Dynamic Alignment of Artificial Legs with the Adjustable Coupling

ANTHONY STAROS, M.S.M.E.[1]

SINCE World War II one of the most significant advances in limb prosthetics has been the introduction of rational principles for fitting and aligning artificial legs *(2,11)*. The University of California (Berkeley—San Francisco), sponsored by the Veterans Administration, has been primarily responsible for the steady improvement in methods and devices used by prosthetists in artificial-leg construction.

To assist the prosthetist in carrying out these principles, a number of mechanical aids or tools were devised. The two adjustable legs—one for above-knee cases (Fig. 1), the other for cases below the knee (Fig. 2)—and an alignment duplication jig (Fig. 3) were developed by the University of California, and are now recognized as important tools of the prosthetist *(4)*. And dynamic alignment of artificial legs is a standard part of the curriculum of prosthetics schools *(1)* and standard operating procedure in most limbshops.

But there have been problems. For one, the limbshop must have a minimum of two adjustable legs for adult cases, and two smaller ones for child cases. A shop of any size requires multiple quantities because frequently a given unit must remain attached to a socket for a particular amputee for an extended period of time. And to make best use of the adjustable legs an alignment transfer jig is needed.

Other limitations in the above-knee adjustable leg appeared when knee units or knee-shank-foot units with fairly complex functions were introduced. Use of the UC adjustable AK leg, with its single-axis, constant friction joint for achieving alignment which is to be transferred to a permanent leg having a somewhat different type of function, is a questionable procedure; i.e., alignment suitable for a constant friction unit may not make proper use of the functions provided by more sophisticated devices. Some prosthetists have learned to accommodate for the required deviations by rules of thumb, but essential are some method and some tool for dynamic alignment to be made directly on the knee or knee-shank-foot mechanism to be used in the final prosthesis.

Ideally, the device should be of simple design and useful for both above-knee and below-knee cases. For the above-knee case, such a device should be inserted between the socket and permanent prosthetic knee for "functional" alignment.

If the unit were simple enough, it would be expected that more generalized use of alignment tools might result, and that facilities in other countries, where it is difficult to procure adjustable legs, could enjoy the advantages of dynamic alignment. Moreover, the alignment-transfer process needed scrutiny to see if simplifications in the equipment necessary might result.

For these reasons, the VA Prosthetics Center developed the Adjustable Coupling, sometimes termed the "Staros-Gardner Coupling."

DESCRIPTION OF THE ADJUSTABLE COUPLING

The adjustable coupling (Fig. 4) consists essentially of two plate assemblies held together by a central toggle pin. Mounted to a middle or intermediate plate but part of one plate assembly are four screw subassemblies, spaced 90 deg. apart, which contain independently adjustable, knurled screws used to "lock" the entire coupling as well as to provide

[1] Chief, Veterans Administration Prosthetics Center, 252 Seventh Ave., New York 1, N. Y.

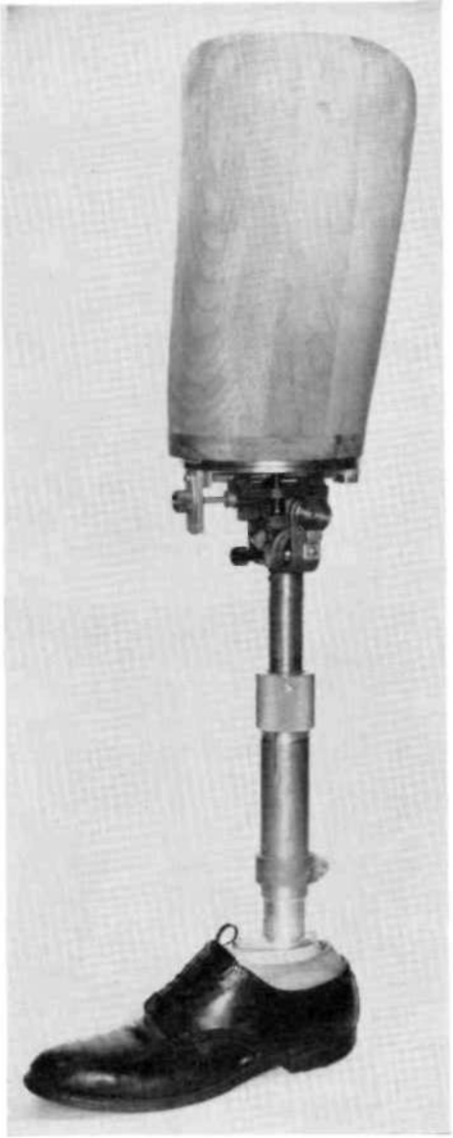


Fig. 1. An above-knee adjustable leg.

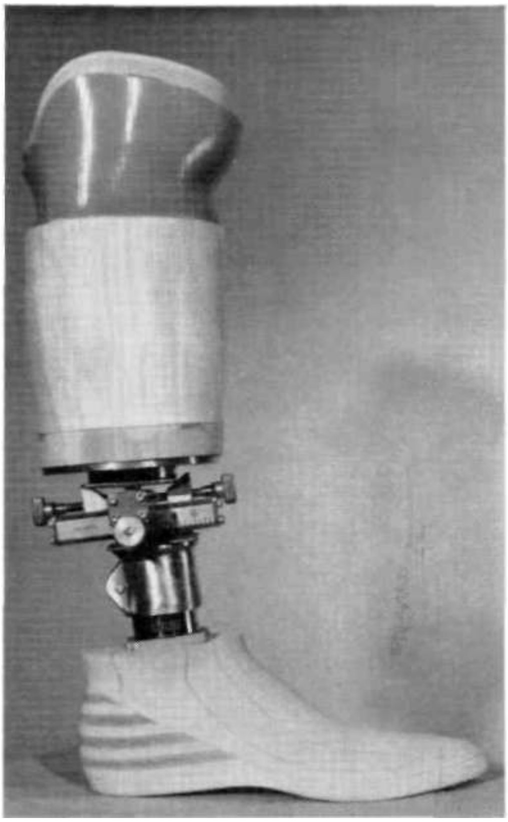


Fig 2. A below-knee adjustable leg used in current practice.

adjustment for adduction-abduction and flexion-extension.

In Figure 5 are illustrated the major assemblies of the coupling. The single-flange part of the toggle and the top plate constitute the top assembly. The bottom assembly contains the "box" part of the toggle, the bottom plate, the intermediate plate, the four tilt-screw subassemblies, and the toggle pin. The bottom and intermediate plates both contain "A" and "P" marks to indicate the anterior and posterior sides, respectively. The two assemblies contain countersunk holes for screws used for attachment to the prosthesis.

The top assembly, primarily offering mediolateral and tilt adjustability, contains a 1-1/4 in., 1/8 in. increment scale for gauging mediolateral adjustments (with an index on the single-flange toggle which is free to slide with respect to the top plate). A tilt scale[2] is provided by markings on the threaded bushings of the four tilt-screw subassemblies. The

[2] All scales have "neutral" positions highlighted. The "neutral" positions on the tilt scales are most important in establishing the middle position of tilt, when top and bottom plates are parallel, or for disassembly, when it is important to "unlock" the coupling by having *all four* tilt screws down at least two increments below "neutral."

indexes for tilt scaling are the lower surfaces of the knurled screws. Scale sensitivity for tilt adjustment is 2 deg.

The bottom assembly provides rotation about the vertical axis and anteroposterior adjustability because the intermediate plate (and toggle "box") is free to move with respect to the bottom plate. On the anterior surface of the bottom plate is the 20-deg. (2-deg. increment) rotation scale. The index is located on the intermediate plate. The anteroposterior adjustment scale consists of a series of arcs, 1/8 in. apart for 1-3/4 in., etched on the top surface of the bottom plate. The index for this scale is simply the outer contour of the intermediate plate.

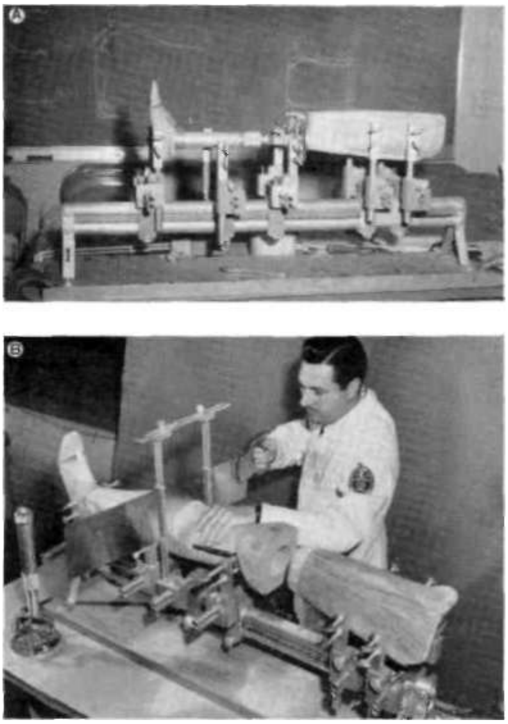


Fig. 3. Alignment duplication jig. A, Adjustable leg mounted in jig. B, Adjustable leg has been removed and wooden set-up substituted. Prosthetist is sawing shank to proper length.

Fig. 4. The adjustable coupling assembled.

The coupling, made primarily from an aluminum alloy (except for the toggle assembly which is steel), weighs 12 oz., is 3-3/4 in. in diameter, and is 1-1/8 in. thick when the plates are parallel. Ranges of adjustment are as follows:

1. *Mediolateral:* Total Range—1-1/4 in.
   Increment of Scale Markings—1/8 in.
2. *Anteroposterior:* Total Range—1-3/4 in.
   Increment of Scale Markings—1/8 in.
3. *Tilt:* Total Range—10 deg.
   Increment of Scale Markings—2 deg.
4. *Rotation:* Total Range—20 deg.
   Increment of Scale Markings—2 deg.

The coupling is disassembled by first lowering each of the four tilt screws two increments on the tilt scale. This operation loosens the entire assembly because it is held together as a result of the forces produced by tightening the force screws, and the toggle pin can thus be disengaged from the toggle box and flange. The top assembly and bottom assembly can then be separated.

Installation of the coupling into a prosthesis is made with the coupling so separated.

INSTALLATION OF THE COUPLING FOR DYNAMIC ALIGNMENT *(10)*

Figures 6 and 7 show the coupling in position for dynamic-alignment trials. When installed, the coupling should be located as close as possible to the distal end of the stump. A piece of material may have to be added to accommodate the wood screws without affecting the socket sealing plate itself. By so locating the coupling, small tilt adjustments on the coupling will produce major changes in the geometrical relationship of stump to prosthetic components distal to the coupling. When the "bench" or static alignment is reasonably close, the 10 deg. range of tilt adjustment is more than adequate.

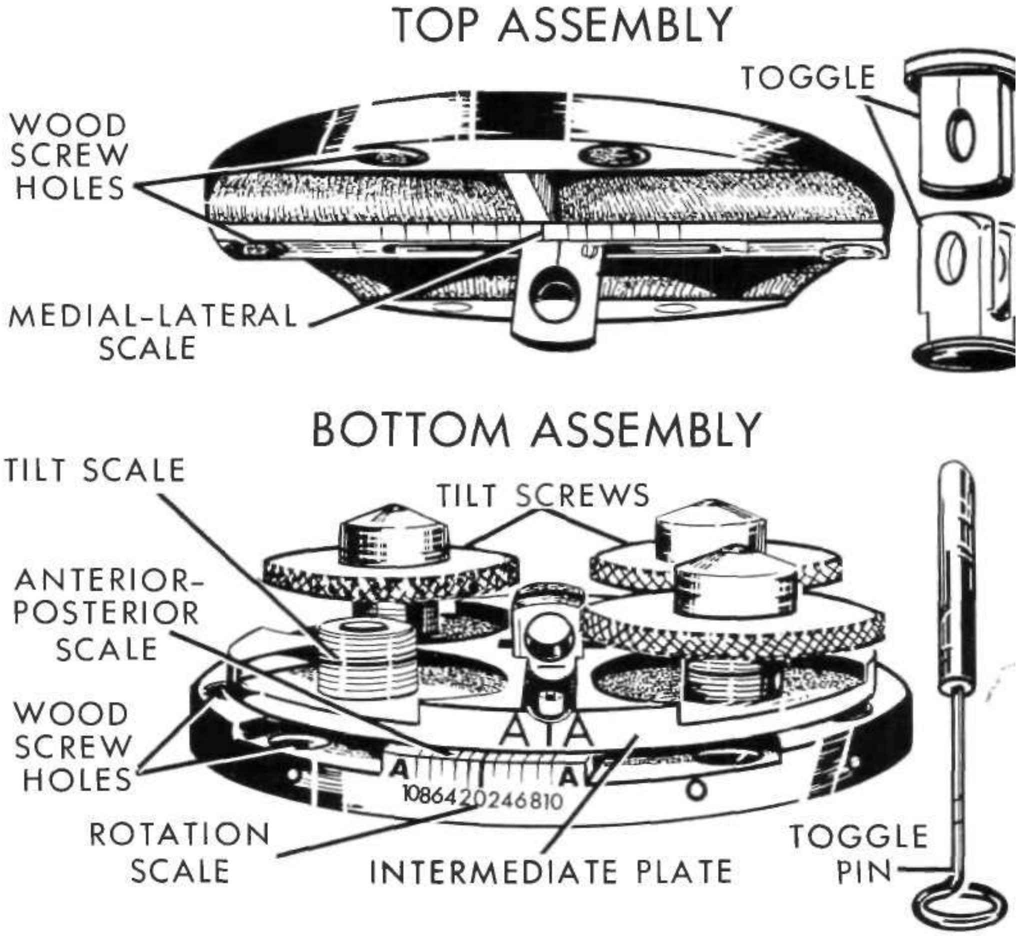


Fig. 5. Major assemblies and parts of the adjustable coupling. The toggle pin is permanently located in the semi circular channel just above the AA marks on the intermediate plate. From *(10).*

After the socket is constructed and the components approximately dimensioned[3] lengthwise, the top assembly of the coupling is attached to the bottom of the socket using as many wood screws as possible (Fig. 8). The bottom assembly then is attached to the top assembly by placing the single-flange part of the toggle within the "box" part and pushing the toggle pin through the holes in both toggle parts. One must make certain that the "A" marks (or "P" marks) are located properly with respect to the socket. The coupling is then set with all adjustments on "neutral" so that top plate and bottom plate are parallel and coaxial, care being taken to ensure that the intermediate plate is not rotated with respect to the bottom plate.

The socket with the coupling attached is then temporarily placed on the above-knee setup (knee-shank-foot) or on the below-knee setup (shank-foot). A height check[4] is made with the amputee standing on the prosthesis.

[3] The over-all length of socket, knee unit, shank piece, and foot, plus 1-1/8 in. for the coupling, should be slightly larger than the amputee's dimensional requirements. Later sanding after a height check will produce accurate longitudinal dimensioning.

[4] With especially long above-knee stumps, the knee center must be dropped during alignment trials because of the thickness of the coupling. Later, during transfer, true or near-true knee-center height can be restored.

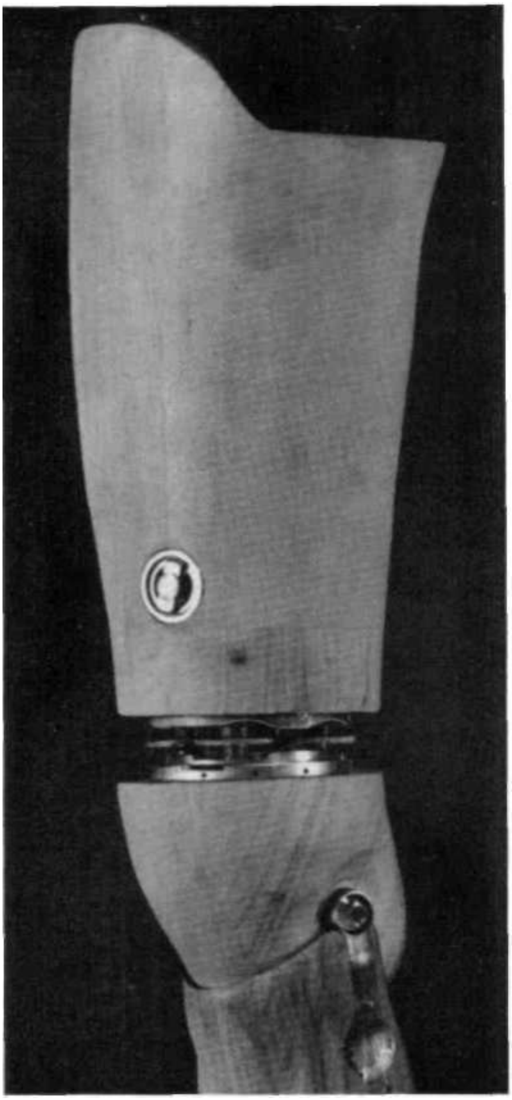


Fig. 6. The coupling installed in an above-knee prosthesis.

Since the coupling has not been fully assembled into the prosthesis, the prosthetist must, of course, assist the amputee in maintaining stability. After the height check has been made, the section of the prosthesis below the coupling (on the knee block or shank) can be sanded to obtain the correct height.

One must consider the desired static or bench alignment before fully attaching the bottom plate assembly to the prosthesis. A recently published chart (8) shows recom-

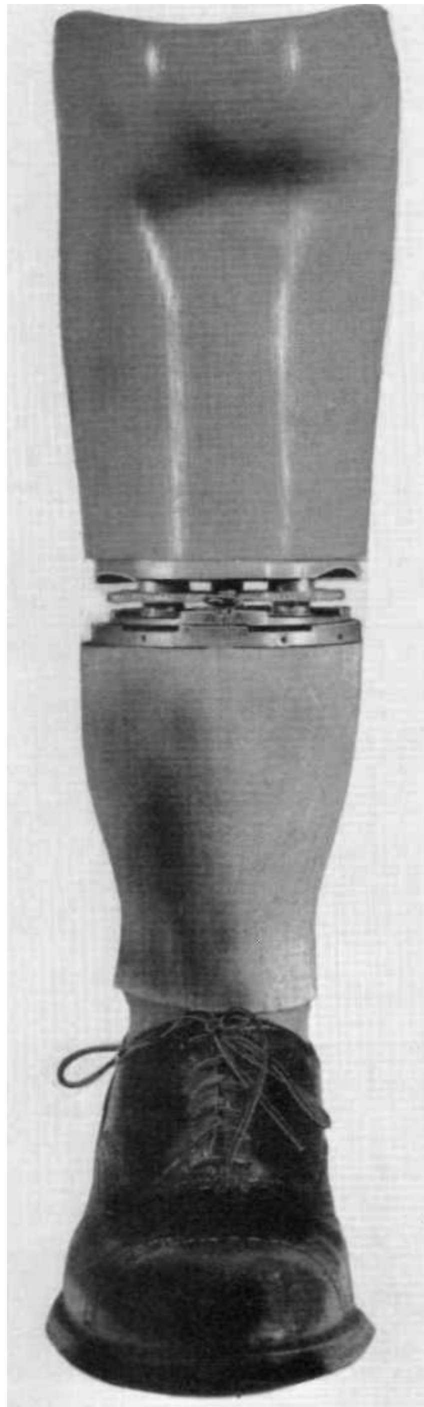


Fig. 7. The coupling installed in a below-knee prosthesis. From *(10).*

mended guides for "bench" alignment when the SACH foot is used. In any case, care should be exercised in locating the bottom assembly to assure that the ranges of adjustment available in the neutrally set coupling will not be exhausted during dynamic alignment.

When the bottom plate is being installed, the countersunk clearance holes are made accessible by shifting the intermediate plate with respect to the bottom plate (Fig. 9).

Dynamic alignment can begin when the coupling is reassembled and "locked" in the neutral position. This procedure should ordinarily be carried out in the following fixed sequence, making the linear adjustments first and the lilt adjustments second:

1. With the amputee *seated,* loosen only the two *front* tilt screws and make the ANTEROPOSTERIOR adjustment. Tighten the two front screws.

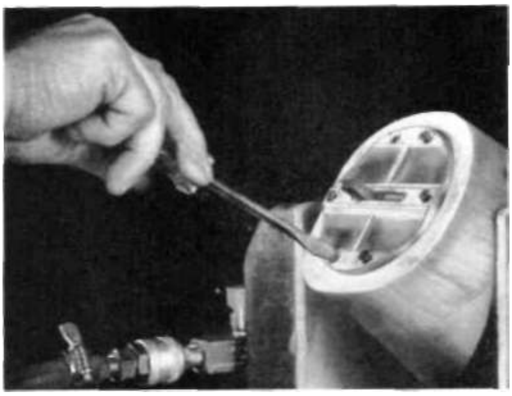


Fig. 8. Attaching the top assembly of the coupling to the bottom surface of the above-knee socket

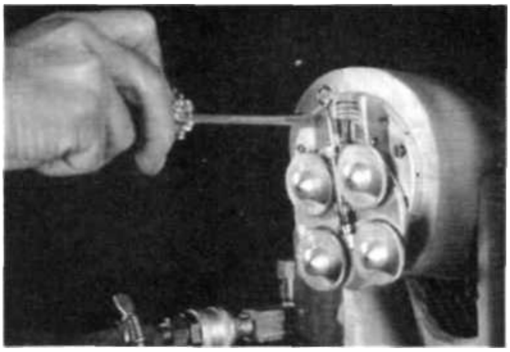


Fig. 9. Attaching the bottom assembly of the coup ling to the top surface of the knee block.

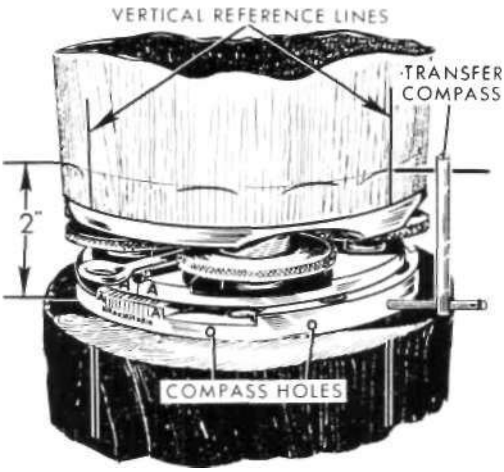


Fig 10. Use of the special compass for an alignment-transfer reference. The vertical reference lines will be used to reestablish anteroposterior, mediolateral. and rotation positions. The horizontal line tangent to the tops of the compass arcs will reestablish tilt. From *(10).*

2. With the amputee *seated,* loosen only the two *front* till screws and make the MEDIOLATERAL adjustment. Tighten the two front screws.

3. With the amputee *standing,* provide TILT adjustment by turning down one of the two tilt screws *on the side to be depressed* (The screw should be turned down only as far as needed for the angular adjustment desired.) Then tighten the till screw diagonally opposite to establish the angular adjustment desired. Next loosen (the same amount) the second screw on the side to be depressed and tighten the screw diagonalh" opposite to complete the angular adjustment and "lock" the coupling.

4. ROTATION may be established or reestablished before the screws are completely tightened in any of the above three adjustments. The rotation scale reading may be recorded before making any adjustment so that the position of rotation may be readily restored.

Alignment Transfer

No special jig is required for alignment transfer with the coupling. Actually, alignment is not "transferred" but rather "maintained" while the coupling is replaced with a permanent material.

Around the periphery of the bottom plate of the coupling, there are ten radial holes located 36 deg. apart that serve as centers for a special compass which is used for scribing reference marks on the socket after dynamic alignment has been completed. The alignment compass is inserted in each of the holes in the periphery of the bottom plate, and small arcs are drawn or scribed on the socket base (Fig. 10). The *tops* of these arcs are then connected bv a circumferential line which will be exactly

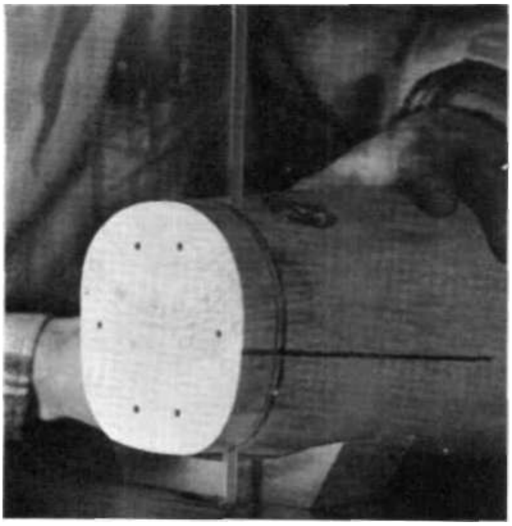


Fig. 11. Using the band-saw to cut the socket immediately below the horizontal-circumferential reference line.

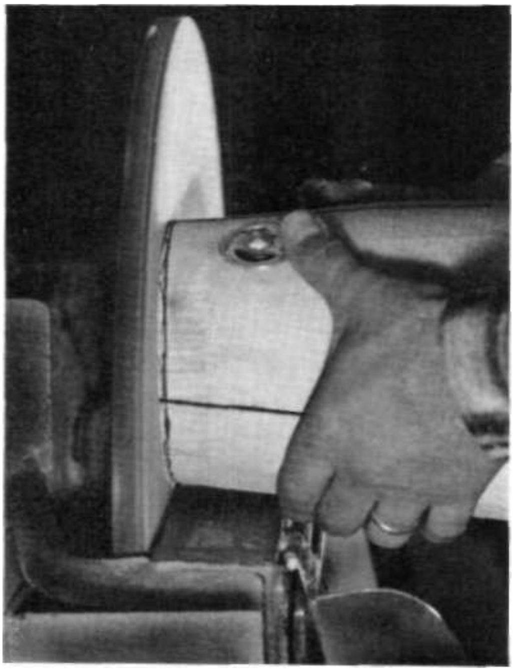


Fig. 12. Sanding of the socket to the horizontal-circumferential reference line,

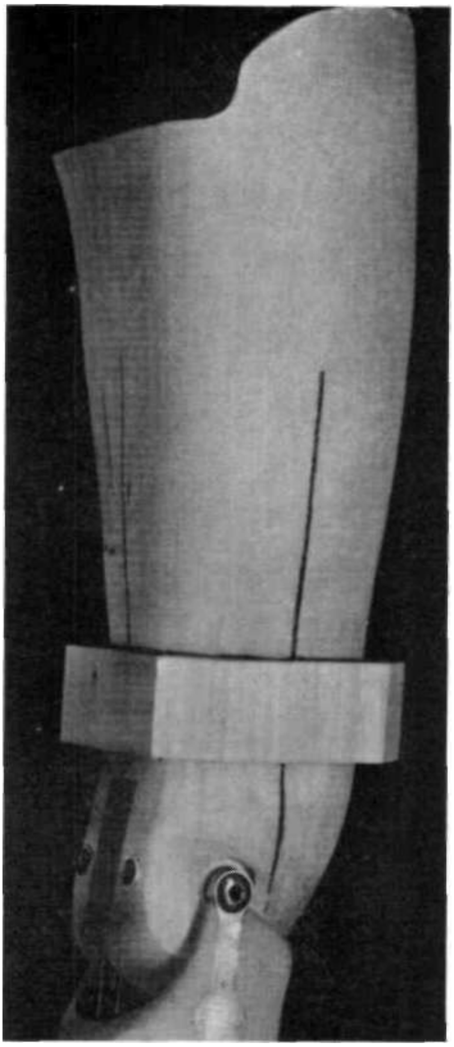


Fig. 13. Replacement of the coupling with a 2-in. wood block. Coincidence of the vertical reference lines must be restored in the alignment-transfer process.

2 in. above the bottom surface of the bottom plate and parallel to it.

At least four vertical reference lines (90 deg. apart) are made on the socket and continued onto the distal component (knee block or shank).

The toggle pin of the coupling is removed and the top and bottom plate assemblies are detached from the socket and from the knee block (or shank).

A saw cut is then made in the socket base[5] *just below* the horizontal circumferential line (Fig. 11) and the socket base is sanded to the line (Fig. 12). A 2-inch-thick wood or foam block (with parallel top and bottom surfaces) is then placed between the socket and the knee block (or shank). The wood or foam block is then firmly attached (with cement, resin, and/or other fastening media) to both socket and knee block (or shank), care being taken to restore the coincidence of the vertical reference lines on the assembled components (Fig. 13). Although not necessary, an apparatus for holding the parts together during cement or resin cure can be used.

If one wishes, the standard alignment transfer jig may be used instead. Following standard procedures, the prosthesis with the coupling may be fixed in the jig and then the coupling removed. Saw cuts through the socket base and knee block (or shank) and substitution of an appropriately sized block of wood will be needed. In the above-knee limb transfer, one saw cut in the socket base will be sufficient if the prosthesis is mounted in the jig with the bottom plate of the coupling perfectly perpendicular to the long axis of the jig.

EXPERIENCE WITH THE COUPLING

The coupling, although primarily designed as a simple device for alignment of "permanent" lower-extremity prostheses, can also be used for temporary, or interim, prostheses.

The coupling has been in routine use in the Limb and Brace Section of the VA Prosthetics Center since March 1961. The numbers of permanent prostheses aligned with the coupling in the 22-month period ending December 31, 1962, were as follows:

Hip-disarticulation	13
Above-knee	130
Knee-bearing	16
"Bent"-knee	3
Below-knee	192

[5] Normally, if there is enough material here for the wood screws to attach the coupling, there will be enough material for this saw cut and the subsequent sanding without disturbing the socket itself.

In addition, 34 above-knee and 22 below-knee sockets were replaced on existing prostheses by use of the coupling.

Experience indicates some economic benefits in use of the adjustable coupling. Starting at the same point in an above-knee prosthesis fabrication (with the socket roughly fitted), the adjustable leg—transfer jig procedure takes, on the average, slightly over 1/2 hr. more than the coupling-compass procedure. The end point for this time measure, in both procedures, is completion of alignment transfer with the prescribed prosthetic components assembled.

A more significant advantage of the coupling accrues from its use in aligning above-knee prostheses when special knee or knee-ankle mechanisms have been prescribed. A prosthesis system with functional features providing more than just a mechanical-friction control at the knee may require some deviation from that alignment which might be used with only mechanical friction. Even an extension bias strap will affect the alignment to be used. Thus, for such devices as the Bock Safety Knee, the Hydra-Cadence (with a relatively free plantar-flexion control), the Mauch hydraulic devices, polycentric linkages, and others, it is well to align the prosthesis with the prescribed special-function system installed. The coupling is designed primarily for dynamic alignment of such systems.

Added to the economic advantage of one device for both below-knee and above-knee use is the simple and inexpensive process for alignment transfer. For a new shop, this means that investment in an expensive jig is not mandatory. Also, because of the comparatively low cost of the coupling itself, many more alignment devices can be available in the shop. Thus, shifting alignment apparatus already installed in a setup awaiting an amputee trial may not need to be as frequent as formerly.

The coupling also facilitates the alignment of replacement sockets. Fitting problems often require the fabrication of a completely new socket before the remaining parts of the prosthesis need replacement. The new socket and coupling can be installed on the "old" prosthesis for dynamic alignment and replacement-

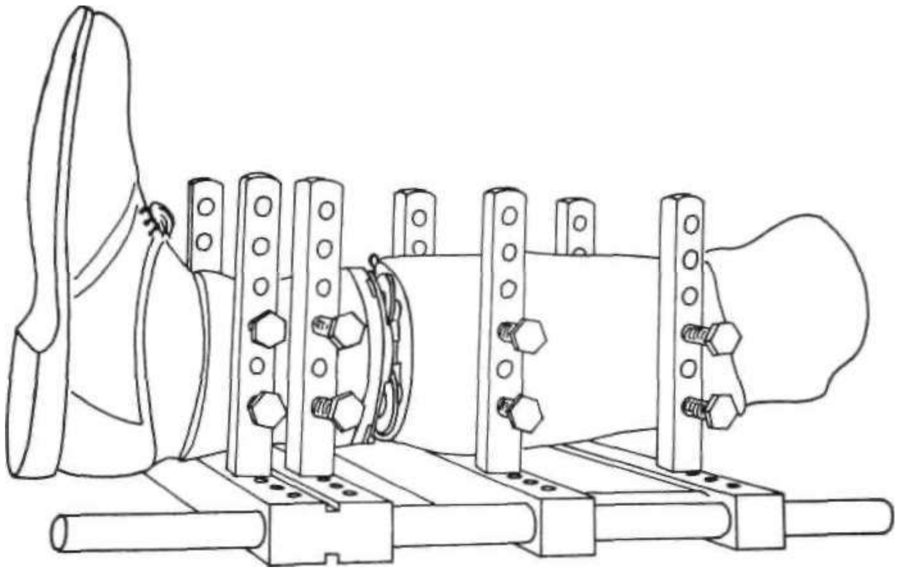


Fig. 14. Special band-saw jig used by Danes during alignment transfer. This jig holds components of the prosthesis in a fixed position to allow parallel band-saw cuts on both sides of the coupling. Subsequent clamping after cementing of wood block to replace coupling is also facilitated by this device.

socket fitting. This process is more expeditious than one in which the adjustable leg is used and then transfer is made to the "old" components. Also, proper fairing of new socket to "old" components can be assured by the coupling method of realignment because fairing problems can be readily observed and immediately corrected. When the adjustable leg is used, fairing problems can be noted only at the time of transfer. Major corrective procedures may then be necessary.

Many foreign practitioners have read and appreciated the various United States' documents which have emphasized the importance of dynamic alignment. But also, many have felt frustrated for, even though they have realized the value of dynamic-alignment apparatus, economic or technical handicaps prevented them from enjoying the use of the devices the practitioners in the United States had readily available. The coupling, therefore, because of its simplicity, can make a significant contribution to the benefit of the disabled all over the world, particularly in developing areas.

The coupling was introduced into Yugoslavia in 1961 *(7).* At about the same time, Denmark became interested in its use. E. Lyquist of the Orthopaedic Hospital, Copenhagen, has published a report on the coupling[6] and on the apparatus he designed for clamping the prosthesis on a band-saw bed for alignment transfer (J). See Figure 14. Dr. B. Zotovic of Belgrade has kindly offered the photograph (Fig. 15) of a prosthesis with the coupling now in use in Yugoslavia. In 1962, the coupling was introduced into Argentina. Still more applications to foreign use are anticipated.

Many clinicians have realized the importance of temporary or interim prostheses (P) for preliminary trials by an amputee. When temporary limbs which have alignment adjustability are used, dynamic stump conditioning and, especially for geriatric cases, evaluation of an amputee's ability to cope with a prosthesis are possible before a final prosthesis is ordered. Of utmost importance in temporary limb use is that prosthesis *"function*

[6] Lyquist (in November 1962) reported that the coupling was being used in all patellar-tendon-bearing fittings at the Orthopaedic Hospital. Some above-knee use was also reported.

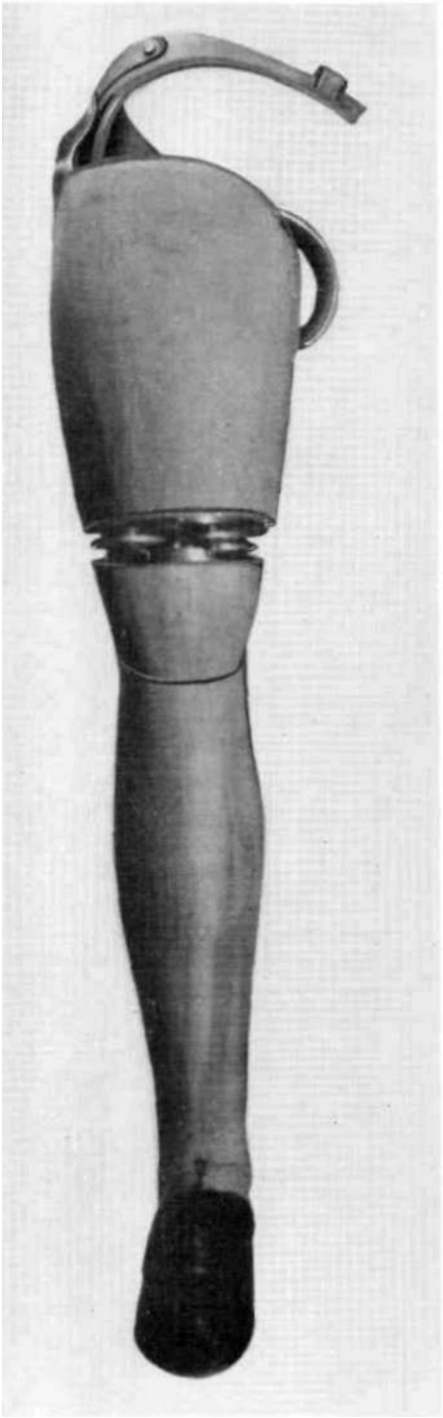


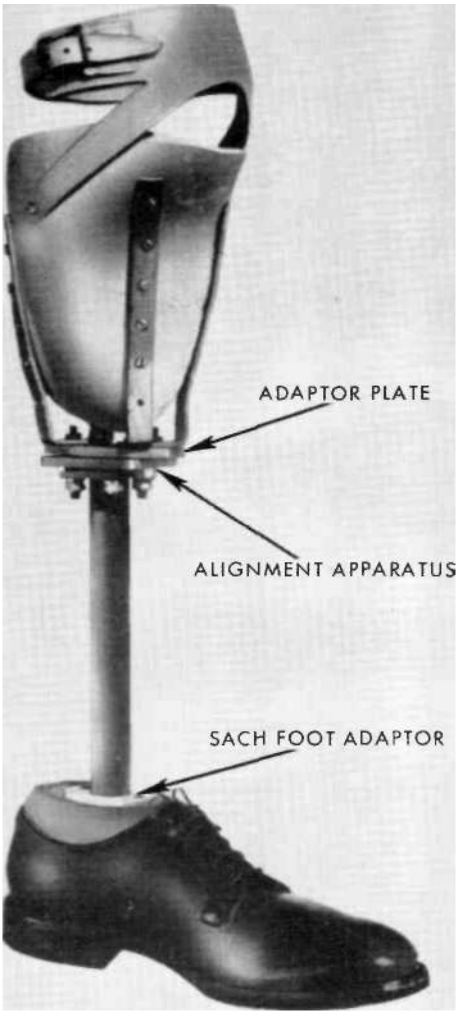
Fig. 15. A Yugoslav above-knee prosthesis incorporating the adjustable coupling tor dynamic alignment.

Fig. 16. The adjustable couplingused with a plaster - of-Paris above-knee temporary sockel and an unfinished knee shank. The three straps are eaeh 1/8 in by 3/4 in. low-carbon steel. From *(9).*

not be seriously compromised" *(9).* A well-fitted, soundly designed socket must be used, and all parts should be continually maintained in proper alignment. Straps provide additional reinforcement of socket to coupling assembly—mostly for horizontally directed loads. For plaster sockets, they are especially helpful since they can be contained within an outer, reinforcing plaster wrap.

There are now available several devices which might be used for temporary prostheses *(9).* Among these is the coupling. Figure 16 illustrates a temporary or interim above-knee. prosthesis incorporating the coupling and making possible the use of the type of knee (and function) anticipated for a permanent prosthesis. Now, not only fit and alignment can be '"tuned" to each other, but both can be "tuned" to function. And, if necessary, function can possibly be altered by a rather

Fig, 17. The adjustable coupling used with a plaster-of-Pa.ris below-knee temporary socket and unfinished shank. The three straps have the same cross-section as those used with the above-knee socket. The position of the carbon steel straps in both the above-knee and below-knee sockets should be reinforced with an extra plaster-of-Paris bandage wrap, as illustrated.



Fig, 18. A temporary or interim prosthesis with the Northwestern adjustable below-knee pylon, plaster-of-Paris patellar-tendon-bearing socket and SACH foot, The three straps are similar to those of the previous two illustrations. An adaptor plate must be provided to iittach the straps to the pylon. In addition to the alignment adjustability available in the pylon, the position of the socket can still be altered if necessary.

rapid change from one knee-shank mechanism to another.

Figure 17 shows the coupling used in a below-knee temporary, or interim, prosthesis. For this level of amputation, the practitioner has the choice of the coupling or the Northwestern Adjustable Below-Knee Pylon shown in Figure 18. This apparatus also has sufficient alignment adjustability available for most below-knee applications in both temporary and permanent prostheses. When attached to a "permanent" (plastic or wood) socket, its advantage is that it can remain in the prosthesis after the dynamic-alignment process is complete.

FURTHER DEVELOPMENT

The Northwestern Adjustable Below-Knee Pylon demonstrates a design principle long sought in alignment apparatus. With it, adjustments needed for dynamic alignment can be made as usual during the early stages of prosthesis fabrication, but the adjustable apparatus is now made a part of the limb obviating a transfer process but sometimes causing a slight increase in limb weight. At a later date, if the cosmetic-shank design allows it, readjustment of alignment can be made without a complete alteration of the prosthesis. Use of a relatively flexible cosmetic cover will probably be best for this purpose; if a plastic-covered foam shank is used, only destruction of the shank before realignment and a foam replacement and plastic finishing after realignment will be required.

Most desirable would be one apparatus, perhaps coupling-like, which could be used in above-knee and below-knee prostheses alike. The present adjustable coupling is both too heavy and too expensive for this purpose. A. B. Wilson, Jr.[7] and Victor T. Riblett[8] have designed a simple and inexpensive plastic, tapered-disc device which might remain in the prosthesis after the primary alignment trials (Fig. 19). At present the device usually must be partly trimmed during the shaping of the limb for cosmetic finishing. Therefore, it could probably not be used at a later date for realignment purposes. But still this device will obviate transfer after initial alignment.

[7] Technical Director, CPRD, NAS-NRC, 2101 Constitution Ave., Washington 25, D. C.

[8] Supervisor, Mechanical Development Branch, Army Prosthetics Research Laboratory, Walter Reed Army Medical Center, Forest Glen Section, Washington 12, D. C.

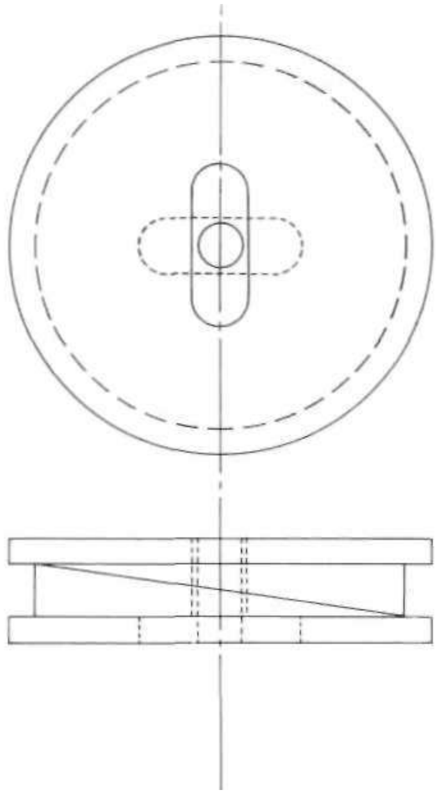


Fig. 19. Schematic drawing of the "Wilson-Riblett wedge," as applied to the VAPC coupling.

In eliminating only the primary-transfer process, a so-called "leave-in" alignment device must be priced at a level which would offer some gain to the prosthetist-user. If, at least with the regular coupling, alignment transfer involves an investment of approximately $5.00 in labor and materials by the limbshop, then the *one-time*, "leave-in" alignment device should cost somewhat less. But even so, possible saving per prosthesis or additional profit is of a very low order of magnitude.

Needed is a device (and prosthesis design) which would allow realignment at a later date without major reconstruction of the prosthesis.

Economic benefits would accrue to prosthetist and amputee alike; at least some of the major cost-saving in the realignment process can be passed along to the customer. Perhaps many prostheses now condemned for alignment reasons would not need to be.

But most of all, such a device would offer convenience, allowing almost immediate accommodation to an amputee's needs. Instead of major delays in receiving a new alignment in a new or grossly altered older prosthesis, rather prompt prosthetist attention can be focused on an alignment problem in the existing limb. The prosthetist, if uncertain of an amputee's over-all fitting problem, can start with realignment of the existing prosthesis in his progressive analysis of the situation. He might be able to overcome what may seem to be socket-fit difficulties without major changes there. But, in any case, he would have readily available the mechanism for study of the problem and the problem's dependency on alignment.

Prosthesis design must of course be changed to accommodate the permanent installation of such a unit. A below-knee shank should preferably be a pylon—cosmetic-cover type, somewhat similar to the Northwestern device. Preferably, the lower part of the above-knee limb thigh (where this device would be placed) should have an easily removable cosmetic cover. Perhaps a simple plastic finish over foam forced into the spaces around a lightweight, inexpensive coupling would be adequate. The foam would need to be cut away (or possibly dissolved by appropriate chemical means) when realignment was necessary. But even with present plastic-laminate finishing methods, realignment would involve only destruction of the laminate and then refinishing.

LITERATURE CITED

1. Anderson, Miles H., John J. Bray, and Charles A. Hennessy, *Prosthetic principles, above-knee amputations* (edited by Raymond E. Sollars), Charles C Thomas, Springfield, Illinois, 1960. See especially pp. 179-241.
2. Eberhart, Howard D., Herbert Elftman, and Verne T. Inman, *The locomotor mechanism of the amputee,* Chapter 16 in Klopsteg and Wilson's *Human limbs and their substitutes,* McGraw-Hill, New York, 1954.
3. Lyquist, Erik, *Jusieiingsapparat type VAPC oj overforingsapparat type OHK.14.01,* Publikation NR 1/62, Ortopaedisk Hospital, Kobenhavn.
4. Radcliffe, Charles W., *Mechanical aids for alignment of lower-extremity prostheses,* Artificial Limbs, May 1954, p. 20.
5. Radcliffe, Charles W., *Functional considerations in the fitting of above-knee prostheses,* Artificial Limbs, January 1955, p. 35.
6. Radcliffe, Charles W., Norman C. Johnson, and James Foort, *Some experience with prosthetic problems of above-knee amputees,* Artificial Limbs, Spring 1957, p. 41.
7. Staros, Anthony, and Henry Gardner, *Report on orthotics-prosthetics research developments in Yugoslavia,* Department of Health, Education, and Welfare, 1962.
8. Veterans Administration Prosthetics Center, *Suggestions for fitting and aligning the SACH foot,* a chart, May 1962.
9. Veterans Administration Prosthetics Center, *Temporary prostheses for lower-extremity amputees,* Technical Report 1, September 1, 1962.
10. Veterans Administration Prosthetics Center, *Use of the alignment coupling,* a chart, July 1962.
11. Wagner, Edmond M., *Contributions of the lower-extremity prosthetics program,* Artificial Limbs, May 1954, p. 8.