Mechanics* and *Prosthetic and Orthotic Shop Techniques.* During the spring of 1964, advanced students undertook courses in *Biomechanics, Properties of Materials, Upper-Extremity Prosthetics,* and *Clinical Affiliation in Upper-Extremity Prosthetics.* The remaining specialized courses are scheduled to be offered during the 1964-1965 academic year.

The four-year curriculum has attracted students not only from the New York area but from other states, as well as one student from abroad (India). It is anticipated that the first degrees will be awarded in June 1965. The Vocational Rehabilitation Administration has made available traineeship assistance in the amount of $3,400 for the junior year and $3,800 for the senior year for promising full-time students pursuing this program of instruction.

Following a successful pilot course given in July 1963, courses were inaugurated in lower-extremity orthotics for physicians and surgeons and for therapists. All these courses have been well attended, and a substantial advance registration exists for the balance of the orthotics courses scheduled for the spring of 1964.

In addition to the regular offerings for prosthetists, five courses have been presented during the 1963-1964 academic year on the total-contact, plastic, above-knee socket. These courses introduced the use of the NYU Flexible Casting Brim technique. A manual entitled *A Flexible Casting Brim Technique for Above-Knee Total-Contact Sockets,* designed for use as a text for this fitting technique, has also been published. Copies can be purchased at SI.50 each from the New York University Medical Book Store, 550 First Ave., New York, N. Y. 10010.

Ivan A. Dillee, C.P., Instructor, lectures to undergraduates at NYU on procedures for the fabrication of an upper-extremity prosthesis.



NYU Flexible Casting Brim.

Early in the 1963-1964 academic year a survev was conducted to determine whether physicians and surgeons who had taken courses in lower-extremity prosthetics during the past seven years would desire an intensive two-day refresher course to review recent advances in prosthetics, with particular emphasis on total-contact sockets, hydraulic mechanisms, and hip-disarticulation fitting procedures. The response was extremely favorable, with approximately 150 persons indicating interest in such a course. The first two-day session was scheduled for April 24 and 25, 1964, for a capacity class.

New York University's regular courses in upper- and lower-extremity prosthetics for physicians and surgeons and for therapists continue to meet a favorable reception. All these courses have been oversubscribed during

the 1963-1964 academic year, and extra sessions have been scheduled to meet the demand.

Listed below is the preliminary schedule of courses to be offered during the 1964-1965 academic year. Additional information and application forms can be obtained by writing to Dr. Sidney Fishman, Coordinator, Prosthetics and Orthotics, New York University, 342 East 26th St., New York, N. Y. 10010.

*Prosthetists*

Total-Contact Above-Knee Prostheses—Sept. 14-19.
Upper-Extremity Prosthetics (Fitting and Harnessing)—Jan. 18-29.
Below-Knee Prosthetics—May 17-June 4.

*Orthotists*

Lower-Extremity Orthotics—Jan. 18-29.

*Physicians and Surgeons*

Advanced Lower-Extremity Prosthetics—Sept. 25-26; Nov. 6-7.
Lower-Extremity Prosthetics—Oct. 5-10; Nov. 16-21; Feb. 15-20; Mar. 8-13; May 10-15.
Lower-Extremity Orthotics—Oct. 19-23; Nov. 30-Dec. 4; Jan. 4-8; Apr. 26-30.
Upper-Extremity Prosthetics—Dec. 14-18; Apr. 5-9.

*Therapists*

Lower-Extremity Prosthetics—Sept. 28-Oct. 9; Nov. 9-20; Feb. 8-19; Mar. 1-12; May 17-28.
Lower-Extremity Orthotics—Oct. 19-23; Nov. 30-Dec. 4; Jan. 4-8; Apr. 26-30.
Upper-Extremity Prosthetics—Dec. 7-18; Mar. 29-Apr. 9.

*Rehabilitation Counselors*

Prosthetics and Orthotics Feb. 8-12; Mar. 22-26.

Richard Lehneis, C.P.O., Instructor, demonstrates techniques for the fitting and alignment of a lower-extremity brace at NYU.

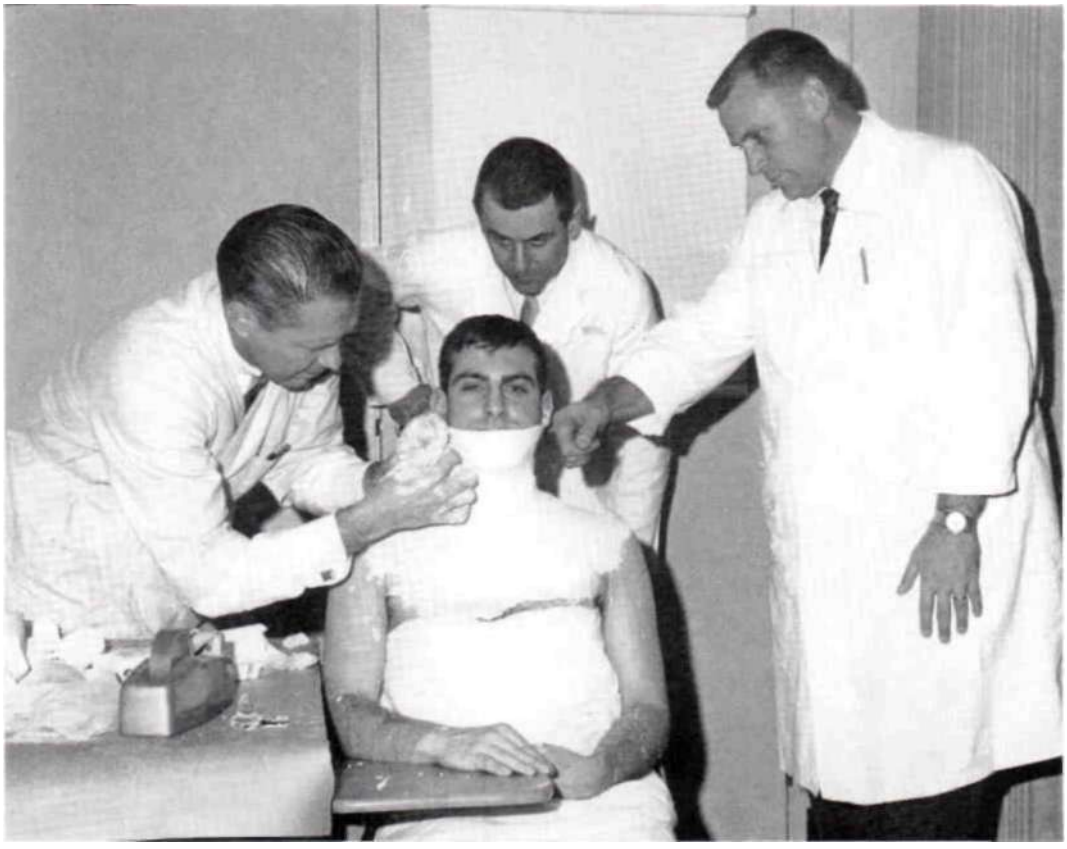
The appointment of H. Richard Lehneis as Chief of the Orthotics Department of the Institute of Physical Medicine and Rehabilitation, New York University Medical Center, was recently announced by Dr. Howard A. Rusk, Director of the Institute. Mr. Lehneis, who will continue to serve as an instructor in the NYU Prosthetics-Orthotics Education Program, was responsible for the development of the NYU Flexible Casting Brim technique and for the NYU technique for the measurement of tibial torsion and toe-out.

*Prosthetics-Orthotics Education at NU*

Northwestern University Prosthetic-Orthotic Education has scheduled two offerings of the course *Spinal Orthotics for Orthotists* during the 1964-1965 academic year. The course has been extended from one to two weeks to provide the orthotist with ample practical experience in spinal bracing, with emphasis being placed on the Milwaukee brace.

A pilot course entitled *Orthotics for Physicians* is scheduled for June 28-July 2, 1965. Dr. Robert D. Keagy, who is responsible for the development of the course, says its purpose is "to give the physician a working background in the field of lower-extremity, upper-extremity, and spinal orthotics." The teaching faculty will include: John H. Moe, M.D., Professor of Orthopedic Surgery, University of Minnesota; Vernon L. Nickel, M.D., Clinical Professor in Orthopedic Surgery at Loma Linda University and Head Orthopedist at Rancho Los Amigos Hospital; Warren G. Stamp, M.D., Associate Professor of Orthopedic Surgery, Washington University. On the final day of the course, clinic teams, composed of physicians and orthotists, will team up for prescription sessions.

Residents training at Northwestern University continue to show increased interest in NU Prosthetic-Orthotic Education courses in lower- and upper-extremity prosthetics. To meet the demands, additional offerings are scheduled for the 1964-1965 academic year. To permit physicians and therapists (who enroll concurrently) the opportunity to obtain the maximum amount of instruction in a single visit, two of the lower- and upper-extremity



Participants in NU course, *Spinal Orthotics for Orthotists,* January 1964. Herman B. Ording, CO., Student; Robert D. Keagy, M.D., Instructor in Orthopedic Surgery at NU; and Roy Snelson, CO., Instructor in Orthotics, Rancho Los Amigos Hospital. The teaching subject is Michael I. Sorkin, Medical Student, NU Medical School.

courses in September and October are being scheduled in consecutive weeks.

Inquiries concerning instructional offerings by Northwestern University in prosthetics and orthotics should be addressed to Dr. Jack D. Armold, Director, Prosthetic-Orthotic Education, Northwestern University Medical School, 401 E. Ohio St., Chicago, Ill. 60611.

Listed below is a tentative schedule of the courses offered during the 1964-1965 academic year:

*Prosthetists*

Total-Contact Plastic Socket Techniques—Oct. 26-31; Nov. 16-21.
Management of the Juvenile Amputee—Nov. 30-Dec. 3; June 14-17.
Upper-Extremity Prosthetics—Feb. 8-Mar. 5.
Below-Knee Prosthetics—Mar. 15-Apr. 2.
Above-Knee Prosthetics—Apr. 12-May 7.
Fitting and Fabrication of Special Prostheses—May 17-June4.

*Orthotists*

Spinal Orthotics—Oct. 26-Nov. 6; June 21-July 2.

*Therapists*

Lower-Extremity Prosthetics—Aug. 31-Sept. 4; Sept. 14-18; Oct. 5-9; Mar. 29-Apr. 2; May 3-7; May 31-June 4.
Upper-Extremity Prosthetics—Sept. 21-25; Oct. 12-16; Mar. 1-5.
Management of the Juvenile Amputee—Nov. 30-Dec 3; June 14-17.

*Physicians and Surgeons*

Lower-Extremity Prosthetics—Aug. 31-Sept. 4; Sept. 14-18; Oct. 5-9; Jan. 18 22; Mar 29-Apr. 2; May 3-7; May 31-June 4.

Upper-Extremity Prosthetics—Sept. 21-25; Oct. 12-16; Mar. 1-5.
Management of the Juvenile Amputee—Nov. 30-Dec. 3; June 14-17.
Orthotics—June 28-July 2.

*Rehabilitation Personnel*

Orientation in Prosthetics and Orthotics—Dec. 7-11; Apr. 5-9.

Edward C. Grahn, B.S.M.E., recently joined the instructional staff of NU Prosthetic-Orthotic Education and will lecture on research, biomechanics, materials, and externally powered prostheses. Mr. Grahn assumed the position of Project Director of NU Prosthetics Research Center on March 30, 1964. Prior to joining Northwestern University, he served two years with the Army Medical Biomechanical Research Laboratory, Walter Reed Army Medical Center, Forest Glen Section, Washington, D. C. He is a graduate of the Illinois Institute of Technology. Upper-extremity research at NU Prosthetics Research Center includes materials and power-transmission studies and the development of new devices, with special emphasis on an electrically powered arm for feeding and toilet care. In lower-extremity research, work is being done on sockets, components, materials, and gait control.

Several members of the NU Prosthetic-Orthotic Education faculty have recently delivered papers at regional meetings of the American Orthotics and Prosthetics Association. At the Region I annual assembly, in Cambridge, Mass., Charles M. Fryer, M.A., presented papers entitled *The Mechanics of Normal Posture and Gait* and *The Application of Biomechanics to Prosthetic and Orthotic Practice.* At the Region III assembly in Baltimore, Md., Charles Rosenquist, CO., lectured on *Spinal Orthotics.* Dr. Jack D. Armold, Director of NU Prosthetic-Orthotic Education, presented a paper entitled *Educational Challenges in Prosthetics and Orthotics* at the Region IV assembly in Warm Springs, Ga. Members of the faculty participating in the program of the Region VI assembly in St. Charles, 111., included Jack D. Armold, Ph.D.; William T. Kernahan, Jr., M.D.; Raymond J. Pellicore, M.D.; Robert G. Thompson, M.D.; Richard Bidwell, C.P.O.; Charles M. Fryer, M.A.; and H. Blair Hanger, C.P. Claude N. Lambert, M.D., is scheduled to be the banquet speaker at the Region XI assembly in Vancouver, B.C., Canada.

Kenneth S. Johnston, Ph.D., of the Northwestern University School of Business, and M. P. Cestaro, Secretary-Treasurer of AOPA, recently discussed plans which it is hoped will result in new accounting aids for AOPA members in the management of their facilities.

## Study of Temporary Lower-Extremity Prostheses at Duke University

Duke University Medical Center has received a three-year grant from the Vocational Rehabilitation Administration for a research project entitled "Use of Temporary Plaster or Plastic Pylons Preparatory to the Fitting of a Permanent Above-Knee or Below-Knee Prosthesis." The project director is J. Leonard Goldner, M.D. Assistants are Frank W. Clippinger, M.D., Donald McCollum, M.D., Bert R. Titus, C.P.O., Robert O. Gooch, C.P., and Grace Horton, R.P.T.

The purposes of the study include the following:

1. To obtain more specific information about temporary plaster or plastic pylons while they are being used by patients prior to construction of a permanent prosthesis.
2. To determine whether it is possible to develop a rapid, inexpensive method for making above-knee and below-knee plaster pylons.
3. To determine whether it is possible to speed the shrinkage of the stump in the above-knee and below-knee amputee in order to permit earlier fitting, better psychological adjustment, and improved physical conditioning with earlier return to work or home activities.
4. To evaluate the use of the total-contact, plastic pylon as an inexpensive, light prosthesis prior to final fitting with a permanent plastic prosthesis.
5. To determine the feasibility of utilizing available metal shins and SACH feet on plaster pylons and below-knee plastic pylons.
6. To determine the validity of current criticisms of the use of the pylon, namely: poor gait pattern, damage to the stump, psychological damage because of appearance, inadequate fit, excessive time required to make an appropriate pylon.
7. To find a means for determining whether certain patients will be able to utilize and tolerate a permanent prosthesis.

8. To determine the efficiency of the VAPC casting machine for making both above-knee and below-knee plaster pylons.

9. To determine the effect of increased work associated with use of a plaster pylon on the patient's circulatory system and his general well-being.

During the first five months of the study, 22 unilateral below-knee pylons, two bilateral below-knee pylons, and 11 unilateral above-knee pylons have been fitted. The age of the patients has ranged from 18 to 82 years.

**Upper-Extremity Development Being Conducted by Gilmatic, Inc.**

Development of upper-extremity components is to be conducted by Gilmatic, Inc., Northridge, Calif., under a contract with the Veterans Administration. Gilmatic manufactures filters and various specialty items. Gilbert Motis, the owner, has been associated with the Artificial Limb Program since its inception in 1945. He was largely responsible for the Northrop C elbow lock, the Northrop-Sierra two-load hook, the F-M (Fletcher-Motis) disconnect, certain Bowden cable fittings, and several other designs of upper-extremity components originally developed at Northrop Aircraft and still widely used in the prosthetics field. Mr. Motis wrote the Northrop final report, a comprehensive book which was widely distributed by the limb industry as well as by the research program.

In later years, he served as a consultant to the UCLA research and case study projects and to the children's prosthetics program, in addition to conducting a broad practice as a consulting engineer.

The new development project aims at providing wrist rotation for above-elbow prostheses, improved elbows, and ultimately hooks (or hands) with control by mechanism within the forearm instead of by external Bowden cables. All these concepts have long been recognized as desirable and some laboratory models have been built, but the devices have not reached wide clinical usefulness. By combining past ideas, the wide clinical experience now available with present devices, newer materials, and ingenious designs, Gilmatic seeks to add function and improve the appearance of artificial arms.

**Excerpta Medica Foundation**

Prompt and comprehensive abstracting of the biomedical literature of the world is provided in the publications of the Excerpta Medica Foundation, a nonprofit organization with offices in Amsterdam, New York, London, Milan, and Tokyo.

The Excerpta Medica Foundation was established in 1946 with the objective of disseminating biomedical information on the widest possible scale, for the benefit of medical and related teaching institutions and hospitals, medical scientists, specialists, clinicians, and research workers. The objective is achieved through the Foundation's 24 monthly abstracting publications covering the entire medical field and related subjects, special reference works, and a series on international meetings which includes the proceedings and abstracts of papers presented at international biomedical conferences.

Of particular interest to persons concerned with prosthetics and orthotics is the Excerpta Medica Foundation's monthly publication entitled *Rehabilitation and Physical Medicine.* Its chapter headings regularly are: General; Basic Sciences; Research; Somatic Aspects; Mental Aspects; Social Aspects; General Therapy; Surgical Therapy; Physical Therapy; Activities of Daily Living; Appliances, Instruments, Materials, Speech and Hearing; Ophthalmological Aspects; Pediatrics; and Geriatrics.

Detailed information concerning Foundation publications can be obtained from Excerpta Medica Foundation, New York Academy of Medicine Building, 2 East 103rd St., New York, N. Y. 10029.

**National Society for Crippled Children and Adults**

Of especial interest to persons concerned with prosthetics and orthotics are the monthly journal of the National Society for Crippled Children and Adults and the Society's recently announced scholarship program.

Each issue of *Rehabilitation Literature,* the Society's journal, contains a major article, digests of selected articles, and comprehensive abstracts of current publications in the field of rehabilitation. Each year the January issue

contains an index of authors mentioned during the preceding year.

The National Society for Crippled Children and Adults announced in February 1964 that it is offering scholarships to finance specialized training for professional workers who help crippled children and handicapped adults. Scholarships are available to physicians, therapists, educators, and other specialists in the field of rehabilitation.

Communications concerning *Rehabilitation Literature* and the scholarships offered by the Society should be addressed to National Society for Crippled Children and Adults, 2023 West Ogden Ave., Chicago, Ill.

### New Directory of U. S. Rehabilitation Facilities Published

The 1964 Directory of Rehabilitation Facilities in the United States is featured in the May-June issue of the *Journal of Rehabilitation.*

Compiled by the Association of Rehabilitation Centers with major financial assistance from the Vocational Rehabilitation Administration, the 52-page directory represents three years of intensive investigation. Listed in the publication are rehabilitation centers, sheltered workshops, hospital rehabilitation facilities, etc.

Information for each facility includes the name of the director, address, telephone number, type of ownership (Government, proprietory, or voluntary agency), organizational memberships, number of patients served (by age and also by type of care), bed capacity (where applicable), service programs (physical restoration, psychological-social, vocational-educational, speech and hearing, recreation, transportation), and professional staff. A grouping of pertinent tables and figures adds to the usefulness of the publication.

Copies of the May-June 1964 issue of the *Journal* are available from the Association of Rehabilitation Centers, 828 Davis St., Evanston, Ill., and from the National Rehabilitation Association, 1029 Vermont Ave., N.W., Washington, D. C. 20005, at a cost of $1.25 each. In quantities of 25 or more, the issue sells for **$1.00.**

### French Atlas of Prosthetic and Orthopedic Appliances

The office of the Committee on Prosthetics Research and Development has recently received notice of the publication in France of an atlas of prosthetic and orthopedic appliances.

Published under the direction of Professor Louis Pierquin, of the Faculty of Medicine of Nancy, the atlas is the result of research and experimentation carried on during the past ten years at the Regional Institute of Rehabilitation in Nancy by a team of physicians, technicians, and rehabilitation personnel. It is intended for the use of all who are interested in prosthetic and orthotic devices. It is essentially made up of pen drawings, and the explanatory text is reduced to a minimum.

The atlas is being produced in a series of ten issues; the first two issues are now being

Dr. Robert E. Stewart, Director of the VA Prosthetic and Sensory Aids Service, and Dr. Roy K. Quamme, Assistant Chief of Staff for Outpatient Service at the VA Hospital in Dearborn, Mich., stand on either side of Otis N. Denny, who has received the Award to the Federal Employee of the Year 1963 from the Detroit Federal Business Association.

printed. The first issue deals with a tibial prosthesis which has been used with success at Nancy since 1958. The second issue deals with a monotubular splint to be used on lower extremities that are paralyzed.

The price of the atlas is 15 francs per copy. Copies may be purchased from M. Fajal, 20 Rue d'Alsace, Vandoeuvre-les-Nancy, Meurthe et Moselle, Nancy, France.

## Otis N. Denny Honored by **FBA**

The Federal Business Association of Detroit, Mich., recently conferred its highly regarded Award to the Federal Employee of the Year 1963 to Otis N. Denny, Chief, Prosthetic and Sensory Aids Unit, Outpatient Service, Veterans Administration Hospital, Dearborn, Mich.

During World War II, Mr. Denny served in the Army and was severely injured as a result of his military service. He is a bilateral, lower-extremity amputee.

In civilian life, Mr. Denny has a long record of highly effective service to disabled veterans and has demonstrated great competence with respect to the assistance that can be provided in their rehabilitation. In 1961 he received a citation from the President's Committee on Employment of the Physically Handicapped for his voluntary efforts which made possible the collection from American veterans of artificial limbs to be distributed to disabled persons throughout the world, and which became part of the cargo of the Hospital Ship *Hope*.

Mr. Denny's disability has not prevented him from being active in many areas. He cares for his lawn and is able to run a tractor. He is mechanically skilled and does much of his own repair work around home in a well-equipped shop.