Improvement and Innovation: Development

Everyone has at one time or another contemplated and perhaps experienced the joy of free thinking unshackled by scientific law. If our indefinite fancies and dreams of progress were to materialize, prosthetics and orthotics methods and devices would be advanced far beyond now practical limits.

Unfortunately, developments of new devices and techniques do not spring spontaneously from a fertile imagination alone. New methods and devices must certainly be based on new concepts exposed as a result of extensive fundamental research or on problems revealed by study of all available literature and practices, particularly clinical experiences. Before a new item may be developed, there is a need to determine design criteria on the basis of a clear and accurate definition of the new concept or the problem.

Although improvement in prosthetics and orthotics is intended primarily for the patient, many advantages may accrue to the manufacturer of components and the fabricator of appliances. The goals of development groups include improved function and comfort for the disabled, as well as convenience in terms of simplicity and durability of devices. Also, the developer tries to aid the manufacturer and fitter not only by providing new products but by making their jobs perhaps a little easier and more profitable.

All new items are generally tested by various means during transition in development, with each item presenting differing requirements for the development programs depending on the problems which it confronts or the new concept it manifests. Basically, there are two groups of items: the first group representing *techniques* including methods, systems, and materials; the second group covers the *devices*. To further define the often subtle variances which exist within these two groups, the following classification is offered:

Group I—Development of Techniques

All efforts are directed toward the ultimate improvement of prostheses and orthotic devices through a continuous investigation of materials, seeking those which meet, as the main criterion, the physical requirements of an appliance. In addition, development is required to integrate such requirements with adaptability, in a simple workable technique, to advanced concepts of fitting, alignment, and function. Technique development, most of which is materials-oriented, may be given the following sub-classification:

A. The development of techniques reflecting new fitting concepts and better fabrication methods but with existing materials.

B. The development of applications of new or different materials and methods.

C. The development of new appliance designs based primarily on the proper application of existing materials and methods.

D. Refinements in applications of existing materials and techniques.

Group II—Development of Devices

As we continue to encourage the development of new components to provide better functional mechanisms and controls for prostheses and orthotic appliances, we need not limit the functions to the precise sites in which normal functions occur in the anatomical members. Our *only* restrictions in providing function are those limitations imposed by the physical shape, size and weight of the appliance.

Device development may be given the following sub-classification:

A. The development of devices (prosthetic or orthotic components) providing a new function in an appliance.

B. The development of devices used as instruments or tools in the preparation or fabrication of an appliance but primarily based on existing principles.

C. The development of devices necessary for a new technique, method, or concept.

EXAMPLES OF TECHNIQUE AND DEVICE DEVELOPMENTS

TECHNIQUE DEVELOPMENTS

A. The development of techniques reflecting new fitting concepts and better fabrication methods but with existing materials.

EXAMPLE: Below-knee weight-bearing brace with PTB type socket (Fig. 1).

Typically, the leg-thigh (or "long-leg") brace has been used for all cases involving the unweighting of the lower extremity. Although such bracing appears to be excessive in certain cases, research has not fully defined the problems which such over-bracing may present. As a step in seeking such information, the below-knee weight-bearing brace using the technique of PTB socket fitting was designed to obviate unweighting the entire extremity for bracing below-knee involvements.

The ischial weight-bearing brace is needlessly heavy, cumbersome, and certainly uncomfortable. Seemingly undue restrictions are imposed upon the normal function of the knee, thigh, and hip muscles when bracing only for an arthritic ankle or foot or malunion of the tibia, fibula or portions of the foot. While improved gait, mobility, and conservation of energy appear evidenced with the use of the below-knee type weight-bearing brace, studies

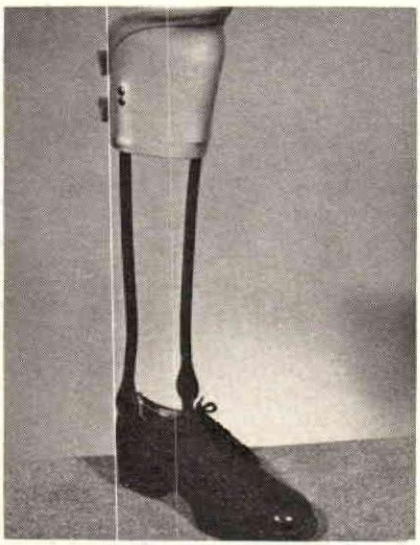

Figure 1. Below-knee weight-bearing brace showing PTB type socket.

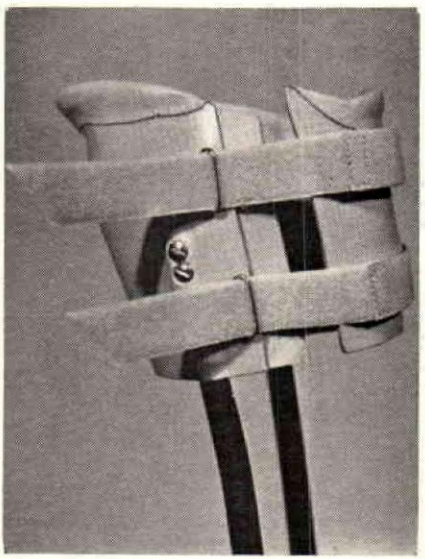

Figure 2. Below-knee weight-bearing brace with adjustable socket secured by "Velcro".

are continuing, to provide more objective information regarding the possible effects of active muscular knee control upon malunions and nonunion of the tibia when braced in the manner described below.

The below-knee weight-bearing brace consists of three basic component groups: the socket, brace bars, and shoe. The socket is the typical plastic-laminate PTB design, hinged in the posterolateral aspect to provide entrance of the limb (Fig. 2). The methods of casting the leg and subsequent mold modifications are typical of those used in the PTB below-knee fabrication techniques. The socket is sectioned in the posterolateral aspect and joined with a hinge.

The socket hinge assembly is constructed from a metal frame tailored to size and containing a hinge and two brackets (to receive the brace bar uprights). The frame is sandwiched in the lamination lay-up and held in position by a string during lamination. The plastic lamination incorporates the frame (with hinge) into the socket body. The most recent below-knee sockets for this type of brace are fabricated without the sponge and leather liner shown in the illustration.

The weight-bearing cast about the knee and upper shank is achieved by use of the casting stand illustrated later in this article: the method of casting used is similar to the technique for casting the below-knee stump. During casting, the patient wears a shoe modified to accommodate the brace stirrup. Alignment of the brace uprights is established on the patient as he stands in the casting stand. Careful reference marks made upon the cast are used to locate the final brace bar positions. Adjustment holes in the upper portion of the brace bar uprights also aid in making more precise dynamic adjustments.

The shoe is modified externally to incorporate a metatarsal rocker bar and a compressible SACH type heel insert. Since limited motion in the brace ankle joint is essential to achieve best unweighting characteristics, these modifications are used to provide "roll-over" function in the shoe, allowing full limitation on ankle joint motion.

The trophic changes which would normally develop in the thigh with the use of the weight-bearing leg-thigh brace and knee lock should be eliminated by use of the below-knee PTB brace.

B. The development of applications of new or different materials and methods.

EXAMPLE: The dip method for plastic finishing of prostheses, a technique using an ethyl cellulose plastic which permits the dipping of components to achieve a reinforced plastic finish (Fig. 3).

The value of this technique will be appreciated most when there is a large production volume. With fabrication techniques using pre-fabricated components, shop time and cost in making a prosthesis up to the point

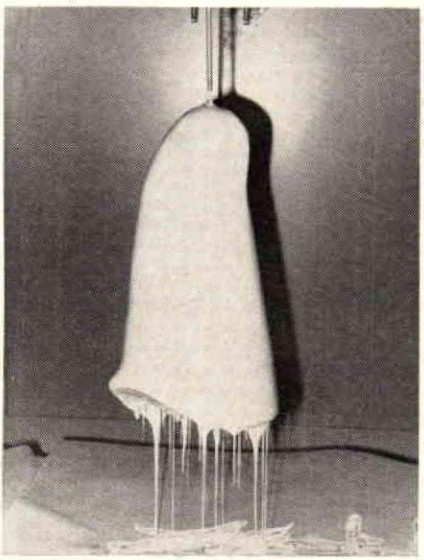

Figure 3. Above-knee socket dipped in ethyl cellulose.

of lamination are considerably reduced. However, the typical plastic-laminate finishing process required to reinforce a prosthesis and provide an acceptable cosmetic appearance still requires the time and skill of an artisan.

Experiments have been conducted using an ethyl cellulose material into which the prosthetic components are dipped and left to drip-dry providing either a clear or pigmented coating of approximately 50 to 60 mils thickness. The technique requires the use of metal or plastic containers (cans) large enough to accommodate an increase in contained volume caused by the introduction of a component which has to be completely submerged in the liquid. A drying rack is needed to hold components between dips.

A total of approximately five (5) dips is necessary to provide adequate strength and a smooth finish in the present experimental method. The first dip is a "tie-coat" sealer, for wood sockets only. The second dip is into the ethyl cellulose, clear or pigmented. The third dip is made over one stockinet (Helanca nylon) stretched over the component for reinforcement. Two more dips are added to finish the process. If a clear dip is used, the last dip should be into a pigmented lacquer.

The only problem in this process is the drying time required between dips. One (1) to two (2) hours time is recommended between dips. However, if a large number of components needed finishing routinely there would be a minimum of delay time and the operations could be assigned to a rather unskilled person to accrue production savings.

The dip operation must be accomplished slowly and methodically to minimize introducing air bubbles into the dip tank. The recommended rate of immersion and withdrawal of a component from the dip tank is 5 to 9 inches per minute. Perhaps a large plant could mechanize this process.

The following table indicates the approximate cost of materials for dip finishing:

		COST OF MATERIAL	
Foot:	Approx. 60 square inches	* .30	** .35
Shank:	Approx. 200 square inches	* 1.00	** 1.15
Socket:	Approx. 340 square inches	* 1.70	** 1.95
		$3.00	$3.45

* Cost computed at $.005 per square inch.
** 15% waste included.

Results of recent tests suggest that the strengths of the dip-coated (ethyl cellulose) specimens (1) without reinforcement and (2) "reinforced" with one layer of Helanca stockinet are at least equal and perhaps greater than those with the typical nylon stockinet laminate finishes using polyester resin. Tests were made applying a vertical load through a tapered mandrel inserted into the specimens, mating tapered wood "cylinders" finished in various manners. A most significant reduction of weight in the test specimens was also noted, as shown in the table on page 271.

C. The development of new appliance designs based primarily on the proper application of existing materials and methods.

EXAMPLE: The medial-opening Syme prosthesis.

Syme's amputation allegedly prepares the patient for ambulation with a stump which can carry, through the stump end, full body-weight at all times. Although the properly performed Syme's operation enables the patient to tolerate weight-bearing upon the end of his stump for short periods of time, most Syme prostheses wearers examined in our Center admitted that they were unable to use their prostheses for long periods of time unless the stump was always securely stabilized in the socket. Our early assump-

TABLE I

WEIGHT CHANGES AND STRENGTHS PROVIDED BY VARIOUS FINISHES ON WOOD CYLINDRICAL SPECIMENS

Specimen Number	Type of Finish	Average Weight of Specimen Before Finishing (ozs.)	Average Weight of Specimen After Finishing (ozs.)	Increase in Weight %	Vertical Breaking Load (lbs.)
1, 2, 3	Ethyl Cellulose dip w/o Helanca Stockinet	4.73	5.86	23.8	3650
4, 5, 6	Ethyl Cellulose dip w/1 layer Helanca Stockinet	4.74	6.04	27.4	3889
7, 8, 9	Ethyl Cellulose dip w/2 layers Helanca Stockinet	4.74	6.38	34.6	3500
10, 11, 12	Ethyl Cellulose dip w/3 layers Helanca Stockinet	4.73	6.87	45.2	3199
13, 14, 15	Polyester Laminate w/2 layers Nylon Stockinet	4.27	6.13	39.3	3189
16, 17	Ethyl Cellulose w/2 layers Nylon Stockinet	4.72	6.87	45.5	2489

tion that better suspension was needed was probably erroneous since above-knee strap suspension did not seem to help. It seemed that the lacer of the older type socket provided a much needed additional weight-bearing, however inadequate otherwise.

It was increasingly apparent that most Syme's amputation stumps responded most successfully to use of an artificial leg when all available areas of weight-bearing and support were provided. However, interference with the normal function of the knee must not be permitted. In order to design a Syme prosthesis which would provide maximum body weight support, it was necessary to employ below-knee weight-bearing concepts. Such a socket design enables the amputee to adjust the weight load distribution between the typical below-knee weight-bearing areas proximally and end-bearing by controlling the thickness of "pads" in the bottom of the socket. The proximal portion of the Syme cast (about the knee) may be formed by using the below-knee casting equipment described later in this article.

The proximal portion of this prosthesis is contoured and fitted like a below-knee socket thus providing proximal as well as distal weight-bearing. An oblong opening is cut into the medial side of the socket shank to allow entrance of the bulbous Syme stump end into the socket. The rounded bottom of the Syme socket is recessed into the top of a special type of SACH foot having a heavy keel with a narrow heel wedge. The socket and foot are united by a heavy steel bolt which passes through the keel and engages a concave washer set into the bottom of the socket flush with its inner surface.

By use of this design (Fig. 4), the completely intact anterior and posterior socket walls will provide a greater resistance to the high parasagittal stresses created during walking, thus increasing the structural strength of

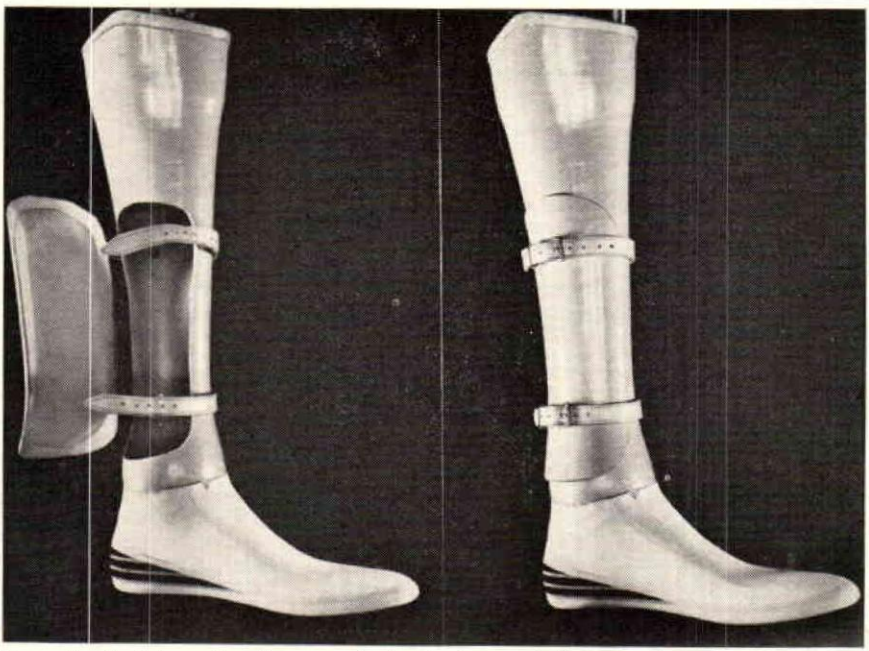

Figure 4. Medial-opening Syme prosthesis showing method of attaching "window" cover. Normally "Velcro" straps will be used to secure the cover.

the Syme prosthesis. There is no need for adding special reinforcements such as Fiberglas; only nylon stockinet and Dacron felt are used in the lamination.

D. Refinements in applications of existing materials and techniques.

EXAMPLE: A vacuum technique for porous lamination using long accepted lamination procedures and resins except that Helanca stretch nylon stockinet is used.

The nonpermeable plastic laminate sockets now generally used certainly have limitations in terms of providing a proper environment for the body. In a way, wood and leather sockets are superior in that moisture from perspiration might readily be transmitted or absorbed. But all realize the hygenic problems and the poor durability resulting from the use of either wood or leather; thus, The Army Prosthetics Research Laboratory devoted a considerable effort to the development of porous laminates, to provide diffusion of water vapor and improved comfort. That Laboratory reported: "Within the limits of strength requirements, maximum porosity should be the goal."

Based on the previous work of the Army Prosthetics Research Laboratory on porous epoxy laminates and most recently on porous polyester laminates using a Banlon knit stockinet, a somewhat different technique was developed by the VAPC for the construction of porous sockets. Both upper extremity sockets and below-knee sockets have been fabricated using a technique not too far different from present laminating procedure and using materials quite familiar to the limb industry.

The interior and exterior surfaces of the socket laminations are made smooth by using tubular Helanca nylon stockinet, of size large enough to cover the mold without stretching to minimize the "ribbing" effect caused by opening the stockinet weave. Approximately thirteen additional Helanca stockinet layers are used to form the bulk of the socket. But with these stockinet layers, between the inner and outer socket surfaces, a reduction in porosity will result because of the large number. These layers therefore must be stretched over the mold sufficiently to open the stockinet weave spaces. This is achieved by selecting a stockinet size requiring a stretch of twice its diameter to cover the mold.

Since, within the limits of strength requirements, maximum porosity is desired, a vacuum system is used to remove all excess resin from the interspaces of the stockinet weave leaving only the stockinet fibers saturated (Fig. 5). In this process, the vacuum also pulls air through the resin.

The mold is first covered with a PVA sleeve. The air space between the PVA and the mold is evacuated to provide an intimate mold separator. The first tubular Helanca nylon stockinet is pulled over the mold. The next thirteen layers of tubular Helanca stockinet are then *stretched* over

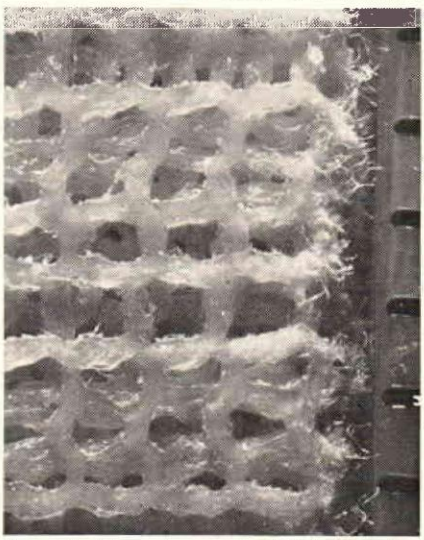

Figure 5. Photomicrograph of Helanca nylon stockinet showing the effects of vacuum lamination over stretched stockinet. Note: Absence of resin in interspaces but the saturation of the stockinet fibers.

the mold. The final layer of tubular Helanca stockinet should be large enough to be pulled on without stretching. A PVA sleeve is pulled over the lay-up to form the resin container. But the top of the sleeve is left open.

The resin is introduced to saturate the stockinet fully. After the stockinet is saturated, the inner PVA sleeve is perforated. The hole punched in the inner PVA sleeve now allows the vacuum, still applied to the inside of the inner PVA sleeve, to be also applied *between sleeves* or directly to the resin and will cause an air flow *through* the resin, producing porosity.

Although difficulties still exist in achieving uniform porosity in undercut socket surfaces, deviations from the present method are being investigated to overcome this problem.

DEVICE DEVELOPMENTS

A. The development of devices (prosthetic and orthotic components) providing a new function in an appliance.

EXAMPLE: The lower-extremity prosthesis torque absorber, a device designed to provide a controlled axial rotation in above-knee and below-knee prostheses.

Axial rotation of the leg segments is indeed an essential part of the dynamics of walking. Studies on amputees reveal a less than desirable gait and show an increase in shear stresses between the stump and socket if some axial rotation is not permitted.

A great portion of axial rotation normally takes place during the non-weight bearing phases of gait; a rather complex powered device would probably be required to duplicate this function. As a simplification and as a contribution at least to control of rotation during the stance phase, a unit which functions only against the torques occurring during weight-bearing was designed. The present experimental device is a simple two-piece design providing a controlled resistance to rotation. It can be used in either an above-knee or below-knee prosthesis.

The "rotator" (Fig. 6), a wafer type design, is 1 1/16" thick by 2¾" in diameter; thus, it can fit into nearly any adult prosthesis beneath the socket. The weight of the unit is approximately six (6) oz.

It consists of two aluminum plates joined by four set screws which hold a standard bearing, the main rotation element. The top plate carries a vane which rotates against four (4) gum rubber bumpers set into the bottom plate (Fig. 7). The material used as

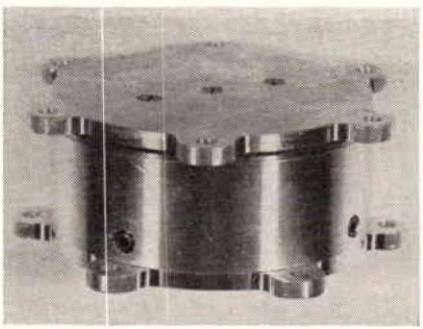

Figure 6. Torque absorber for above- and below-knee prostheses.

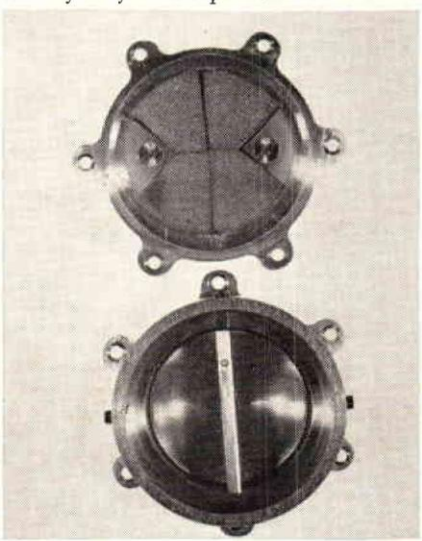

Figure 7. Internal view of torque absorber showing the elastomer inserts in the top section and the vane attachment in the bottom section.

well as the size and shape of the bumpers control the amount of resistance to rotation. The resistance of the present unit is 40 inch lbs./15° deflection each side of center.

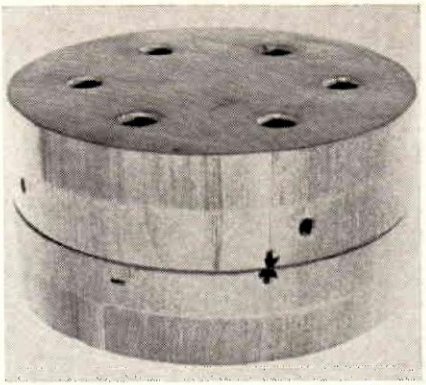

Figure 8. The torque absorber "sandwiched" between two pieces of wood to facilitate attachment to the prosthesis and for external shaping.

It is intended that the rotator element will be sandwiched between two pieces of wood when produced commercially (Fig. 8). Each inner surface of the wood plates is attached to the aluminum "rotator" by epoxy resin and machine screws. The top and bottom surfaces of the wood "sandwich" in turn, can be glued to the standard wood prosthetic shank providing a uniform base material for easy shaping and finishing. Current evaluation studies are concentrating on the following:

(1) The different resistance characteristics, if any, required in the above-knee and the below-knee prosthesis.
(2) The effect on the gait of an above-knee wearer of above-knee and below-knee locations for the "rotator."
(3) The different resistances that may be required in control of internal and external rotatory motions.

B. The development of devices used as instruments and tools in the preparation or fabrication of an appliance.

EXAMPLE: The alignment coupling, a device designed to facilitate the proper dynamic alignment between the various components of a lower extremity prosthesis (above-knee socket to thigh or knee and below-knee socket to shank or foot).

During the last few years prosthetic knee units containing varied and more highly refined functions have been developed for routine amputee use. The standard alignment device used (the adjustable leg) is a single axis mechanical friction device of pylon construction. Transfer of alignments obtained upon such devices will probably be inadequate when a knee-shank unit having entirely different functional characteristics is substituted. Ideally, the proper alignment of a prosthesis can best be achieved with the various *permanent components* adjusted under dynamic conditions, thus incorporating in the determination of alignment the integrated influence of the functions offered by all the components used.

Similarly, it must be understood that an existing alignment cannot be imposed upon a new socket in instances where the remaining components of a long-worn prosthesis will not be changed. The new socket fitting will influence the nature of the stump weight-bearing and control; the influences change with each new socket fitting as do the forces acting about the stump. For instance, maintaining a pre-set alignment of a prosthesis upon which a suction socket replaces a "plug-fit" will certainly cause problems. Such problems and alignment difficulties encountered during the early fittings of fluid-controlled knee mechanisms stimulated the development of the coupling.

The VAPC alignment coupling (Fig. 9) can be used to determine the best alignment of above-knee or below-knee prostheses using any prescribed combination of components (Fig. 10). The coupling has the rotary, angular

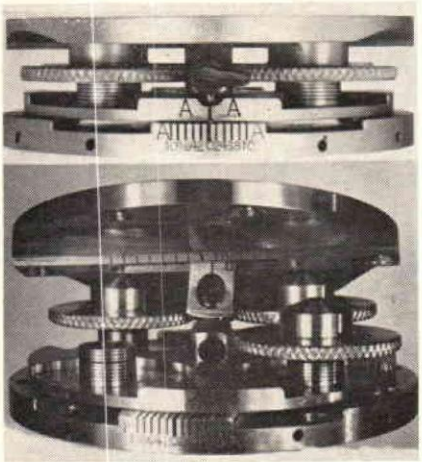

Figure 9. Alignment coupling.

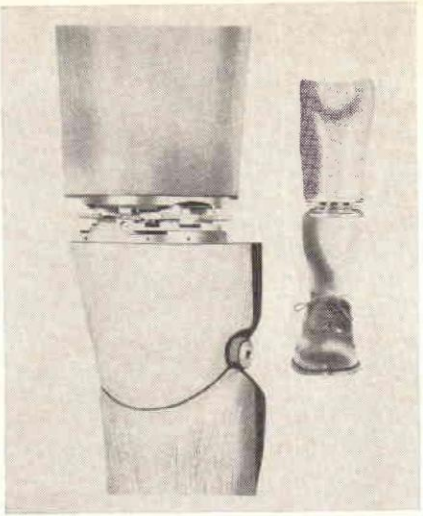

Figure 10. Alignment coupling in above- and below-knee prostheses.

and linear adjustments of both the above-knee and below-knee adjustable legs.

The coupling measures 3¾" in diameter, is 1⅛" thick (measured along the vertical centerline) and weighs slightly under 1 lb. It consists of two aluminum plates (top and bottom) joined centrally by a 1⅛" long stainless steel toggle-type column, having a circular slide on each end. The two plates contain countersunk holes to provide screw or bolt attachment to wood or metal prosthetic components above and below the coupling.

Each plate has a channel of rectangular cross-section (to contain the slides) for horizontal linear adjustments; the two channels are oriented at right angles to one another permitting full horizontal plane adjustment of one plate with respect to the other.

A third and intermediate aluminum plate rests upon the bottom plate and contains four threaded bushings fitted with four mushroom-shaped cap screws with knurled rims. The simultaneous adjustment of any two opposing screws (or screw-pairs) allows control of the angular relationship of the top plate with respect to the bottom (tilt). These adjustment screws, when firmly tightened, also serve to prevent any relative motion of all three plates. With the cap screws loose, rotation of the top plate with respect to the bottom one can be made.

The alignment coupling is designed as a simple device for economical production. Except for the central toggle, it was originally made of 7075 aluminum, but in production, aluminum-magnesium alloy castings have been employed. All components are of relatively simple design.

The unit provides combinations of the following adjustments in the ranges listed (the adjustment calibrations are primarily used to provide reference for readjustments):

Tilt, 10° in any direction between upper and lower plates.

Linear, Anterior-Posterior Positioning, 1½" both directions from center.

Linear, Medial-Lateral Positioning, 1¼" both directions from center.

Rotation, 10° both directions from center.

The coupling is used in the thigh section of above-knee prostheses. In the below-knee, as well as in the above-knee, the coupling should be inserted into the set-up as close as possible to the end of the stump. Placing

the coupling near the bottom of the socket will reduce the projected effects of angular adjustments which ordinarily necessitate linear (A-P and M-L) readjustments as compensation.

Alignment duplication is achieved by use of the alignment duplication jig or the transfer compass. The procedure of transfer using the alignment duplication jig requires one saw cut above and parallel to the coupling base. The location of the cut can be made to coincide with the thickness of a pre-cut wood block. The procedure of transfer using the transfer compass also involves a saw-cut 2 inches above and parallel to the coupling base to match a pre-cut wood block made two inches thick. Use of the transfer compass enables the prosthetist to locate the level and orientation of the saw cut which can be made on a band saw.

In addition to the functions previously mentioned, the coupling may be used in temporary prostheses to provide a continuing means of adjustment during the prosthetics training of a patient. It has also been found valuable in research to determine the mutual effects that the functional characteristics of various combinations of prosthetic components and alignment have on each other.

C. The development of devices necessary for a new technique, method, or concept.

EXAMPLE: VAPC Casting Stand (Figure 11), a device using three separate and adjustable components to form the cast of a thigh stump under weight-bearing or with two other adjustable components, to form the cast of a below-knee stump under weight-bearing.

Use of the quadrilateral above-knee suction socket has certainly contributed to the reduction of problems in fitting the above-knee stump. Although problems in body-weight support and prosthesis control were appreciably diminished by the rationale underlying quadrilateral socket shape, the high contrast in the forces acting about the thigh stump (1) in the upper areas (positive forces at ischial level) and (2) in the distal areas (negative forces at stump end) still created a serious problem in further restricting an already disturbed circulatory mechanism. To overcome this difficulty particularly, a new socket-fitting concept (total contact) has been introduced. Now the entire stump is made to have contact with the socket wall but still with control of the distribution of weight and other forces acting on the various stump tissues according to the individual capability of the tissues. Of great significance is the control of the force magnitudes as functions of levels within the socket but particularly the forces created about the stump end. Since suddenly changing force distributions can be as detrimental, if not more so, than an overall high force distribution, techniques such as the "tension analysis" system of UCLA have proven very advantageous for controlling the gradient of forces within the socket. The success of this technique indicates that primary socket fitting should be based on circumferential measurements along the length of the stump.

Casting the Above-Knee Stump

A pressure gradient must be planned into the socket beginning with a very low pressure (contact) at the bottom and increasing gradually to the forces required to provide the main control and weight-bearing at the top. To make a socket that will provide a stabilization of the stump under conditions of high force concentrations, it is first necessary to plan the socket shape so as to accommodate the stump changes which occur during periods of high force (in the stance or weight-bearing phase). Full control of the fit is probably most nearly achieved with a socket fabricated over a stump replica

formed from a weight-bearing cast. Unfortunately, we must deliberately deform the upper thigh stump to place a nearly vertical component of support under the ischium and gluteofemoral areas.

In addition, when using a weight-bearing method of casting in which the entire stump is wrapped, the overall forces are distributed about the entire periphery of the stump minimizing distortion of tissue. Although the tissue mass of the thigh stump appears to accommodate distortion in any direction, each muscle compartment is confined within the fascial bulkheads formed by the connecting tissues, aponneuroses and fascia, etc., restricting the deformation to the limits imposed by these structures. Often during surgery, however, the muscle packs at the site of amputation are severed and may retract somewhat. Slight stump elongation which occurs during casting takes place within these muscle groups thus helping to restore them to a safe anatomical attitude.

Hence, a device (Figure 11) was designed to form the cast of a thigh stump under conditions of weight-bearing. The device consists of (1) a stand assembly, (2) cross member assembly, (3) posterior socket form, (4) anterior socket form and (5) lateral socket form (Figure 12).

The stand assembly includes a vertical upright, a base plate, and a vertical traversing head. The cross member provides adjustable attachments for the socket form brackets and for positioning the lateral form. This assembly is attached to the stand assembly and is pivoted around an axis at right angles to the upright to provide flexion and extension adjustment of the forms (as a unit).

The posterior socket form consists of the major weight support surface and part of the vertical posterior wall with a section representing part of the medial wall. The contour of the posterior form is based upon concepts of socket shape developed from successful quadrilateral fittings and anthropometric measurements. The medial section of the posterior socket form helps to establish the medial-to-lateral width of the socket and the proper position (medial-lateral) of the ischium upon the posterior socket support. The pos-

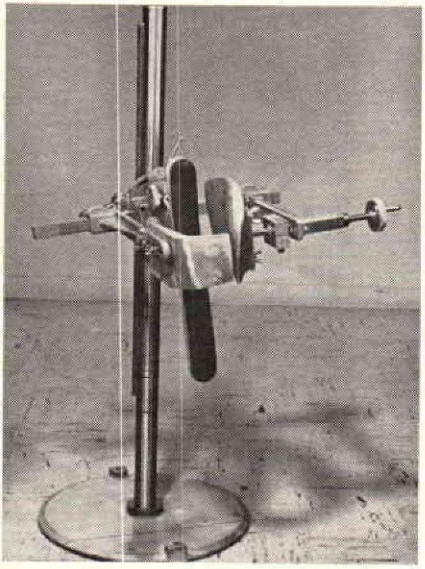

Figure 11. Casting stand with above-knee forms.

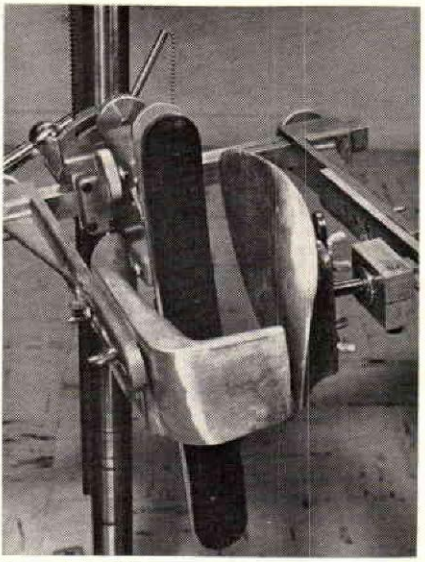

Figure 12. Close-up of above-knee casting forms showing contours and apparatus for adjustments.

terior socket form is adjustable with respect to the stump in a medial-lateral plane. This medial-lateral adjustment is used to orient the adductor longus tendon in its proper position relative to the anterior socket form.

The anterior socket form contains a proximal anteromedial flare and a rectus femoris channel. The form is pivoted so that a reasonably even distribution of the posteriorly directed forces will result within the guides provided by this form's shape. A locking mechanism is provided locking the pivot of the anterior form once the proper attitude has been achieved. The resistive characteristics of the stump tissues and the individual contours of the stump tissues and the stump position in relation to the contours of the forms determine the orientation of this form when it is pressed against the anterior of the stump. The anterior section is also adjustable in position proximally and distally, a control used depending upon the length of stump. Usually a low position is used for long stumps and a higher one for short stumps.

The lateral socket form consists of a flat surface adjustable for varying degrees of adduction or abduction. Adjustments are also provided for medial or lateral positioning of this form as well as for a limited range of flexion-extension. The normally flat surface of the form can be readily given rather sharp curves to provide the contouring necessary for the best lateral support.

Before casting the stump, the patient must be carefully examined and all pertinent prosthetic information recorded on an information form. This information will be used to define the most nearly exact contours and size of the socket.

An estimate is obtained by a socket plan based on stump dimensions. The following rules for the initial plan have proved successful:

a. 1/3 of the most proximal circumferential stump measurement is used for the initial setting of the M-L socket dimension.
b. 1/5 of the most proximal circumferential stump measurement is used for the initial setting of the A-P socket dimension.

Further refinement of the contour provided by the socket forms is achieved by trial adjustments of the various segments of the stand about the unwrapped stump. Once the correct settings are achieved the forms may be lowered away from the stump.

The patient's stump is then wrapped with elastic plaster-of-Paris bandage and then after the positions of the forms have been adjusted to compensate for the thickness of the wrap, the fixture is elevated about the stump restoring the original position of weight-bearing.

The elastic plaster-of-Paris wrap provides the tension required to maintain the stump volume during the shaping process in the casting fixture. The forms shape the cast to provide the socket contours which stabilize the stump at a prescribed attitude under weight-bearing conditions.

Previous methods of mold modification have required a careful analysis of stump musculature to classify its resiliency (soft, medium or firm). Based upon these criteria a pre-determined amount of material was removed from the mold to provide a desired tension within the socket. We have found that stumps cannot be so simply classified but range in degrees of softness and firmness. The varied reductions in stump volume caused by casting are proportionate to the muscular resistance to compression and distortion. Hence, the most dependable method for classification of stump musculature is based upon the amount of stump distortion (circumferential reduction) which occurs during casting—as compared to the circumferential stump measurements originally recorded.

In this present method, classification of stump resiliency for mold modification is no longer required. The casting pressures will cause the magnitude

of volume change (circumferential reduction) to be greater on soft stumps and less on firm stumps. Hence, further reductions to the cast circumferential measurements are made using the reduction factors indicated on the work sheet shown as Figure 13.

WORK SHEET FOR TOTAL-CONTACT SUCTION SOCKET

	ORIGINAL STUMP MEASUREMENTS COLUMN A	MOLD MEASUREMENTS COLUMN B	MOLD MEASUREMENT REDUCTION SCALE COLUMN C	MODIFIED MOLD MEASUREMENTS COLUMN D
CIRCUMFERENCE 0" (ISCHIAL LEVEL)			MOLD MEASUREMENT Less 1/2" to 5/8"	
CIRCUMFERENCE 2" BELOW			MOLD MEASUREMENT Less 1/4" to 3/8"	
CIRCUMFERENCE 4" BELOW			MOLD MEASUREMENT Less 1/8" to 1/4"	
CIRCUMFERENCE 6" BELOW			MAINTAIN ORIGINAL STUMP MEASUREMENT	
CIRCUMFERENCE 8" BELOW			MAINTAIN ORIGINAL STUMP MEASUREMENT	
CIRCUMFERENCE 10" BELOW			MAINTAIN ORIGINAL STUMP MEASUREMENT	
CALCULATE A-P & M-L from CIRCUMFERENCE at ISCHIAL LEVEL A-P = 1/5 of the CIRCUMFERENCE M-L = 1/3 of the CIRCUMFERENCE				
CALCULATED ORIGINAL A-P →			RE-CALCULATED A-P BASED ON MOLD CIRCUMFERENCE IN COLUMN B ←	
CALCULATED ORIGINAL M-L →			RE-CALCULATED M-L BASED ON MOLD CIRCUMFERENCE IN COLUMN B ←	

Figure 13.

Although initial A-P and M-L dimensions have been established for casting the stump, these dimensions were computed from the original *stump* circumferential dimensions. Once the proximal *mold* dimensions have been established, it is necessary to recompute the A-P and M-L dimensions based upon the smaller mold measurements (the new, compression-dependent proximal circumference) resulting from the tension of the elastic plaster wrap and the casting process itself. The work sheet illustrates the mold modifications required after casting to control the forces acting upon the entire stump particularly the proximal-distal gradient of these forces.

Casting the Below-Knee Stump

Fitting of the below-knee socket requires considered technical skill and experience. The more successful prosthetist will understand the weight-bearing capabilities and the physiological functions of the anatomical knee structure. Although the major weight-bearing areas of the below-knee stump have been clearly defined and have been recognized in practice for many years, the development of standard, reliable fitting methods exploiting the full weight-bearing capacity of these areas has not yet been achieved. Primary are those problem areas over the various bony prominences which still create fitting difficulties due to improper socket size and contouring.

Carving of a well-fitted wood socket is extremely difficult since the socket must first be made large enough for stump entrance which is used to determine fitting contours. Any socket reliefs necessary for intimate contouring will reduce the effectiveness of the weight-bearing surfaces since such subsequent carving in the socket for purposes of "relief" results in an additional

increase in socket volume. The resulting error is usually of sufficient magnitude to permit the stump to drop further into the socket, off the intended weight-bearing areas. Each time the procedure is repeated the effectiveness of the intended weight-bearing areas is further reduced.

Stump casting methods which require cast modifications by removal of material over weight-bearing areas and build-up of material over bony prominences similarly cause problems in socket fitting. Modifications usually adversely affect the transverse dimensions of the stump replica which has been taken from a non-weight-bearing cast by finger and hand deformations. These methods do not provide reliably the accuracy in socket size and contouring necessary for proper weight-bearing.

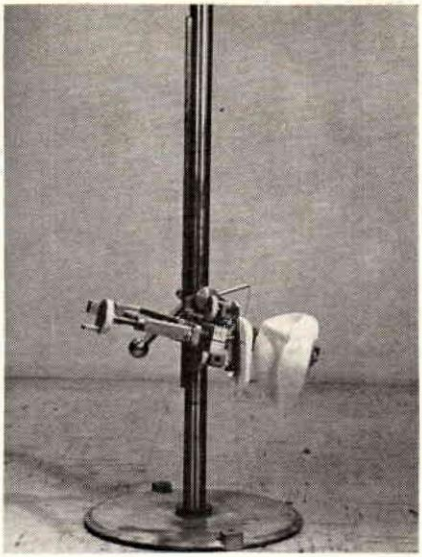

Figure 14. Casting stand with below-knee casting forms.

Recently, a stump casting method was developed limiting body weight support to the designated weight-tolerant areas of the below-knee stump as a cast impression was made. Subsequently, below-knee casting forms were made adaptable for use with the VAPC above-knee casting stand (Figure 14).

The casting forms consist of two sections:

(1) An anterior section internally shaped to provide stump contact anteriorly in the known weight-tolerant areas.

(2) A posterior section designed to provide the necessary counter-forces against the posterior of the stump.

During casting the pre-positioned forms (Figure 15) provide stump support only in the intended weight-bearing areas. The non-weight-bearing contours of the stump are formed by the elastic plaster-of-Paris wrap.

The proximal portion of the anterior socket form is contoured to provide patellar tendon support. The anteromedial and anterolateral oblique walls are contoured to establish firm stump contact on both sides of the tibia. In this manner, contact along the anterior crest of the tibia is prevented. The form contour immediately below the patellar tendon protuberance creates a concavity of sufficient size to prevent contact of all the bony anterior tibial protuberances: the tibial tubercule, the anteromedial tibial condyle, the anterolateral tibial condyle, and the crest of the tibia.

The anterior below-knee socket form is mounted upon a plate having attachment screws which mate in the slots of the form-holding bracket. These slots provide medial and lateral position adjustments of the form. Angular adjustments of the below-knee forms are provided by means of a pivot in the center of the plate.

The proximal portion of the posterior form is contoured to provide the upper posterior socket flare, to shape a relief for the hamstring tendons. The form is tapered distally to encompass the gastrocnemius bulge preventing the formation of steps in the cast.

The posterior below-knee form contains two bolts for its attachment to the form-holding bracket. The bracket is slotted providing a vertical sliding

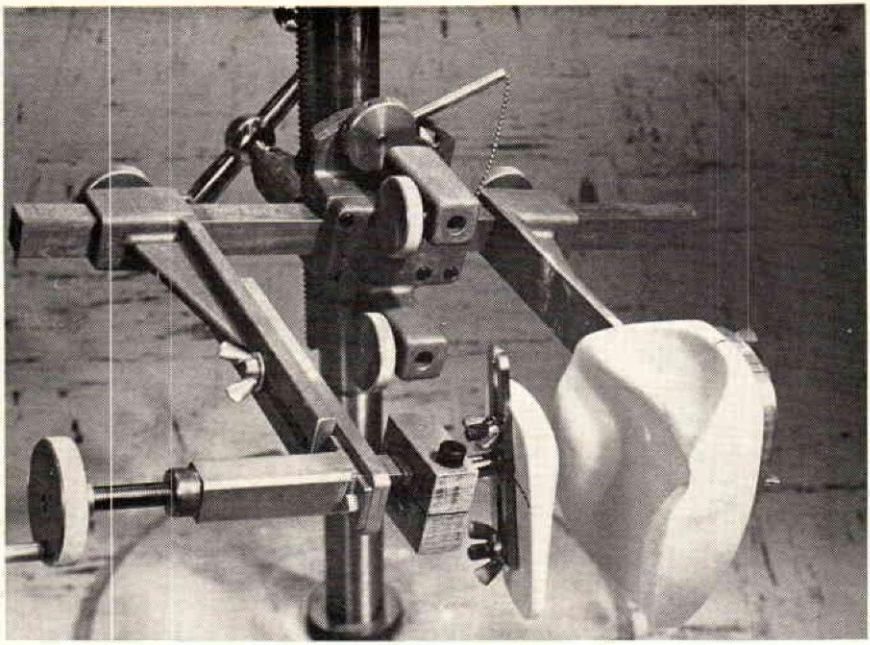

Figure 15. Close-up of below-knee forms showing contours and apparatus for adjustments.

adjustment. The bracket provides a pivot with a locking mechanism to secure the posterior form in any position.

The below-knee casting procedure is similar to that used in above-knee stump casting. The casting stand is adjusted to the proper height and the angular orientations of the forms are established. Pre-fitting adjustments of the various segments of the stand are based on prosthetic information data. During the trial fitting the patient stands with his stump held between the casting forms (with the patella on the form's tendon protuberance). The posterior form is moved against the back of the stump to provide contact. Using the small wheel adjustment on the bracket, the A-P distance is reduced until the patient's weight is *partially* supported. The proper distance between the two forms is established when the patient no longer feels the tendency to slip "through" the "socket" and is still able to pull his stump up between the forms. The bracket positions are marked to serve as references for proper repositioning when shaping the cast subsequently. Also an outline of the sound foot is traced on a paper secured to the floor; this defines a reasonably exact alignment reference for restoration of the patient's original position.

The elastic plaster-of-Paris wrap then placed on the stump provides the tension required to maintain the volume of the stump during the shaping process in the casting fixture. The fixture forms shape the cast to provide the socket contours which stabilize the stump in the prescribed attitude and under weight-bearing conditions.

The stump replica resulting from a cast taken in this manner represents the shape, size and contour of the below-knee stump under weight-bearing conditions. The PTB hard socket with closed-end and the PTB conventional socket may be fabricated over the cast *normally without* further modification. NOTE: This model requires the addition of an extension to the mold for the open-end socket, the socket with foam-end, below-knee weight-bearing brace sockets, and Syme sockets.