Harness Patterns for Upper-Extremity Prostheses

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The comparatively recent development of more functional components for artificial arms has made it necessary to analyze in greater detail the requirements of harnessing the power needed for effective operation. Just as an automobile is helpless without a well-designed and well-built engine and transmission system, so an arm prosthesis is helpless without a well-designed and well-constructed harness. To build a successful harness system requires not a knowledge of some long-lost art but, instead, a careful appraisal of the wearer, of the device to be worn, and of the available tools to be put to work. Since the modern body harness constitutes a dynamic coupling between a human being and a mechanism designed to replace a living extremity, the problem of devising it is also one of dynamics and of what some call "human engineering."

Many illustrations of typical harness patterns are presented later in this article. But it is not enough for the harnessmaker simply to reproduce what is shown in these drawings of typical patterns or to superimpose on an individual amputee a generalized harness pattern of any particular type. He must first understand the purpose of the harness, the requirements of the particular prosthesis involved, and the body motions available, and he must then apply his own skill and judgment in making appropriate modifications to suit the individual case. It is, of course, far more important to produce a harness that will give the desired functional results than it is to produce one that looks exactly like any one of the drawings. The illustrations are therefore intended as general guides only, not as a detailed description applicable to every case of amputation at the indicated level. When planning and making any harness, the prosthetist should examine the location of each element to ensure proper function with the expenditure of minimum effort on the part of the particular wearer concerned.

The first and most simple requirement of any harness is that it must hold the prosthesis securely on the stump. The second is that it must be comfortable to the amputee. Generally, suspension, as such, is easily obtained, but to suspend the prosthesis properly and at the same time to assure maximum comfort for its wearer is more difficult. If either of these requirements becomes a matter of choice, then comfort must be the more important consideration. If the harness is not comfortable, or at least tolerable, the person for whom it was intended will soon hang it politely on a suitable nail. Since almost no harness can be constructed satisfactorily without a few compromises at first, it is unwise to promise complete success on the first try.

The third and all-important requirement of functional body harness is that it must supply a source of power for the operating components of the prosthesis. This means simply that residual body motions must be harnessed to replace lost functions of the natural member, but to provide controls that are operable in an effective and yet inconspicuous manner poses a complex problem. It requires an examination of the body motions that can be utilized by the harness without detracting from the usefulness of the remaining normal hand and without introducing unduly awkward gyrations of parts of the anatomy not ordinarily involved

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in arm activity. The higher the level of amputation, the greater the control requirements but the fewer the sources of control. The problem is further complicated by the need to maintain the proper balance between adequate suspension, acceptable comfort, and worthwhile function, for each of these needs is often satisfied only at the expense of the other two.

A look at the background of harnessing for upper-extremity prostheses *(7,8,9,15,17,22)* reveals that, when devices were generally passive in nature, so was the harness. As devices have increased in function, so has the harness also. Today the development of devices has in general surpassed the art of harnessing them. With the proper approach, however, and using a common-sense analysis both of the amputee's capabilities and of the requirements of the prosthesis, an accomplished limbfitter can in almost every case turn out a very acceptable harness that will meet functional needs to a surprising degree.

HARNESSING FOR THE BELOW-ELBOW CASES

The prosthesis for the unilateral below-elbow case is unquestionably the simplest to harness. For the reason that the below-elbow amputee retains his own elbow, and therefore usually requires replacement of prehension only, he can almost without exception be harnessed successfully. At least three feasible control motions are to be had. In order of decreasing usefulness, they are arm flexion on the amputated side, shoulder depression on the amputated side, and scapular abduction. The choice and extent of use of these three motions, singly or in combination, is largely a matter of personal preference depending on the area in which the terminal device is required to operate. With the elbow flexed to 90 deg. and with the terminal device located slightly above the level of the head, for example, arm flexion is almost completely spent. Using scapular abduction under the same circumstances, however, the below-elbow amputee can still operate the terminal device satisfactorily. Successful wearers of below-elbow prostheses develop their own individual patterns of operation and subconsciously learn to operate the device in all areas in which it is called upon.

The problem of transmitting the force and excursion of body motions from the source to the point of use has in the past involved a wide variety of materials. Rawhide thongs and leather laces are only two of many that have been used, even as late as only a decade ago *(1).* The flexible metal cable and wrapped-wire housing adopted from the aircraft industry is currently the most widely used and is the most satisfactory available today. It is based on the Bowden principle (Fig. 1), which makes it possible to transmit force and excursion from the body to the terminal device regardless of elbow angle *(21).*

Utilizing any or all of the three useful body motions, together with the Bowden-cable transmission system in every case, two alternate harness patterns are available for the below-elbow amputee with a stump of medium length. The first is known as the "figure-eight" harness, the second as the "chest-strap" harness. In addition, there are two special modifications, one for the very long and another for the very short below-elbow stump. These are, respectively, the "double-axilla-loop" harness and the "dual-control" harness. Finally, there is the special harnessing arrangement using the biceps cineplastic muscle tunnel to provide force and excursion.

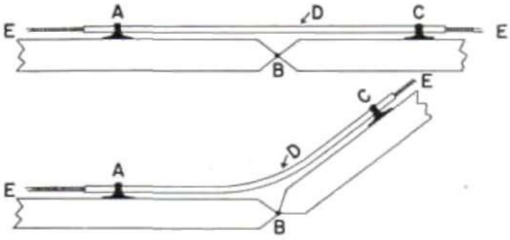

Fig. 1. The principle of the Bowden cable for transmitting tension forces applied at one end. Although point *C* is brought closer to point *A* when rotation occurs about *B,* the housing *D* prevents slack in cable *E* by preserving the *effective* path length *A* to C. A counterforce is required at the opposite end to return the flexible cable to its original position. Other types of Bowden cables are based on the torque principle, as used in speedometer cables, or the push-pull principle, as used in the temperature controls of the automobile heater.

THE BELOW-ELBOW FIGURE-EIGHT HARNESS

The Harness Pattern

The figure-eight pattern, of which Figure 2 presents a typical example, is the harness most commonly used in the unilateral below-elbow case, the axilla on the sound side being the site of anchor for capturing the relative motion. The front view of Figure 2 shows the suspension portion of the harness. The front harness strap, passing over the shoulder at the pectoral interval on the amputated side, buckles to the inverted Y-strap supporting the leather triceps pad, which in turn supports the socket through the flexible elbow hinges. The back view shows the transmission system from harness to terminal device. The general path of the control cable is such that sharp bends and curves of small radius are avoided as much as possible.

The chief purpose of the control system is to transmit force and excursion to the terminal

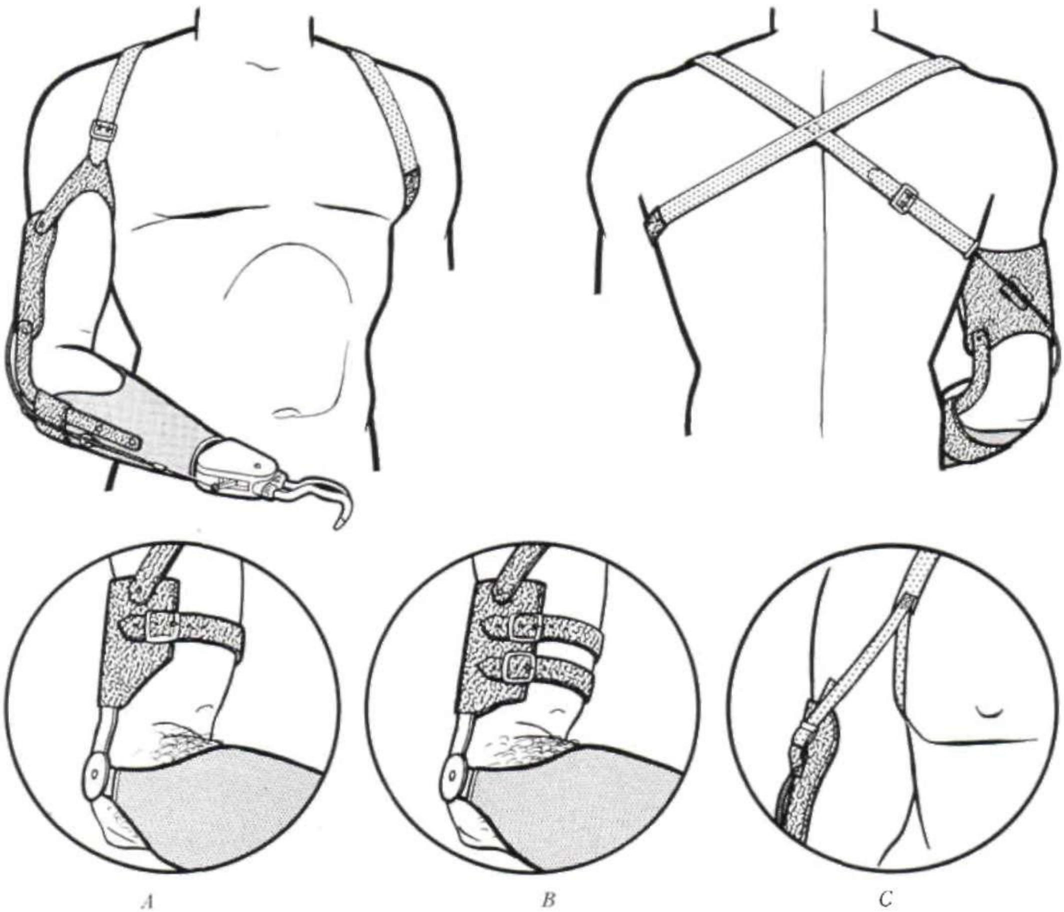

Fig. 2. The below-elbow figure-eight harness. A simple webbing loop passes around the sound shoulder, the front portion being used for suspension, the back for attachment of the control cable. The inverted Y-suspensor. triceps pad, and flexible elbow hinges are constructed of 4 to 6-oz. strap leather and lined with 4-oz. pearl horse-hide or equivalent. The proximal retainer on the triceps pad is of the flexible leather type to improve cable life. The three circled inserts show possible variations in individual cases. Circle *A* illustrates the leather half-cuff as used in combination with rigid elbow hinges and a single billet. Circle *B* shows a hall-cuff with two billets, again in combination with rigid elbow hinges. Circle *C* shows the inverted Y-strap as made from fabric instead of leather. Any of the combinations shown may be used as required to furnish the necessary stability depending upon occupational needs, level of amputation, and other factors.

device. When, however, the amputee must pick up loads with forearm extended, the cable is expected to assist in support whenever the load is of any appreciable magnitude. This, then, is an example of what is meant by the proper balance of forces that is needed to meet amputee requirements. Both suspension and control system should be so constructed and adjusted as to be comfortable and yet be able to meet a reasonable load-support requirement without unnecessary displacement of the prosthesis. Tests for determining allowable displacements and other important factors have been set forth by Carlyle *(5,6)*.

As shown in Figure 2, the harness is padded and protected under the axilla, and the control cable is so adjusted that it cannot come into contact with the amputee's back. For maximum excursion, the cross of the harness should be below the cervical vertebrae and not more than 1 in. toward the sound side of the vertebral spine. The control attachment strap *(i.e.,* the strap attached to the flexible control cable) should lie at the midscapular level. In the course of constructing the harness, visual observations of all these details should be made while the wearer goes through the movements to be expected in normal use.

Because of the simplicity of the figure-eight harness, minor deviations usually are not serious. Occasionally, indeed, exceptions to the normal placement of the harness cross are necessary and desirable to improve comfort. The figure-eight harness can be worn successfully by the majority of below-elbow amputees with ordinary duties, it is easy to construct and there is little chance for error, and it is functional and comfortable in most cases. Together these advantages generally represent the reason why it is so widely used. It readily adapts itself to vocations that are clerical in nature and to individuals requiring medium duty, such, for example, as the lifting that might be required of a stockroom worker.

Below-Elbow Cliffs, Pads, and Hinges

To furnish suspension and socket stability, three types of cuffs and pads, with and without fillers, are available, and any of several types of hinges, some flexible and some rigid, may be used. The circled inserts *A* and *B* of Figure 2 show some of the variations giving greater and greater stability as needed in the individual case. The choice of cuff and hinge combination is strictly a consideration for the prescription team, the rule being to provide maximum stability with the absolute minimum of harness. Prescription criteria and suitable templates for cuffs are described in considerable detail in Section 5.6 of the *Manual of Upper Extremity Prosthetics (27).* It should be remembered that many combinations of hinges and cuffs are available and that no one cuff must necessarily be accompanied by any particular type of hinge. Moreover, the prescription for any given amputee should take into account his own individual requirements and personal preferences.

There are at least two ways of making cuff suspension systems, material selection being the principal distinguishing factor. The preference of the limbmaker may enter into the choice of technique largely because of the fabrication facilities that happen to be available. Leather has long been used in the limb industry, and it is readily adaptable because of its molding characteristics. Although the ability of leather to conform readily to the shape of the arm represents something of an advantage over webbing straps (circled insert *C* of Figure 2), its tendency to absorb perspiration and thus to deteriorate, as well as to acquire unpleasant odors, is considered by many to be a distinct argument against its use in arm cuffs. The webbing strap, while perhaps less stable, offers the advantage of being easily washed and quickly replaced. Modern synthetic fabrics now available commercially can be laundered without undue shrinkage and may be reapplied without stretching under load.

The below-elbow cuffs and pads usually are made of 4- to 6-oz. strap leather and are lined with horsehide or similar material. The fabrication of this component calls for the cutting, sewing, and fitting skills of the limbmaker. To make the Y-shaped leather suspension strap, a paper pattern is first cut to conform to the amputee's arm. When the template lies smoothly against the arm above the bulge of the biceps and will reach properly from the triceps pad or cuff to the webbing suspension strap passing over the shoulder at the pectoral interval, its shape is reproduced in 4- to 6-oz. strap leather or equivalent. The lower legs of the leather suspension strap are then riveted to the cuff or pad in such a position that the "V" lies smoothly against the arm and will support axial loads.

The webbing inverted Y-suspensor is prepared by folding a piece of 1/2-in. webbing back on itself in such a way as to form a "V." The apex of the "V" is then sewed directly to the front suspensor strap of the harness at such a level as to give a smooth transition from the harness to the cuff or pad. The lower attachments to the cuff or pad are made by means of 1/2-in. buckles.

Again, material selection is the chief factor determining technique. When leather is used, it is hard to determine the proper length of the legs of the "V" and to assure proper alignment without later adjustments. Moreover, unless leather components are coated with nylon *(10,16)* or similar material, the effects of perspiration will soon become apparent. Conversely, the webbing Y-suspensor offers easy adjustment of alignment and also resistance to perspiration by virtue of its washability. When fitted properly, both systems are acceptable, and hence personal preference is an influencing factor.

THE BELOW-ELBOW CHEST-STRAP HARNESS

Although the figure-eight harness is suitable for most below-elbow cases, it does not meet all vocational requirements. Heavy-duty activities, such as those of a farmer, requiring frequent lifting of loads greater than 50 lb., can best be accommodated by a below-elbow chest-strap harness. Figure 3 shows a typical example. By the addition of the shoulder saddle to reduce unit stresses on the shoulder and opposite axilla, the load-supporting capabilities and amputee comfort can be greatly improved, but to obtain a satisfactory result with the chest-type harness presents a greater challenge to the harnessmaker.[2]

As shown in Figure 3, there are basically three elements in the below-elbow chest-strap harness—the chest strap to hold the harness on, the shoulder saddle to serve as an anchor for suspending the prosthesis, and the control attachment strap for operating the terminal device. To connect the shoulder saddle and to suspend the prosthesis, two lengths of 1/2-in. leather or webbing are used. They originate on the back of the shoulder saddle, thread through D-rings on the cuff, and then buckle to the front of the saddle. This arrangement distributes the load on four points of the saddle and two points of the cuff and offers the inherent self-equalizing effect by virtue of the D-rings.

The control attachment strap is connected to the chest strap and utilizes arm flexion and scapular abduction on the amputated side. Since no definite anchor is involved, neither scapular abduction nor shoulder flexion on the sound side can be harnessed, so that, unlike the case with the figure-eight harness, in the chest-strap design these body motions cannot be used as a source of reserve excursion. Although this basic difference is responsible for the improved comfort of the chest-strap harness, lack of a positive anchor not only robs the amputee of a third control motion but actually permits the harness to rotate upon the chest when excessive forces are applied to the control cable.

The indications for and advantages of the chest-strap harness lie in its improved comfort and greater lifting capacity. The chief reasons for its selection over the figure-eight arrangement are concerned with vocational considerations, relief of unavoidable discomfort in the opposite axilla, and amputee preference based on his past experience. Both the figure-eight and the chest-strap harness may be used with almost any combination of hinges and cuffs. It may not be desirable to use a triceps pad and a shoulder saddle in combination, but there is no law against this possibility. The rule, as always, is to try for maximum stability

[2] It has been said that some limbmakers construct the chest-strap harness simply because they do not know how to make the figure-eight design. There appears to be no real evidence to prove which type really is the older, but it is generally accepted that the chest strap was the forerunner of the figure-eight. Regardless of priority, both patterns are acceptable, and each offers advantages and disadvantages.

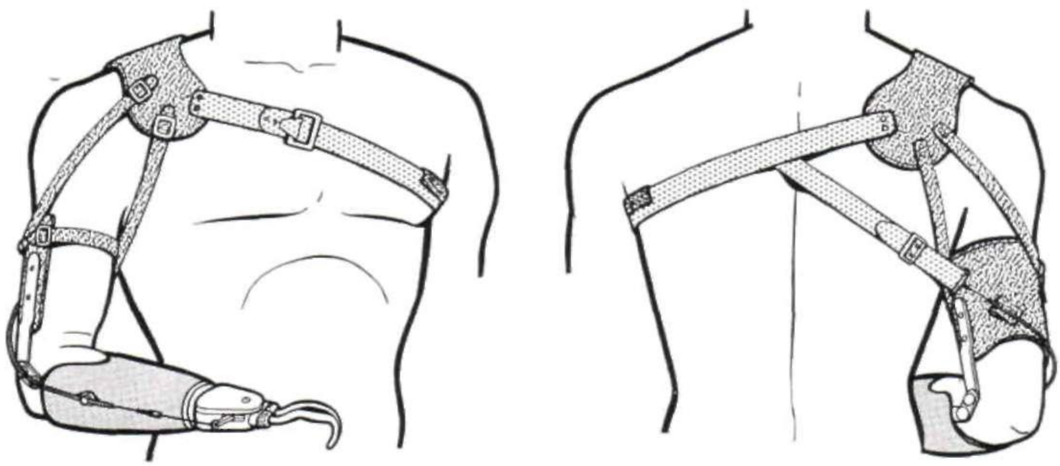

Fig. 3 The below-elbow chest-strap harness The two suspensor straps running through D-rings are attached to a leather shoulder saddle Improved stability and reduced unit stresses over the shoulder offer greater ability to lift axial loads. Normally, the below-elbow chest-strap harness, used on amputees requiring heavy-duty service. is constructed in combination with half-cuff and rigid elbow hinges.

with a minimum amount of harness. This being the case, the figure-eight harness should be tried first.[3] If it is not satisfactory, then the more complicated chest-strap harness may be resorted to. For detailed discussions of fabrication techniques for both harnesses, reference may be had to Section 5.0 of the *Manual of Upper Extremity Prosthetics (27).*

THE DOUBLE-AXILLA-LOOP HARNESS

The increased frequency of successfully fitted wrist-disarticulation cases has led in such instances to a departure from the typical below-elbow harness pattern. A very simple and useful harness has been reported by the Naval Prosthetics Research Laboratory *(28)* for use with transcarpometacarpal cases, and the technique is also adaptable to wrist-disarticulation cases. As shown in Figure 4, a double axilla loop originates the initial body motion on the sound side and provides its own reaction point on the amputated side. A solid piece of Bowden cable extends from the proximal reaction point located on the axilla loop on the amputated side to the distal reaction point located on the arm socket. The cable housing is covered with a piece of plastic tubing to prevent pinching of flesh and pulling of hair on the subject's arm.

It should be pointed out that the double-axilla-loop harness is only a means of supplying

[3] Except, of course, in those cases where extremely heavy duty is a requirement from the beginning.

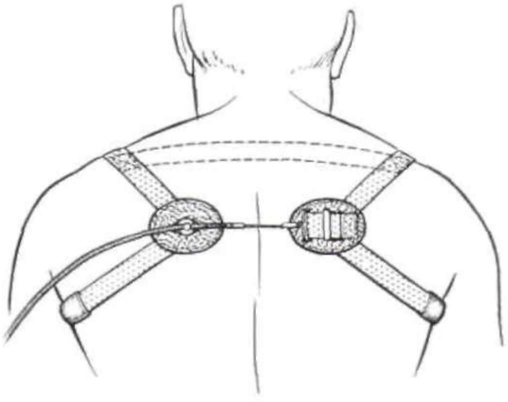

Fig. 4. The double-axilla-loop harness for wrist disarticulations and transcarpometacarpal amputations. The loop on the amputated side serves as the reaction point, relative motion being produced when the sound shoulder is flexed. The control cable continues to the distal reaction point on the arm socket (Fig. 5) The auxiliary elastic strap indicated by dotted lines may or may not be needed. *Courtesy U S Naval Hospital, Oakland, Calif. (28).*

terminal-device operation. Suspension must be inherent in a well-fitted socket, which usually must be split to facilitate donning, the condyles of the wrist being the principal means of retaining the socket on the stump (Fig. 5). Wrist disarticulations can be fitted by this technique at first. If it proves to be unsuccessful for any reason, the harness may easily be replaced with a conventional below-elbow figure-eight harness *(29).*

THE BELOW-ELBOW DUAL-CONTROL SYSTEM

As opposed to the problem of fitting the wrist disarticulation and other long below-elbow stumps, there is the one involving the fitting and harnessing of the very short below-elbow slump. Use of the split-socket type of prosthesis furnishes a means of increasing the range of elbow flexion through a mechanical step-up. Thia expedient greatly improves the versatility of the below-elbow prosthesis and in the majority of cases proves to be very satisfactory when using the below-elbow figure-eight harness based on the single-control principle.

For marginal cases with insufficient torque about the elbow to lift the prosthetic forearm, another departure has been made from the usual pattern of control. The below-elbow dual-control system, shown in Figure 6, uses a forearm lever loop and a split-housing cable system. Since in this case the cable housing is in two separate pieces, the effective distance between the reaction point on the arm cuff and that constituted by the lever loop on the forearm shell is no longer independent of elbow angle, so that arm flexion produces

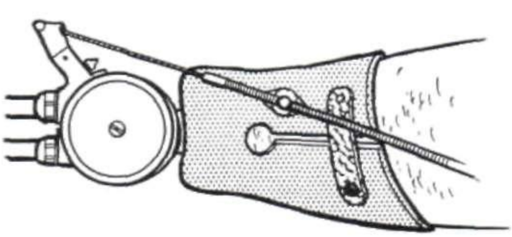

Fig. 5. Wrist-disarticulation socket for use with the double-axilla-loop harness. Control cable extends to the proximal reaction point located on the axilla loop on the amputated side (Fig. 4).

forearm flexion. When used with the very short below-elbow stump, the dual-control system thus provides an assistive lift for forearm flexion, sometimes especially needed when forearm flexion is begun from full forearm extension. Ordinarily the short below-elbow case has enough torque about the elbow to stabilize the forearm, so that no elbow lock is required. When the forearm socket is stabilized by the stump, the force from the harness is transmitted to the terminal device.

The familiar rule of first trying the less complicated harness should be applied at this level also. If the forearm cannot be flexed by the stump without unnecessary fatigue, or if forearm flexion is painful, then the dual system is indicated. Amputees fitted with the dual control should be checked periodically to see whether the residual muscles have hypertrophied enough to be adequate for unassisted forearm flexion, in which event the single control may be substituted. No harm is done by using the below-elbow dual-control harness when its necessity is questionable, but again the usual desirability of simplicity of harness would suggest discard of the assist lift when adequate function can be obtained without it.

THE BELOW-ELBOW BICEPS-CINEPLASTY SYSTEM

The Case for Cineplasty in General

Since World War II, there has been, especially in the United States, a considerable revival of cineplastic surgery *(2,14,24,26)* to produce muscle tunnels capable of harnessing for the operation of artificial arms. Practically all available muscles of the arm and two major muscles of the chest (the pectoralis major and minor) have been harnessed by various means to operate arm prostheses. Two basic philosophies have developed in the use of the cineplastic muscle tunnel. First established was the idea of using the muscle motor to power the terminal device. The advantages of this means of independent terminal-device operation, without relying upon body motions, were readily apparent, to say nothing of the possibility of eliminating body harness completely in some cases.

Some authors, for example Mount and

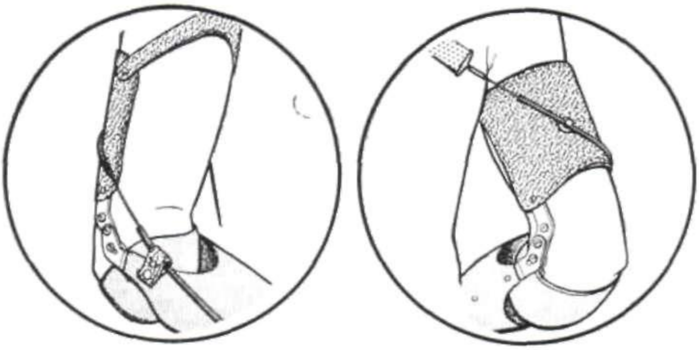

Fig. 6. The below-elbow dual control using the split-socket type of prosthesis for the short below-elbow case. Since the cable housing is in two pieces, arm flexion assists in lifting the prosthetic forearm. The stump is then used to stabilize the elbow for terminal-device operation, no elbow lock being needed. The design of the step-up elbow hinges has been discussed in detail by Alldredge and Murphy (*1*).

Bernberg *(19),* discuss the advantages of an increased sense of pressure and generally improved sense of perception when a muscle motor is harnessed to a terminal device. Mount and Bernberg say "The results generally indicate that the two Ss [subjects] using cineplastic prosthesis distinguished, compared and recognized given objects with greater skill and precision than the Ss [subjects] using prosthesis of the harness type." Although further scientific tests to support this observation have not been conducted, subjects successfully fitted with both a conventional and a cineplastic prosthesis indicate that they have a better sense of pressure or feel with the latter.

In the second philosophy developed, the pectoral tunnel is used to operate the elbow lock in the shoulder-disarticulation case. Obviously, the advantage in this case lies in the provision of the additional source of control.

It may be stated, without reservation, that of all the possible arrangements involving cineplasty, the greatest degree of success has been obtained using the biceps muscle tunnel to power terminal-device operation in the below-elbow case. This does not mean that the combination of other muscle tunnels and other levels of amputation may not be successful in individual cases. Spittler and Fletcher *(24),* Kessler *(14),* Alldredge *et al. (2),* and Taylor *(26)* report other muscles and other levels of amputation successfully fitted with cineplastic prostheses. Because, however, the other cases have not yet been proven clinically in the general sense, the discussion of the fitting of cineplasty is here restricted to the below-elbow biceps system.

In the below-elbow biceps case, fitting is greatly simplified because the muscle tunnel is above the first sound joint in the amputated stump. The socket may thus be made to harness residual pronation and supination, and it does not require window-type construction *(26)* since the tunnel is once removed in the upper arm.

Because the biceps tunnel in the below-elbow case is able to avail itself of the physiological characteristics of muscle *(13),* adequate force and excursion are to be had. Since normally muscles are contracted to produce prehension, contraction of the biceps muscle tunnel should effect closing of the terminal device. For this reason it is generally accepted that a voluntary-closing device is most desirable for use with cineplastic amputees. Of course if the improved sense of pressure is to be had, then it may be best to use the voluntary-closing terminal device. Regardless of all data presented here and elsewhere, however, many biceps tunnels have been successfully harnessed in the below-elbow case with the voluntary-opening terminal device.[4] This

[4] Although common-sense logic might lead one to suppose that improvement in pressure appreciation would be obtainable only were the terminal device voluntary-closing, it turns out that considerable improvement is to be had also from muscle tunnels harnessed to voluntary-opening devices. The tests conducted by Mount and Bernberg *(19)* were, for example, all made with amputees wearing voluntary-opening hooks. How does the amputee so fitted estimate the amount of force being exerted at the hook fingers? He measures "holdback" and subtracts it mentally from the known total force exerted by the hook when no restraint is applied.—ED.

circumstance can only suggest that the prescription of the terminal device in cineplasty is largely in the same area as is the prescription of the terminal device in the conventional case using body harness.

The back-and-forth discussion of these factors is endless. It is therefore useful to have a look at the indications for cineplasty as seen from the point of view of the amputee. Needless to say that, in the growth of prosthetics clinic teams, new amputees are seeing more and more the types of prostheses worn by other amputees. Usually when the wearer of a conventional arm prosthesis sees a cineplastic type he feels that a "Cadillac" version of an artificial arm is available for him. No doubt personal choice, or the individual desire for a cineplastic type of prosthesis, is the major consideration. Amputees who were not too favorable at the time of discussing the cineplasty procedure have not obtained the same degree of success and training as have those who indicated their preference for cineplasty from the beginning.

Another important factor relates to vocation. If a below-elbow amputee desires to do, for example, mechanical work on an automobile, he often finds himself lying on his back on a dolly. In this position, he is quite restricted in body motions for using a shoulder-harness prosthesis. For the wearer of a conventional prosthesis to operate his terminal device in this position involves the use of many body motions other than those ordinarily involved.

Although no real criterion has yet been developed for the selection of individuals for the cineplasty type of prosthesis, it can be stated categorically that the personal preference of the individual and the vocational considerations are of prime importance and should therefore be discussed thoroughly with the patient before reaching a decision.

The Two Established Systems

Prosthetic fitting and socket construction for a biceps-cineplasty below-elbow prosthesis are very similar to the conventional techniques. The socket must provide stability and a means of attaching a terminal device. Suspension of the prosthesis may be handled in various ways. Two power-transmission systems have been developed, one at the University of California at Los Angeles and the other at the Army Prosthetics Research Laboratory. A comparison of the efficiencies of the two systems has revealed that they have quite similar characteristics *(3)*.

The UCLA Below-Elbow Biceps-Cineplasly System. The power-transmission system of UCLA consists of a muscle-tunnel pin, a dual-cable power-transmission system, and a twin cable mounting harnessed to the terminal device. All parts of this system, shown in Figure 7, have been available commercially for some time, and the arrangement has received wide use in the field. Three types of cuffs are available for suspension in the UCLA system. The epicondyle cuff (Figs. 8 and 9), the epicondyle clip (Fig. 10), and the epicondyle strap (Fig. 11) may be used with any selection of either flexible or metal double- or single-axis elbow hinges. The method of installing the UCLA system is described in detail in Section 10.0 of the *Manual of Upper Extremity Prosthetics (27).*

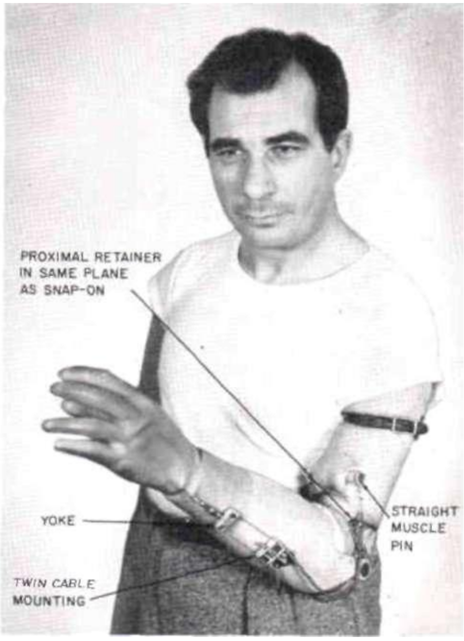

Fig. 7. The UCLA below-elbow biceps-cineplasty system with epicondyle cuff and rigid elbow hinges. The twin cable mounting is connected to the yoke to allow positioning for adequate operating excursion.

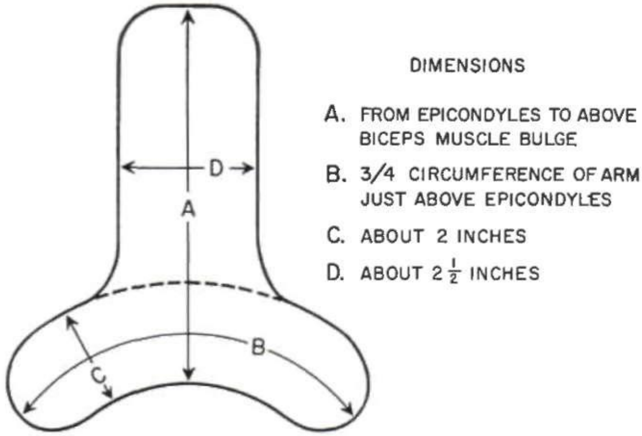

Fig. 8. Pattern for the UCLA epicondyle cuff.

The UCLA system is quite adequate and very simple to harness and provides easy pre-positioning and ready adjustment of effective cable length. It has met with a very large degree of success throughout. Compared to the APRL system *(3),* it offers the advantage of being applicable to a wider selection of terminal devices inasmuch as the control system may be mounted either on the top or on the bottom of the arm socket (Fig. 12). It offers also the advantage of allowing pre-positioning of terminal devices with less friction throughout the cable system.

The APRL Below-Elbow Biceps-Cineplasty System. The APRL system, as it appears in the *Manual of Upper Extremity Prosthetics {27),* has been revised to improve function. The principal modifications (Fig. 13) have been to adopt flexible leather hinges and to discard the so-called "transit elbow hinges." Since these changes *(4),* indications have pointed to a greater degree of success when the biceps tunnel is used with a voluntary-closing terminal device.

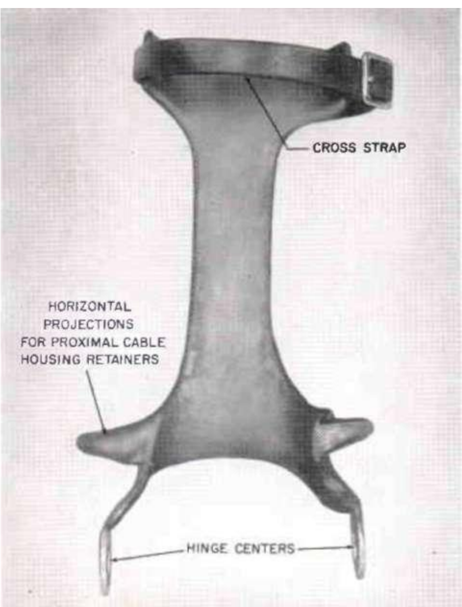

Fig. 9. Alternative design of the UCLA epicondyle cuff, constructed of stainless steel and covered with horsehide, the rigid hinges being attached to the cuff before covering. The cross strap at the top helps to stabilize the cuff on the arm.

Although both the voluntary-closing and voluntary-opening hands and hooks are recommended routinely for use with biceps tunnels in below-elbow amputees, experience has shown that voluntary-closing devices have offered a number of special advantages. The available excursion can be increased by utilizing spring forces in the terminal device to recover excursion, thereby stretching the biceps tunnel into pre-tension beyond the rest length of the muscle *(13).* Moreover, the improved ability to select prehensile forces at the finger tips makes it possible for amputees to handle, say, an ice-cream cone without crushing it or to wield a hammer or other heavy object without dropping it. Expressed amputee reaction seems to indicate, furthermore, that a considerable amount of pressure appreciation is realized through the use of the voluntary-closing terminal device, where the biceps is contracted for gripping an object. Of course, some pressure appreciation is lost when the voluntary-opening device is used, for then the biceps is contracted to open the device against the tension of the spring or rubber band, and the grasping force is exerted by the spring or rubber band upon relaxation of the muscle. Although no published data are

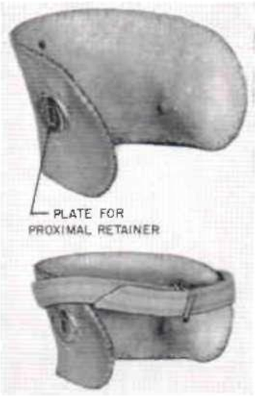

Fig. 10. The UCLA epicondyle clip, constructed of stainless steel and covered with horsehide. Conventional baseplates are attached to be used as the proximal retainers for the dual cable system. The clip can be used with or without the auxiliary elastic strap as needed to maintain the clip in position when the arm is flexed. The epicondyle clip has also been constructed of a semirigid plastic such as "Royalite."

available to support the claim of improved pressure appreciation with the voluntary-closing device, there are sound indications from active users that such a cue to the pressure exerted is of definite advantage.

Since no published instructions for installing the APRL below-elbow biceps-cineplasty system are available, a simplified set is included here. The first step is to cut and check a paper template for the epicondyle strap in order to assure proper size and shape before proceeding to make the finished strap. The typical size and shape are indicated in Figure 11. The pattern should be placed around the arm and examined for comfort, both with the patient's elbow extended and in maximum flexion (Fig. 14). If the biceps tunnel is located low on the arm, the template should be shaped as indicated by the dotted lines in Figure 11 to allow for maximum passive stretch. By thus lowering the front portion of the epicondyle strap, comfort, as well as excursion, is improved.

With the epicondyle strap fastened in place, the normal elbow center is marked on the projecting hinge tabs. Standard baseplates are located as close to these points as possible and are held in place with a clamp on the upper edge (Fig. 15). They are then so aligned that the cable housings will follow smooth curves from the tunnel pin through the elbow center to the two distal retainers on the arm socket. Notation should be made of the approximate angles shown in Figure 11.

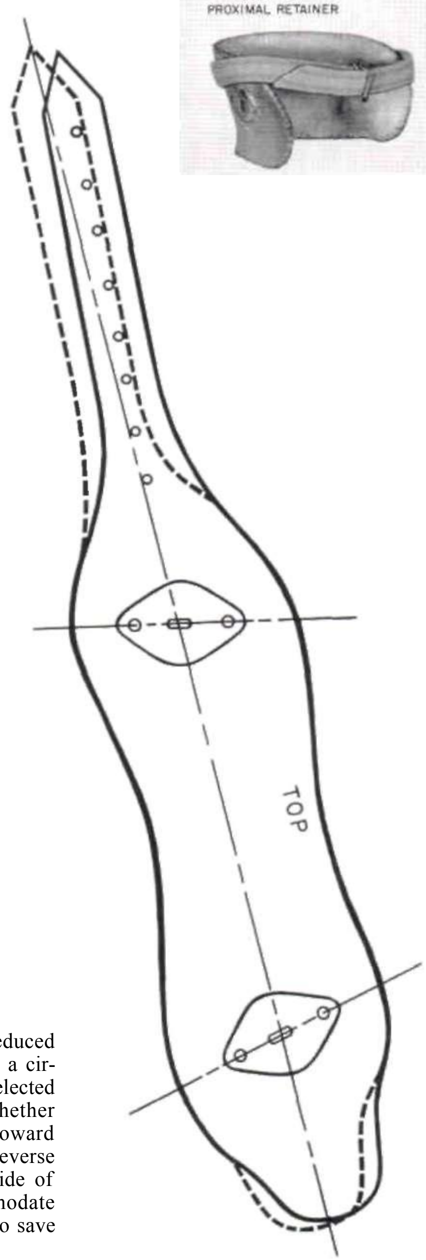

Fig. 11. Typical pattern for the APRL epicondyle strap, reduced to exactly half the size needed to produce a strap for an arm with a circumference of 10 1/2 in. Placed as drawn on the grain side of the selected leather, this template makes a left or a right strap depending on whether the amputee prefers to have the strap buckle toward the medial or toward the lateral side of the arm. To produce a strap buckling in the reverse directions, the template is turned over and placed on the grain side of the leather. The dotted lines indicate a modification to accommodate a biceps tunnel located low on the upper arm when it is desirable to save space in the anterior fold of the elbow.

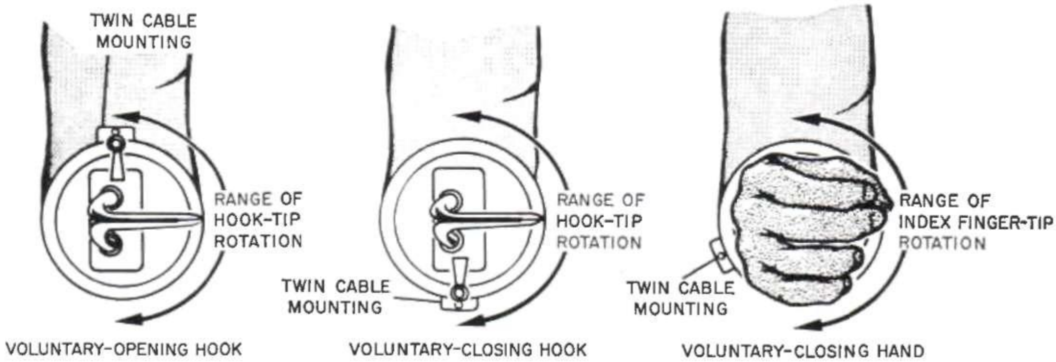

Fig. 12. Alternate locations of the twin cable mounting for various terminal devices in the UCLA below-elbow biceps-cineplasty system. If it is desirable to interchange between the voluntary-opening hook and the voluntary-closing hand, two snap portions of the twin cable mounting may be used, one toward the lower side and another on the top side of the socket.

Fig. 13. Completed installation of the APRL below-elbow biceps-cineplasty system. The epicondyle strap is used in conjunction with flexible leather hinges, the hinges being adjustable by means of strap-type buckles placed at the points of attachment on the arm socket. The ox-bow tunnel pin, fitted with "Dot Fasteners" for joining to the sheave-type cable equalizer, is recommended for use with the APRL system. A flat cable-extensor mechanism is used to allow cable adjustment within the system and to permit interchangeability of terminal devices. Insert shows a variation in pin design that is available commercially.

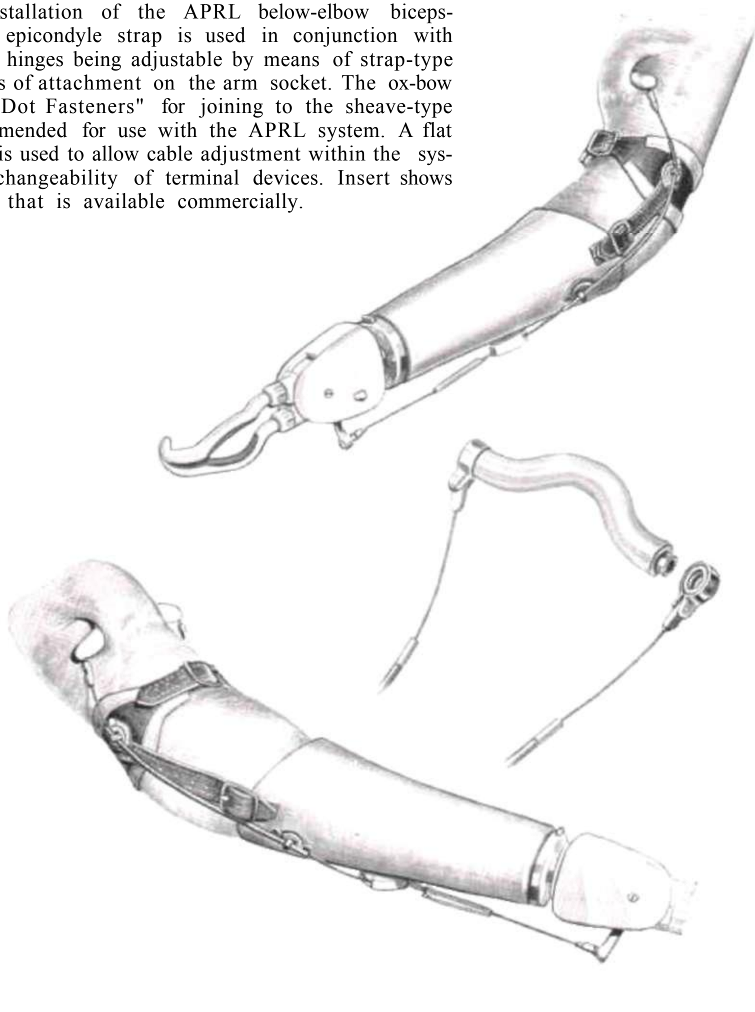

Fig. 14. Procedure for checking the paper template when making the epicondyle strap.

Fig. 15. Placement of the baseplates on the epicondyle strap. They should be so positioned that the cable housings pass through gentle curves from the muscle tunnel to the distal baseplates on the arm socket.

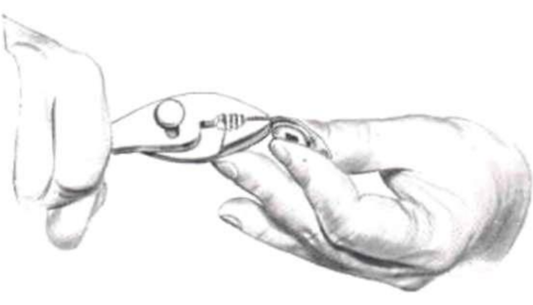

Fig. 16. Bending the ears of the proximal baseplates to conform to the contour of the epicondyles. This detail gives added stability in supporting axial loads and improves amputee comfort.

The extending ears adjacent to the rivet holes on the two proximal baseplates should now be bent, as shown in Figure 16, to follow the contour of the epicondyles, thus giving greatly improved comfort as well as added stability in supporting axial loads. The baseplates are then riveted to the epicondyle strap by means of the top rivets only.

Two pieces of 4-oz. strap leather 5/8 in. wide are now cut long enough to connect the epicondyle strap to the arm socket. A piece of nylon or vinyon strap is attached by rubber cement to the inside of the leather straps, and the whole is stitched along each side. One end of each of these two flexible hinges is then laid under one of the lower ears of the proximal baseplates and the lower rivets are driven in.

With the epicondyle strap fastened in position, the arm socket is placed on the patient, and the proper length of the flexible hinges is determined. Finally, the positions of the distal hinge attachments are marked, and the hinges are riveted to the socket, adjustment being provided for by the two buckles.

The arm socket and epicondyle strap are now put in place, the cable-housing retainers are attached to the baseplates on the epicondyle strap, and the cable housings are continued through the elbow center in such a way as to maintain a gentle wave to a point approximately 2 in. below the top of the arm socket (Fig. 13). The arm is then removed from the patient, and the baseplates are riveted in position on the socket. The male end of the cable lengthener is now attached to the terminal device, the lengthener is extended to the full-open position, and the other end of the lengthener is attached to the sheave equalizer.

Next the cable housings are installed and adjusted to obtain maximum elbow flexion and extension without compression or stretch of the housings. The ends of the housings are trimmed so that, when the ferrules are installed, the housings will terminate flush with the rivets on the baseplates. The ferrules are then pinched slightly with a diagonal cutter.

A female snap-on attachment is now fastened to one end of a length of cable, and the attachment is snapped to the pin. The free end of the cable is fed through one cable housing, down through and around the sheave, and back up through the other cable housing. The terminal device is opened, the muscle tunnel is pulled into passive stretch, and the cable length is measured. The cap fitting is installed according to manufacturer's instructions. Normally, the cable will be a little too long. Adjustment may be made by taking up on the cable-length adjuster.

After a period of use of the prosthesis, the amputee may find that the adjuster can no longer remove slack from the system. This development can be expected in some cases. It is only an indication that the tunnel has stretched with use. In this event, the control cable should be detached, shortened, and reattached as in initial cable installation.

The APRL system as described here has been used experimentally with a great deal of success, but the lack of commercial availability of components in the past has limited its use in the field. It is designed primarily to be used with the voluntary-closing type of terminal device. Furthermore, the frictional losses in pre-positioning are greater than in the UCLA system, and unless the sheave equalizer is placed on the top of the socket use is limited to voluntary-closing terminal devices. This circumstance makes interchangeability of a voluntary-closing hand and a voluntary-opening hook quite impractical. The APRL system is primarily recommended for use with the epicondyle strap, which normally gives ample support for axial loads without appreciable displacement of the socket.

A distinct advantage of the APRL system over that of UCLA is that the effective cable links between the equalizer and the muscle tunnel may be adjusted while at the same time maintaining equalized forces. To adjust the effective cable links between the twin cable mounting and the muscle tunnel in the UCLA system requires a turnbuckle, which in effect changes the links of the cable housing, thus increasing frictionai losses within the system.

HARNESSING FOR THE ABOVE-ELBOW CASES

Basically, two functional requirements must be met in above-elbow cases. Not only must prehension be provided for but it must be usable at various degrees of forearm flexion. Experience has shown that satisfactory prehension can best be obtained through a normal range of forearm flexion when provision is made for stabilizing the forearm at the selected level of operation. Thus, to the two basic functions there must be added the requirement of elbow lock. The body motions easily accessible and available for controlling these three functions in the above-elbow prosthesis are arm flexion, arm extension, and scapular abduction.[5]

At present there are three satisfactory harness patterns for the above-elbow case, two based on the so-called "dual control" and the third based on "triple control." The two dual-control systems—the above-elbow figure-eight harness and the above-elbow chest-strap harness—utilize arm flexion for forearm flexion and terminal-device operation, elbow lock being effected by arm extension. In the triple-control harness, arm flexion is used to produce forearm flexion, arm extension gives elbow lock, and terminal-device operation is obtained by shrug of the sound shoulder. Each of the three systems has its own advantages and disadvantages, and each therefore has indications and contraindications in individual cases.

THE ABOVE-ELBOW FIGURE-EIGHT HARNESS

From the wearer's point of view, the above-elbow figure-eight harness (Fig. 17) constitutes the easiest way of meeting the requirements of the above-elbow case. It is simply a modified below-elbow figure-eight design with provisions for the added functional requirements. Although in the below-elbow case it is essential mechanically to maintain a constant effective distance between the proximal and distal reaction points of the terminal-device control cable (Bowden principle), in the above-elbow case two functions may be obtained from a single cable by splitting the cable housing and substituting for the distal reaction point a lift lever on the forearm shell.

[6] It may be noted that the techniques for harnessing the above-elbow amputee can be applied equally well to articulated braces for flail arms.

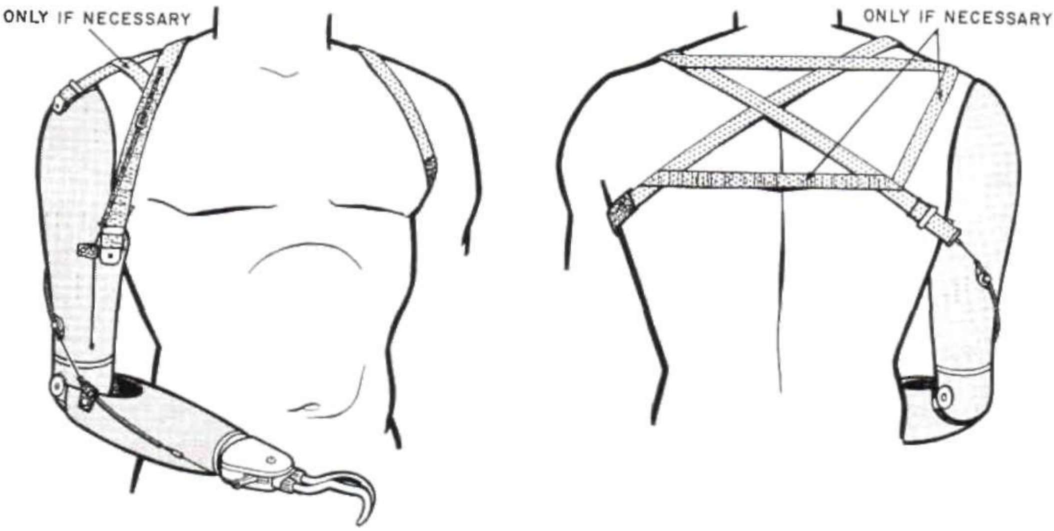

Fig. 17. The above-elbow figure-eight harness. The basic structure consists of a loop about the opposite axilla, the front portion supporting the arm and the rear portion attaching to the control cable so that arm flexion gives forearm flexion and terminal-device operation. The piece of elastic inserted in the front portion provides for relative motion for elbow locking by arm extension, the elbow-lock control being attached to the nonelastic portion. Suspension is improved by the lateral support strap and indicated auxiliary straps when necessary. As in the below-elbow dual control (Fig. 6), the cable housing is split so that arm flexion gives forearm lift when the elbow is unlocked, the leather lift loop on the forearm shell serving as the distal reaction point. If it is difficult to start the forearm into initial flexion, two baseplates may be used on the arm socket. The length of the leather lift loop on the forearm shell should be such that, when the forearm is extended, the distance from the center of the cable to the center of the elbow is equal to the distance from the center ot the forearm to the center of the cable housing. This arrangement reduces the amount of force needed to start the forearm into initial flexion without increasing the excursion required for full forearm flexion,

This arrangement couples forearm flexion and terminal-device operation to produce the dual control as used in the case of the very short below-elbow stump. Motion in the control source elicits terminal-device operation or forearm flexion depending on whether the elbow is locked or unlocked.

In the dual-control system, arm flexion is used as the source of control for forearm flexion and terminal-device operation, sometimes augmented by scapular abduction at large elbow angles, such as when the terminal device is near the mouth. A piece of elastic-webbing is substituted for the nonelastic front attachment strap of the below-elbow figure-eight harness. It is attached at the level of the clavicle and extends to the adjustable buckle on the arm socket, a minimum of 6 in. being desirable for easy operation of the elbow lock. The elbow-lock control cable is attached to the nonelastic portion of (he front attachment strap by means of a piece of 1/2-in. webbing bearing a 1/2-in. adjustment buckle. Arm extension thus produces relative motion between the elastic webbing and the nonelastic control strap in such a way as to induce elbow locking. Thereafter arm flexion controls terminal-device operation. With proper training and practice the amputee can become very adept in effecting smooth operation of all three prosthetic controls.

Suspension is improved by adding a connecting strap, known as the "lateral support strap," above the cross on the amputee's back. It extends laterally across the shoulder to a buckle on the lateral side of the arm socket. Proper adjustment of the lateral support strap controls alignment in the abduction-adduction plane. With these modifications, the below-elbow figure-eight harness is adapted to become the figure-eight for the above-elbow case. In summary, the alterations include insertion of the elastic webbing in the front to help suspend the socket and to provide for relative motion for elbow-lock control, addition of the lateral support strap over the shoulder to contribute to socket stability, and the use of the two-piece cable housing to give forearm flexion when the elbow is unlocked.

The two optional straps indicated in Figure 17 together improve suspension, increase the available excursion, and assist in maintaining the control attachment strap on the shoulder when the arm is raised. The over-the-shoulder strap forms a webbing network to support axial loads and to stabilize the lateral support strap and front attachment strap on the shoulder. The cross-back elastic strap not only gives greater excursion both in scapular abduction and in arm flexion but it helps to prevent the control attachment strap from riding over the shoulder during extreme arm flexion, such as when the amputee is working in areas over his head. But again, following the rule of simplicity whenever possible, the above-elbow figure-eight harness should be tried first without the two optional straps. If that proves unsatisfactory, then the extra straps may be added.

For a detailed description of the technique of fabricating the above-elbow figure-eight harness, reference may be had to Section 6.7 of the *Manual of Upper Extremity Prosthetics (27)* or to the report of the NYU Committee on Above-Elbow Harness *(20)*. It will suffice here to describe some of the common errors often leading to difficulties. Careful observation should always be made to be certain that the elastic straps are not too short and that the proximal end and distal buckle of the front suspensor strap are properly positioned. A minimum of 6 in. of elastic is required to give sufficient excursion for operation of the elbow lock and to provide adequate length for adjustment of tension in the strap.

Placement of the proximal end of the elastic suspensor not lower than the clavicle enables the amputee to feel the elastic stretching over the deltopectoral interval during the elbow-lock operation, thus furnishing an additional cue to ensure reliable elbow function, and it permits the minimum of 6 in. of elastic to be used without bringing the attachment too far down on the socket. Normally the harness cross should lie approximately 1 in. toward the sound side of the vertebral spine. Crossing the harness at this point usually brings the control attachment strap over the lower third of the scapula, where maximum excursion may be utilized. The cross should be below the seventh cervical vertebra, thus avoiding the discomfort caused when the harness rides up. If the cross is more than 1 in. toward the sound side, the axilla loop is unduly decreased in size, with consequent increase in discomfort at the axilla.

The control attachment strap should not fall so low as to prevent arm abduction, and the lateral support strap should not ride too high on the neck. If the cross is farther to the amputated side, the control attachment strap may ride too high. Placement of the lateral support strap 1/2 in. forward of the acromion is found to result in optimal stabilization of the prosthesis on the stump without causing rotation. Attachment of the lateral support strap should be 2 in. below the acromion. When it is attached at a lower point, the strap rolls back and forth over the shoulder, and higher attachment results in poor cosmesis because of the interference of the buckle with the shoulder pad of clothing. Placement of an adjustable buckle at the junction of the front support strap and elastic suspensor provides optimal position for adjustment of the elbow-lock control cable.

The placement of the elastic suspensor strap markedly influences the effectiveness of the elbow-lock control motion. If excess slack is left in the elbow control cable, it must be taken up by the control motion before the lock will operate, and consequently the total excursion will then be greater than necessary. At the same time, there must be sufficient slack in the cable to permit relaxation of tension for resetting the elbow-lock mechanism.

THE ABOVE-ELBOW CHEST-STRAP HARNESS

The chief advantages of the above-elbow figure-eight harness are that it is functional and simple and will satisfy the needs of most vocational activities. As in the below-elbow case, however, if there is a requirement for the harness to lift heavy loads, then another type is indicated. Again as in the below-elbow case, the chest-strap harness (Fig. 18) is recommended for the above-elbow amputee whose activities commonly involve heavy-duty work. By supplying a shoulder saddle and thus reducing the unit stresses over the shoulder, the above-elbow chest-strap harness provides greater comfort, and hence greater loads can be accommodated.

The shoulder saddle has taken two forms, the leather type and the webbing type. The leather type is precisely like that used in the below-elbow chest-strap harness. Figures 19 and 20 illustrate webbing-type shoulder saddles that furnish adequate suspension on the lateral side of the arm socket and provide for the relative motion needed for elbow lock and for dual control. The operational pattern of body motions is identical to that used with the above-elbow figure-eight pattern. Arm flexion manages dual control *(i.e.,* forearm flexion and terminal-device operation), and arm extension controls the elbow lock.

The above-elbow chest-strap harness has as its chief advantage the ability to lift axial loads with lower unit stresses over the shoulder. Its primary disadvantage lies in its characteristic tendency to rotate about the chest owing to lack of a positive anchor. Again as in the below-elbow case, the simpler figure-eight design should be applied to the above-elbow case whenever it can be made to serve the amputee satisfactorily. The above-elbow chest-strap harness should be adopted only when the simpler figure-eight harness proves to be inadequate in any given case.

THE ABOVE-ELBOW TRIPLE CONTROL

In the above-elbow triple-control harness (Fig. 21), arm flexion produces flexion of the forearm, arm extension provides elbow-lock control, and extreme flexion of the sound shoulder (shrug) gives terminal-device operation. Although the control system is quite simple, it requires the amputee to distinguish

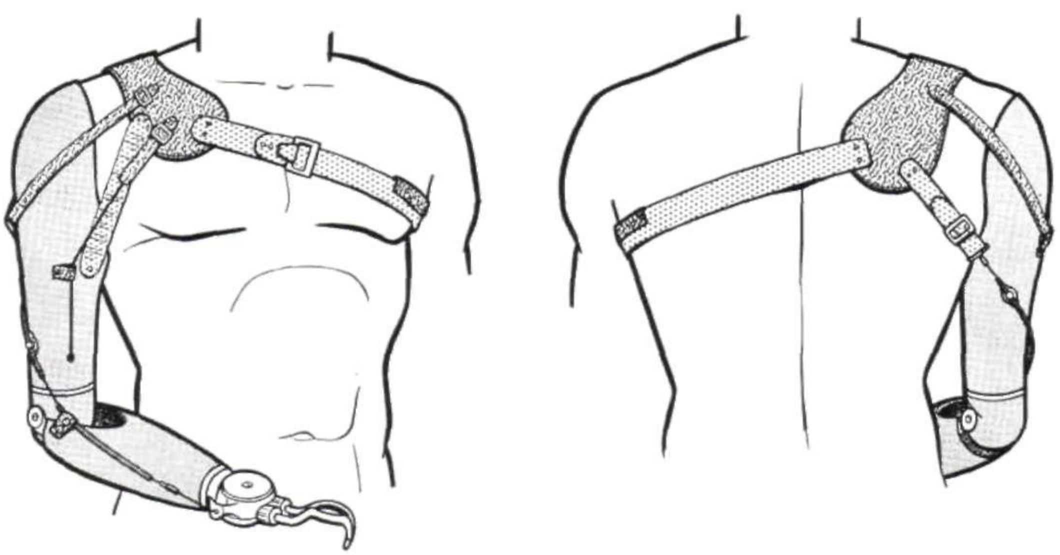

Fig. 18. The above-elbow chest-strap harness using for suspension a leather strap threaded through a D-ring on the lateral wall of the socket and attached to a leather shoulder saddle at two points, The strap for the control cable may be attached either to the shoulder saddle, as shown, or to the chest strap at the midspine position. As in the below-elbow case, this type of harness improves lifting ability and reduces unit stresses over the shoulder on the amputated side. The elbow-lock control cable is attached to the front of the shoulder saddle, and again a piece of elastic is used as the front suspensor between shoulder saddle and arm socket.

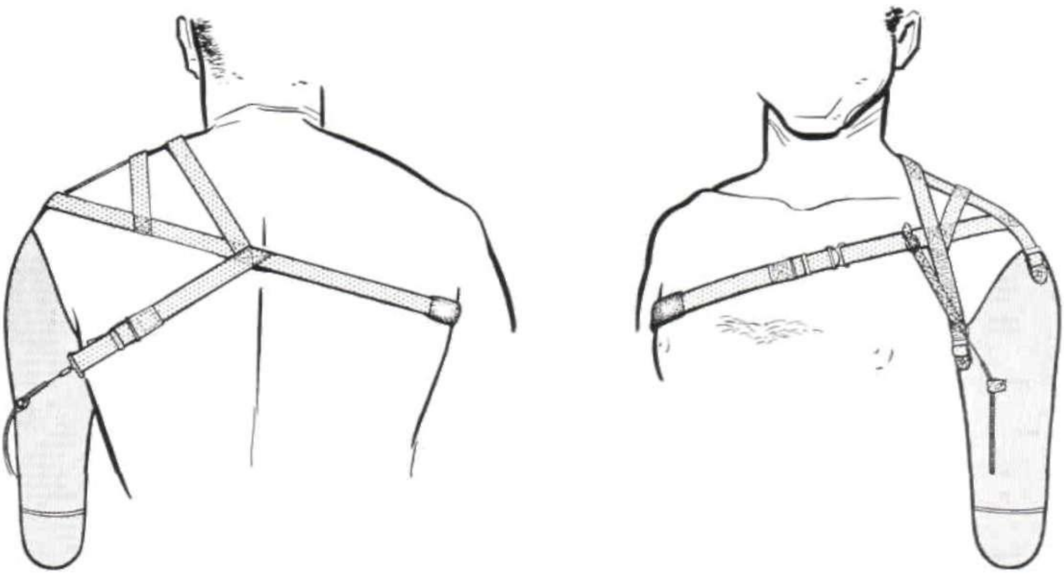

Fig. 19. The above-elbow chest-strap harness with webbing shoulder saddle. The functional arrangement is identical to that in the above-elbow chest-strap harness with leather shoulder saddle (Fig. 18). The leather has simply been replaced with a webbing saddle designed to give the same function. The technique is best used on individuals who perspire freely but who nevertheless need the chest-strap type of harness for heavy lifting.

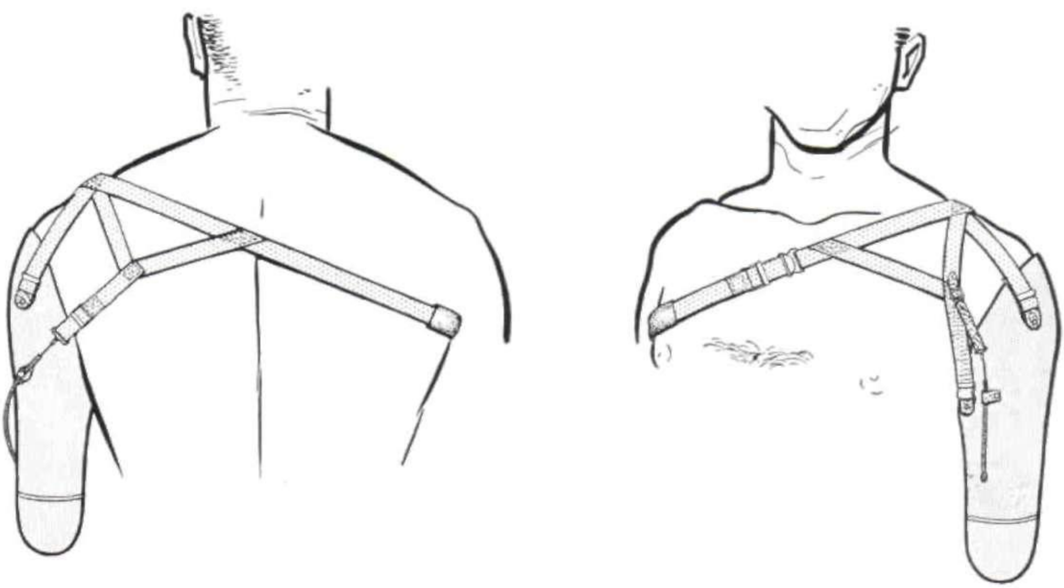

Fig. 20. An alternative construction of the webbing shoulder saddle for use with the above-elbow chest-strap harness. Beginning at the point of attachment on the front of the arm socket, the principal strap passes over the shoulder on the amputated side, continues across the amputee's back, goes under the opposite arm, crosses the chest, again passes over the shoulder on the amputated side, and buckles to the rear portion of the socket. This arrangement equalizes the forces when axial loads are encountered. A Y-type construction is used to connect the control cable to the chest strap at the midspine position and at the point where the chest strap crosses the shoulder. A similar construction is used in front, the lower leg of the "Y" being made of elastic to permit the relative motion needed for elbow-lock control.

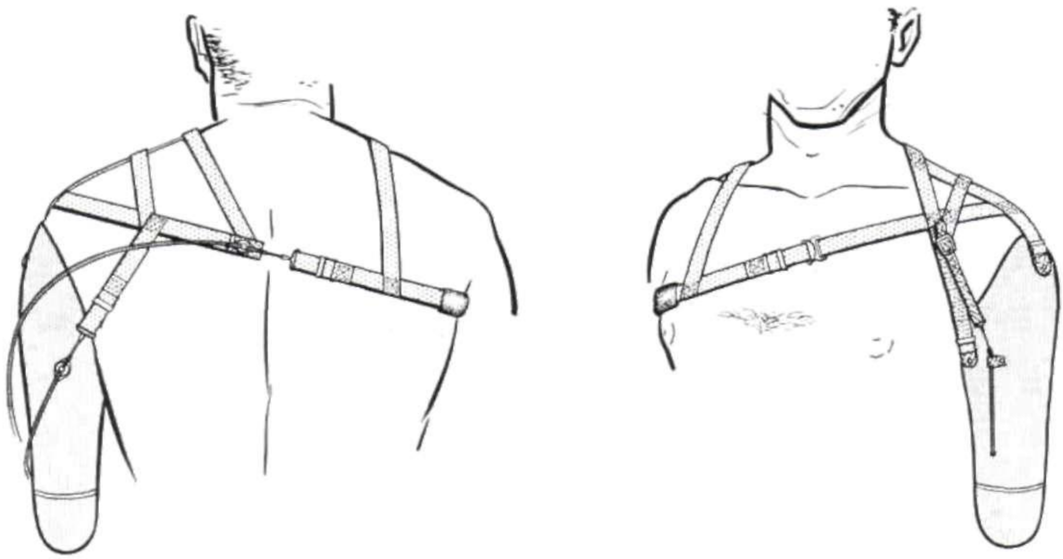

Fig. 21. The above-elbow triple-control harness. It differs from the dual-control pattern in that three body motions are required. The axilla loop uses shrug of the opposite shoulder to operate the terminal device, so that in this case the chest strap is separated at approximately the midspine position. Relative motion takes place between the axilla loop on the sound side and the reaction point located on the portion of the harness on the amputated side. A supporting shoulder saddle is constructed of a webbing network, and the control attachment strap for forearm flexion is attached at a point over the superior spine of the scapula on the amputated side. Arm flexion then lifts the forearm. Arm extension is harnessed as usual, a piece of elastic being used as the front suspensor strap to provide for the necessary relative motion

between arm flexion on the amputated side and extreme flexion of the shoulder on the opposite side to yield two separate controls. Above-elbow amputees with long stumps can usually make this distinction readily enough; those with medium to short stumps find it very difficult.

The advantage of triple control lies in the possibility of operating the terminal device without first locking the elbow. But the complexity of fabricating the triple-control system has been a major disadvantage and has discouraged its use. It is recommended for amputees requiring versatility in the use of the prosthesis, but it should be approached cautiously by the harnessmaker.

HARNESSING FOR THE SHOULDER-DISARTICULATION CASES

To provide adequate functional harness for the shoulder-disarticulation amputee has always been especially difficult because of the lack of the control source otherwise available from humeral motion. In the absence of an arm stump, it has been to date, for all practical purposes, impossible to provide any satisfactory voluntary motion of the prosthetic arm about the shoulder, and consequently a substitute must be sought for arm extension, the control source commonly used by the above-elbow amputee for operation of the elbow lock. The alternatives are to use manual operation of the lock by the sound hand or else to harness some residual control source ordinarily remote from arm function.

Since in any case manual control is undesirable because it interrupts two-handed activities, the trend has been to utilize other body motions such as those of the head or shoulders. The nudge control *(11, 25, 27),* with the operating button located on the shoulder cap of the prosthesis, was designed to be operated by pressure from the chin. But this system leads to such awkward appearance in use that it has since been more or less superseded by harness designs utilizing shoulder motions. The perineal strap, with function based on relative displacement between shoulders and pelvis, is disliked by most amputees and therefore has been used less and less except where special complications prohibit other arrangements. The most practical system worked out to date involves use of a waist band or equivalent. At the present time, there are four satisfactory harness patterns for the male shoulder-disarticulation case and two suitable for the female. For the male, there are three dual-control systems, all operated by scapular abduction, elbow lock being accomplished in the first case by shoulder elevation on the amputated side, in the second by flexion of the opposite shoulder, and in the third by shoulder extension on the amputated side. The fourth system for the male utilizes the triple-control principle—scapular abduction to provide forearm flexion, elevation of the shoulder on the amputated side to give elbow lock, and shrug of the opposite shoulder to operate the terminal device. Since all four of these systems involve a chest strap unsuited to the female, two special arrangements have been worked out for women. Both are built around a brassiere, and both utilize dual control, in the one case operated by scapular abduction, in the other by motion of the opposite shoulder. In both cases, elbow lock is effected by elevation of the shoulder on the amputated side.

HARNESS PATTERNS FOR MEN

Dual Control with Shoulder-Elevation Elbow Lock

Of the four shoulder-disarticulation harness systems for males, the one most often used with the least trouble involves scapular abduction for dual control of forearm flexion and terminal-device operation, elbow lock being managed by elevation of the shoulder on the amputated side. As in all dual-control systems, excursion of the control source, in this case bilateral abduction of the scapulae, produces either terminal-device operation or forearm flexion depending on whether the elbow is locked or unlocked.

Figure 22 presents the basic details of this harness pattern. A webbing chest strap attaches to the front of the shoulder cap, passes under the axilla on the sound side, crosses the back at the midscapular level so as to utilize the maximum available excursion, and attaches to the control cable positioned on the back of the shoulder cap. An elastic suspensor strap extends from the top of the shoulder cap, diagonally across the back, and attaches to the chest strap at a point just toward the sound side of the vertebral spine. The length of the chest strap is so adjusted as to permit full terminal-device operation without bringing the cable into contact with the skin.

Elbow-lock operation by shoulder elevation is provided for by linking the elbow control cable to a waist strap encircling the trunk below the thoracic cage, thus establishing an anchor to oppose shoulder elevation. Although adequate force for elbow locking is usually available, care is taken to position the cable reaction points in such a way as to eliminate as much frictional resistance as possible.

This system offers several distinct advantages over other methods of harnessing the shoulder-disarticulation case. It involves the minimum amount of harness needed to operate the three basic controls, and it has the inherent advantage of avoiding any possibility of interference between elbow locking and the other two functions. Thus training is simplified considerably, and the success of the individual harness may be determined at the time of fitting.

Dual Control with Opposite-Shoulder Elbow Lock

A second shoulder-disarticulation harness system seen frequently also uses scapular abduction for dual control of forearm flexion and terminal-device operation, but elbow lock is effected by a forward rotation of the sound shoulder. The arrangement for dual control is precisely like that just described, the difference in the harness as a whole being concerned with the method of elbow locking (Fig. 23). In addition to the chest strap and the elastic suspensor strap, there is provided for the sound shoulder a webbing saddle, the cross-back extension being attached to the elbow control cable near the point of stabilization on the back of the shoulder cap. Again the lengths of the straps are so adjusted as to

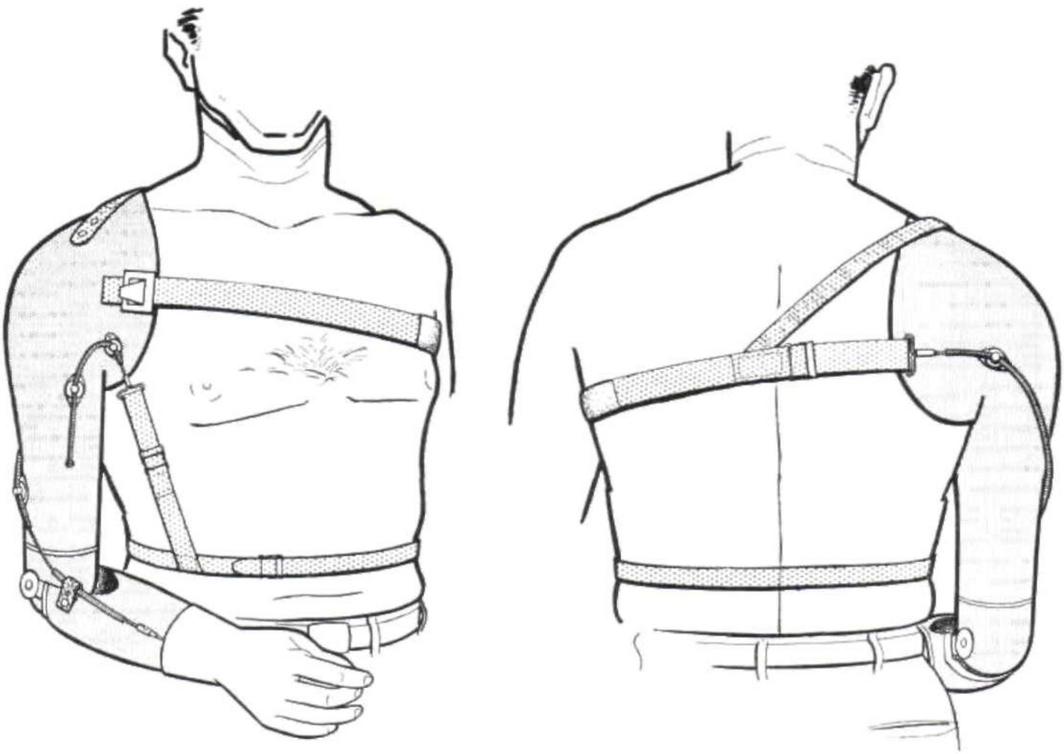

Fig. 22. Shoulder-disarticulation harness using scapular abduction for dual control, elbow lock being operated by shoulder elevation on the amputated side. After Pursley *(23),* by permission of *Orthopedic and Prosthetic Appliance Journal.*

permit adequate excursion without the cables touching the flesh.

Although this system eliminates the need for the waist strap, it obviously introduces more complicated harness about the shoulders, and it offers the inherent disadvantage of the possibility of inadvertent locking or unlocking of the elbow in the course of forearm flexion or terminal-device operation. If, however, care is taken to keep the chest strap at the mid-scapular level while making the opposite-shoulder loop as high as possible, and if the amputee is thoroughly trained, the two operating body motions can usually be separated satisfactorily.

Because in this system the elbow-lock control cable traverses a comparatively long path, and also because the associated harness moves across the entire surface of the back, the frictional forces involved are sometimes such that the alternator spring in the elbow is not strong enough to return the control cable to the relaxed position. When this is the case, an additional spring may be added on the inside of the arm section (Fig. 24). Since this extra spring force makes the elbow lock more difficult to operate, it has the incidental advantage of making it easier for the amputee to separate opposite-shoulder shrug from scapular abduction, thus helping to avoid inadvertent elbow action. If difficulty is still encountered, separation of controls is sometimes made easier if the opposite-shoulder loop is adjusted to require an extreme flexion of the sound shoulder before elbow locking is induced.

In any event, a considerable period of practice is usually required before the average amputee can manage separation of controls systematically and with the necessary confidence. Training is thus more prolonged than is the case with the shoulder-elevation elbow

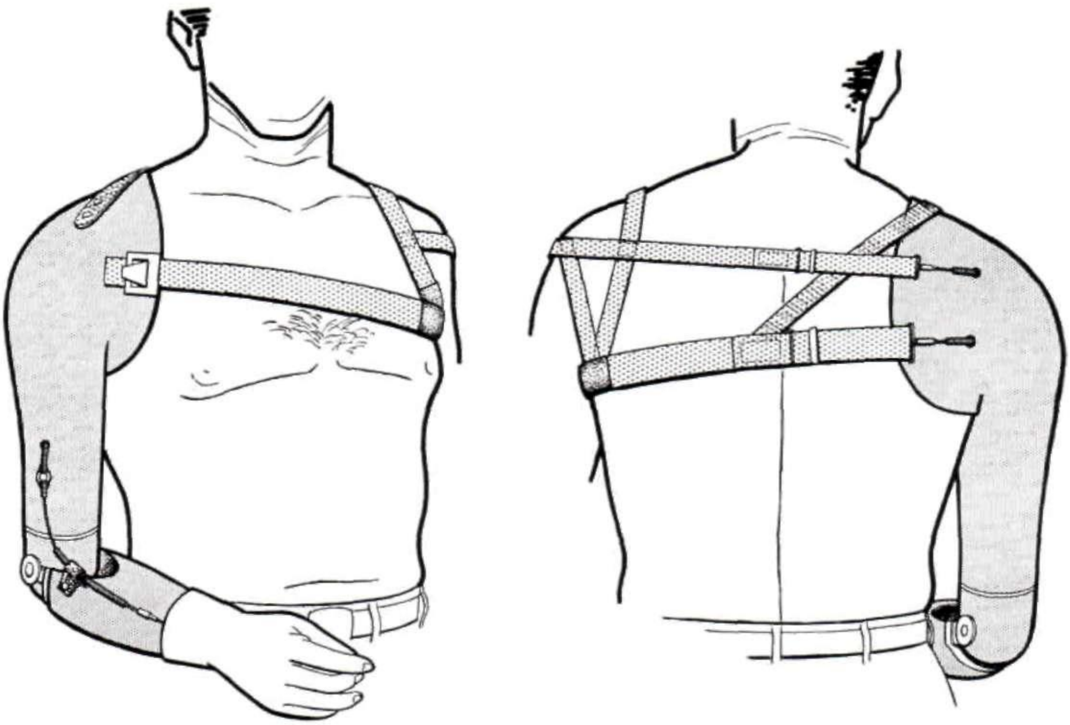

Fig. 23. Shoulder-disarticulation harness using scapular abduction for dual control, elbow lock being operated by flexion of the shoulder on the sound side. After Pursley *(23),* by permission of *Orthopedic and Prosthetic Appli~ance Journal.*

lock, and consequently the dual-control harness using opposite-shoulder lock offers the further disadvantage that the ultimate success in any given case is difficult to determine at the time of initial fitting.

Dual Control with Shoulder-Extension Elbow Lock

Figure 25 presents the dual-control shoulder-disarticulation harness utilizing shoulder extension to lock and unlock the elbow. The lower leg of the front attachment strap contains a piece of 1-in. elastic, the front elbow-lock control being connected to the nonelastic part of the chest strap. Thus shoulder extension produces a relative motion for elbow locking.

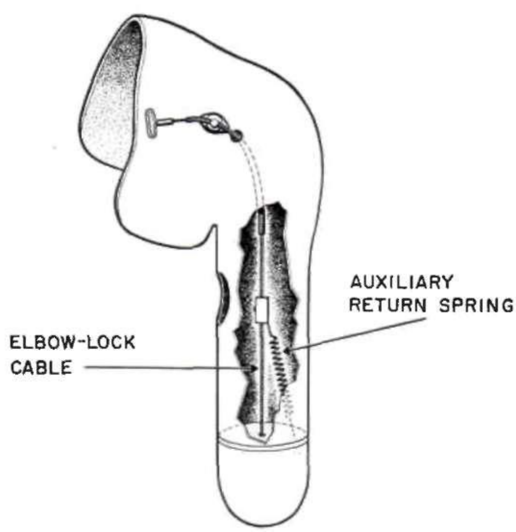

Fig. 24. Installation of the elbow-lock cable, showing arrangement when auxiliary spring is needed to return cable to relaxed position. The additional spring force makes it easier to separate the elbow-lock control motion from scapular abduction. After Pursley *(23),* by permission of *Orthopedic and Prosthetic Appliance Journal.*

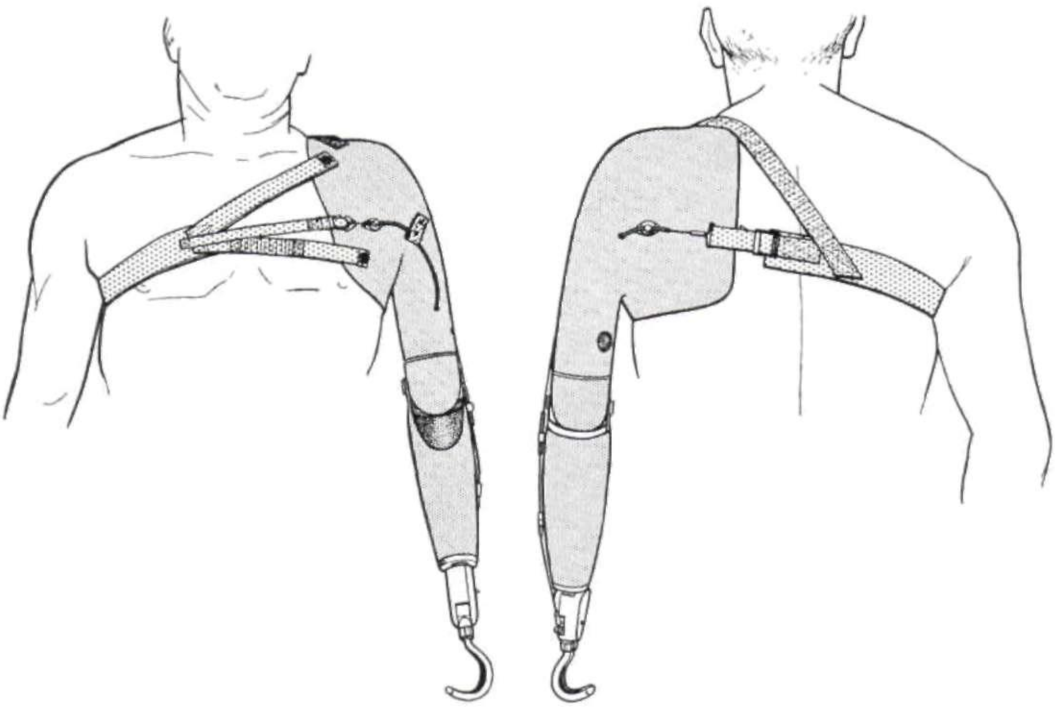

Fig. 25. Shoulder-disarticulalion harness using scapular-abduction dual control, elbow lock being operated by extension of the shoulder on the amputated side The chest strap terminates in front in a forked arrangement for attachment to the socket. A piece of 1-in. elastic is inserted in the lower leg of the fork, and the elbow-lock control cable is attached to the base portion of the chest strap just beyond the elastic, thus providing for relative motion upon extension of the shoulder on the amputated side.

To operate the prosthesis starting with forearm extended, scapular abduction is used to produce forearm flexion. While maintaining enough force on the lift cable to hold the forearm in the desired position, the amputee extends his shoulder on the amputated side to lock the elbow. Thereafter scapular abduction operates the terminal device.

Although this system may be used on any shoulder-disarticulation case, amputees retaining the humeral neck are the most successful. Patients without the humeral neck experience difficulty in coordinating the two body motions. In any event, the length of the elastic and the position of the wide attachment are both critical. Normally a piece of 1-in. elastic 1 1/2 in. long is used as a start. If the elbow is difficult to operate, the elastic portion is made longer. If the elbow operates inadvertently, the elastic is shortened so as to require more definite shoulder extension to lock and unlock.

Although this type of shoulder harness is quite new, experience to date would suggest consideration of new elbow mechanisms especially designed for use with it. An obvious advantage is elimination of the waist band and opposite-shoulder loop used respectively in the other two dual-control systems.

Triple Control

In the triple-control system for shoulder disarticulation, as in the triple control for above-elbow cases, the three necessary functions are provided by three control sources, one for each. The usual and generally most successful pattern utilizes scapular abduction for forearm flexion, shrug of the sound shoulder for terminal-device operation, and elevation

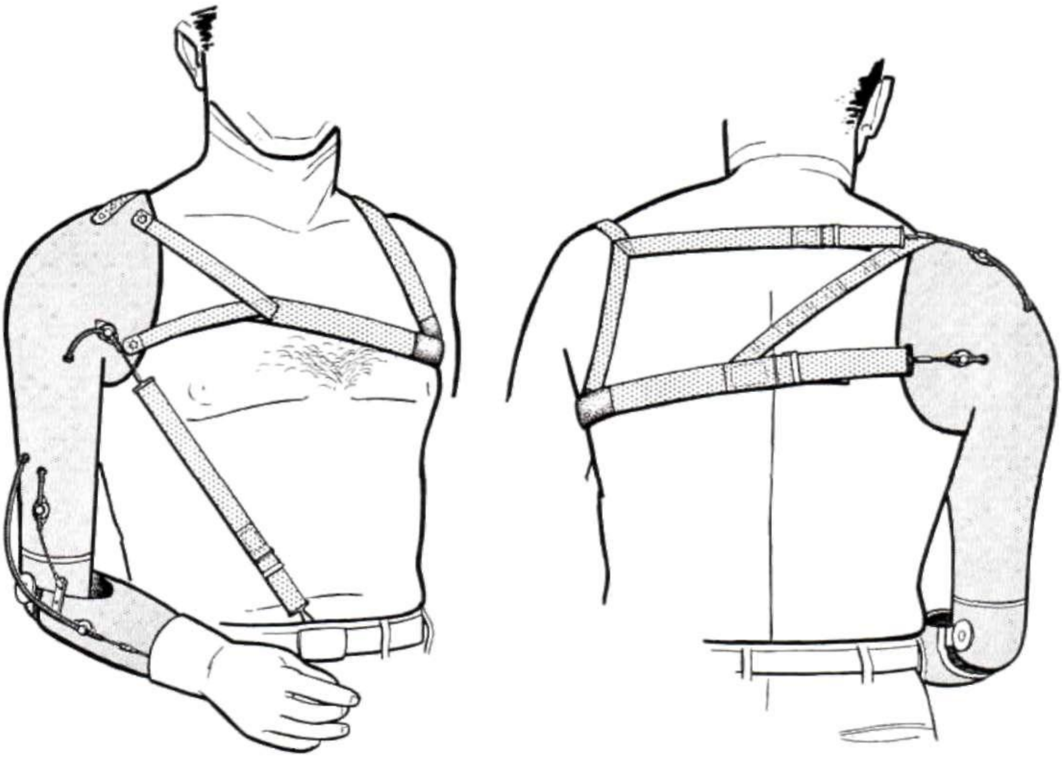

Fig. 26. Shoulder-disarticulation harness utilizing triple control. Scapular abduction provides forearm flexion; shoulder on sound side operates terminal device; elbow lock is operated by shoulder elevation on the amputated side. After Pursley *(23),* by permission of *Orthopedic and Prosthetic Appliance Journal.*

of the shoulder on the amputated side for control of the elbow lock. The basic pattern (Fig. 26) involves a minor modification of the chest strap seen in Figures 22 and 23, an elastic suspensor strap also similar to that seen in Figures 22 and 23, an opposite-shoulder loop with an extension passing over the seventh cervical vertebra or slightly below it, and a linkage between elbow control cable and waist band.[6]

Although the triple control requires more harness than do the other three patterns for shoulder disarticulation, it offers certain advantages not to be had from dual control. Separation of terminal-device operation from forearm flexion offers improved control over prehension, since during forearm flexion no force or excursion is introduced affecting the terminal device. Likewise, as in the case of the dual control with shoulder-elevation elbow lock, the triple-control system overcomes the difficulty of separating elbow lock from the other two functions, so that inadvertent elbow locking or unlocking is avoided. The result is, again, simplified training and the possibility of determining the success of the harness at the time of initial fitting.

[6] Use of the waist band, as in Figure 22, is largely a matter of personal preference. Some amputees like it, some do not. When the amputee wishes to dispense with the extra waist strap, the elbow control may be anchored to an item of clothing such as a button at the top of the trousers near the fly, as in Figure 26. The control strap then passes out of the shirt between buttons, so that no special opening is needed. But of course when this arrangement is used, the prosthesis is inoperable when the wearer is unclothed.

HARNESS PATTERNS FOR WOMEN

Since the chest strap, common to all four harness patterns for male shoulder-disarticulation cases, is unsuited for most women, harness designs for female shoulder-disarticulation amputees are best based on some other principle. The most satisfactory method found to date for eliminating the chest strap is to utilize as part of the harness a brassiere made of sturdy material.[7] As shown in Figure 27, a strip of 1-in. webbing is sewed around the lower edge of the brassiere known to bra designers as the "diaphragm band." The shoulder cap is so designed as to project in front below the breast on the amputated side to provide an anchor point *(B)* to which the diaphragm band is attached. An elastic suspensor strap attaches to the top of the shoulder cap at *A*, passes diagonally down the back, and is sewed to the diaphragm band at *C* somewhat toward the sound side of the vertebral spine. For ease in adjustment and to provide for ready laundering, a buckle is used at *D,* a clip-type disconnect is installed at *E,* and attachments at *B* and *A* are made with snap fasteners. The arrangement for control of the elbow lock utilizes the waist band[8] in the same way as in the corresponding pattern for the male (Fig. 22).

Although in this harness design the diaphragm band crosses the back somewhat lower than the midscapular level desired with the chest strap, adequate excursion is usually available from biscapular abduction, which, as in the male patterns of Figures 22, 23 and 25, provides dual control of forearm flexion and terminal-device operation. Shoulder elevation provides control of elbow locking.

A problem encountered with the design shown in Figure 27 is that in flat-chested

[7] Not chiffon or lace!

[8] When the waist band is disliked by the female amputee, the elbow control strap may be anchored to a girdle or pantie girdle, just as it may be anchored to the trousers in the male.

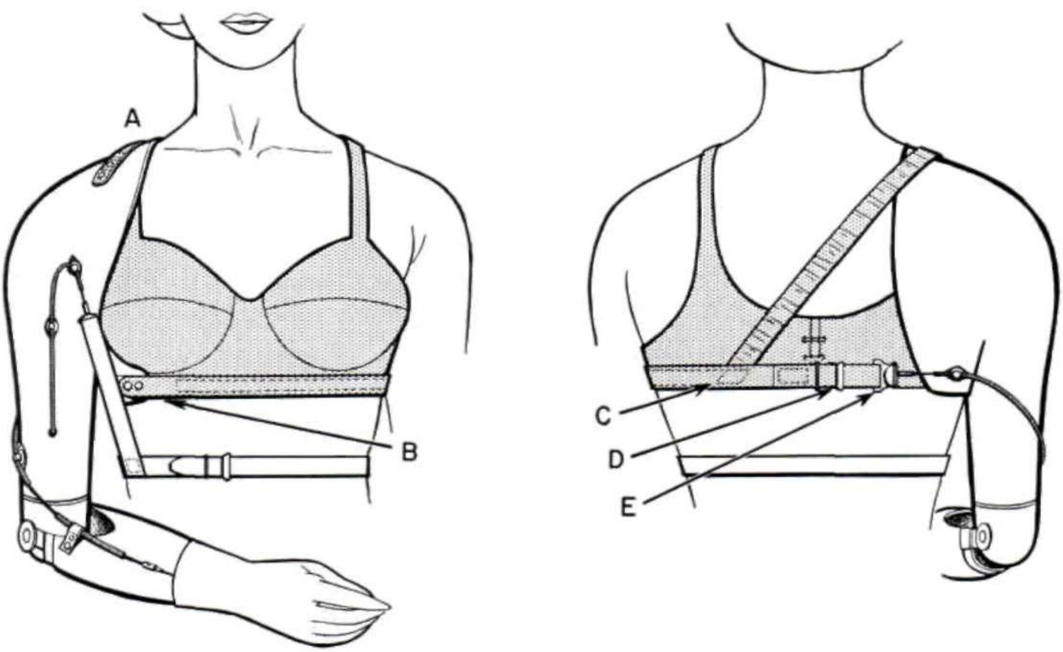

Fig. 27. Harness for female shoulder-disarticulation cases, made integral with bra but detachable from arm socket for laundering. Scapular abduction provides dual control of forearm lift and terminal-device operation, while elbow lock is effected by shoulder elevation on the amputated side. After Pursley *(23),* by permission of *Orthopedic and Prosthetic Appliance Journal.*

persons or in those with comparatively small breasts it is sometimes difficult to get adequate stability, so that operation of the dual control causes the brassiere to rotate upon the chest. When such a situation prevails, use may be made of the modification shown in Figure 28, where the brassiere is called upon to provide suspension only, the loop about the sound shoulder furnishing the dual control. Here, as in Figure 27, attachments *A, B,* and *D* are made with snap fasteners so that the entire harness can be removed from the arm socket for laundering, the elastic suspensor being sewed to the diaphragm band at *C.*

SOME SPECIAL CONSIDERATIONS

A distinguishing characteristic of the shoulder-disarticulation amputee is that the available control sources are for the most part of comparatively high force but of low excursion. Most commercially available terminal devices require an average of 1 3/4 in. of excursion for full operation, and normally 2 to 3 in. of excursion are needed to produce full forearm flexion of 135 deg. Generally, the total exceeds the excursion available from scapular abduction. This means that if, in a dual-control system with a voluntary-opening hook, where the excursions for forearm flexion and for terminal-device operation are additive, the amputee is to be able to open the hook at the mouth, some means must be found for obtaining the extra excursion. The only other alternatives are to use a voluntary-closing hook, in which case the excursion used in forearm flexion is regained for hook operation, or to use triple control, in which case forearm flexion and terminal-device operation are obtained from two separate sources. But many shoulder-disarticulation amputees do not care for voluntary-closing terminal devices, and others, for this reason or that, are not always able to manage the triple control.

Since in general the force available from scapular abduction far exceeds that needed for forearm lift and prehension, some of the

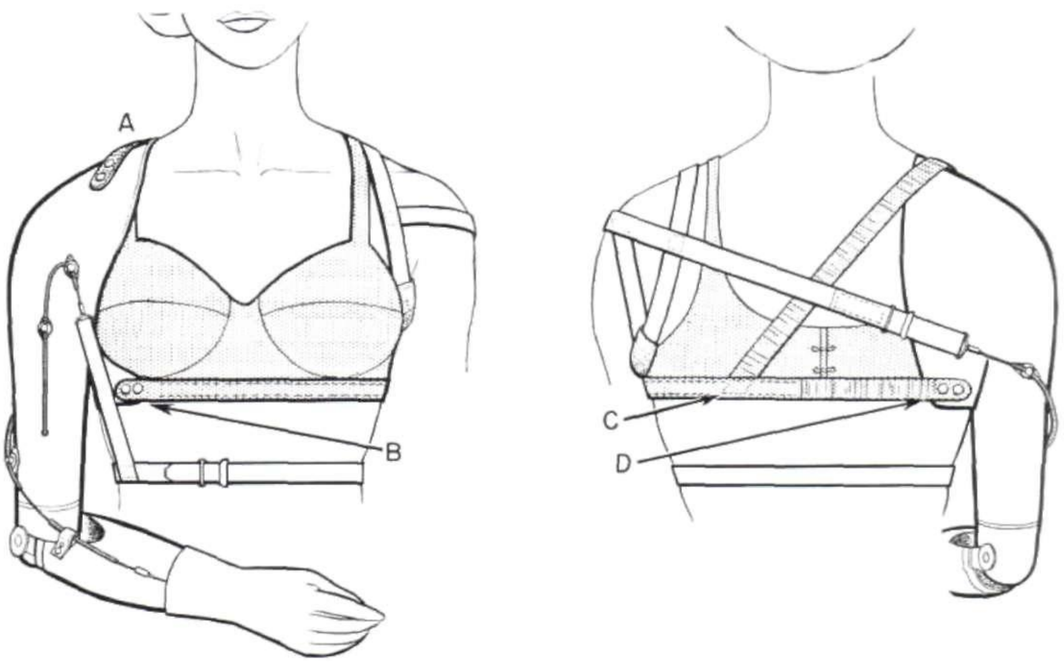

Fig. 28. Alternative harness for female shoulder-disarticulation cases in which the simpler arrangement of Figure 27 proves too unstable. Here the bra is used for suspension only. The loop over the sound shoulder provides dual control of forearm lift and terminal-device operation, while elbow lock is effected by shoulder elevation on the amputated side After Pursley *(23),* by permission of *Orthopedic and Prosthetic A ppliance Journal*

force may be sacrificed in the interest of obtaining an increase in excursion. The "block-and-tackle" cable system shown in Figures 29 and 30 provides a two-to-one step-up in excursion at the expense of surplus force. It may be used with any of the six harness systems whenever added excursion is needed either for forearm flexion or for terminal-device operation. In Figure 23, for example, it is applied to the dual control. In Figure 26, it is used to step up forearm flexion in the triple control. It could equally well be installed in the system of Figure 22, should that prove to be necessary in any given case. Conversely, when excursion step-up is not required for the patterns of Figures 23 and 26, an external cable routing may be used, as in Figure 22. In any case, careful analysis of the excursion available and of that required for the terminal device prescribed forms the basis of judgment as to whether the step-up system is indicated or not.

Although the six harness patterns described here represent the most generally successful designs now in common use for the shoulder-disarticulation case, no one of them provides a voluntary control source for motion of the upper arm about the shoulder. This deficiency, of course, imposes upon the shoulder-disarticulation amputee a rather serious limitation not characteristic of the normal arm. Some provision for arm flexion-extension is possible by making the arm socket in two pieces, a humeral section and a shoulder cap, and using the so-called "sectional plates" *(25,27).* But this arrangement is intended for manual pre-position only. Recently *(12)* a shoulder-disarticulation arm has been designed with a shoulder joint giving a combination of flexion and abduction to permit comfortable sitting at a table or desk, but again arm lift is manual, there being no satisfactory control source for voluntary flexion-abduction about the shoulder cap. Development of an additional voluntary control source to simulate the motion of the normal glenohumeral joint is now perhaps the most pressing need of the shoulder-disarticulation amputee.

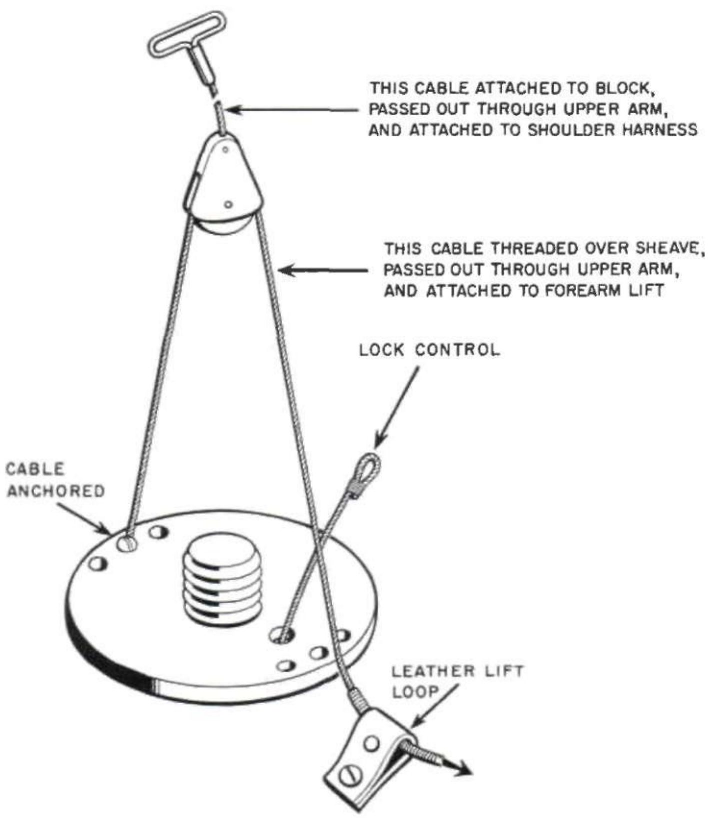

Fig. 29. Cable system for reducing the amount of excursion needed in the shoulder-disarticulation dual control. After Pursley *(23),* by permission of *Orthopedic and Prosthetic Appliance Journal.*

HARNESSING TOR BILATERAL ARM AMPUTEES

As compared to the unilateral case, the prosthetic requirements of bilateral arm amputees are magnified many fold. Experience shows that the unilateral subject uses his prosthesis chiefly to hold, carry, or assist in activities requiring two hands. Bilaterals, on the contrary, are required to rely wholly on their arm substitutes for both one-handed and two-handed activities. The pre-

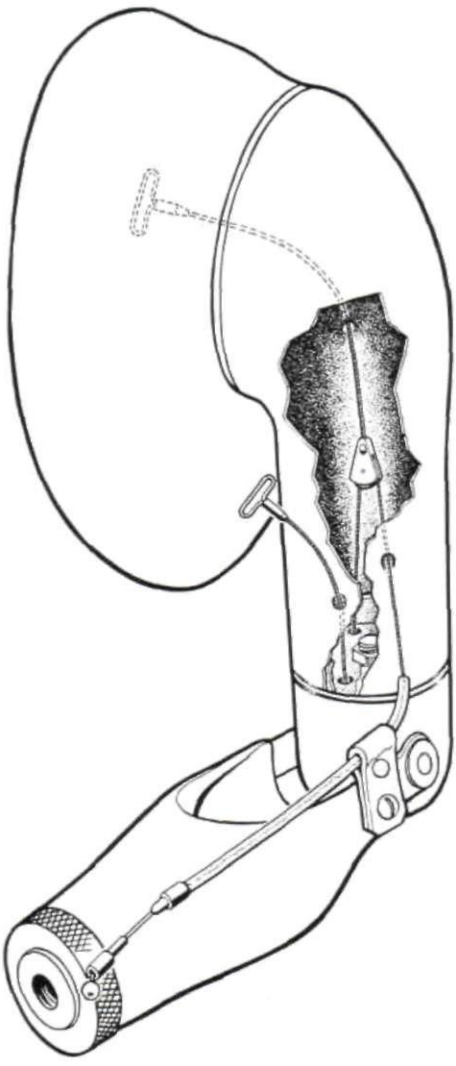

Fig. 30. Installation of the excursion-reducing cable system shown in Figure 29. After Pursley *(23),* by permission of *Orthopedic and Prosthetic Appliance Journal.*

scription criteria and techniques of fitting are therefore modified for the bilateral in an attempt to provide general operation in areas where the unilateral uses his normal hand. Bilateral arm amputees must, for example, have access to the pockets, both shirt pockets and side and hip trouser pockets if possible. They must be able to brush the teeth, comb the hair, use a buttonhook to manage button closures, and perform a great variety of other essential activities in the course of daily living. In general, all of these functions require action close to the body, behind the back at waist level, or at face, neck, or above the head. The prescription criteria for bilaterals therefore require special attention to personal as well as vocational needs, and consideration must be given to such special items as easily operable wrist disconnects and wrist-flexion units. Fabrication techniques are altered to provide for greater strength, and socket margins must be carefully determined in order to assure maximum socket stability for improved control.

In below-elbow cases, residual pronation and supination is, of course, priceless. In every step of amputee care, every effort should be made to maintain forearm rotation. Attention should be paid this matter from the time of the original amputation and should continue through prescription, socket fitting, and fabrication of the harness.

A matter of the greatest importance to the bilateral arm amputee is that of being able to get the harness and prostheses on and off without help from others. Bilateral above-elbow and shoulder-disarticulation amputees can almost always manage to get their prostheses off without help, but they sometimes require assistance in putting the arms on. Special brackets mounted on a wall in a bedroom are often needed to help amputees otherwise unable to perform independent donning. If, for example, a bilateral with short above-elbow stumps cannot control his prostheses while reaching for the harness cross on his back to remove the harness by pulling it over his head ("skinning-the-cat"), he hangs the cross over the wall hook by simply backing up to it. He then bends his knees to lift the straps over his head. Leaving the harness cross on the hook, he then removes the prostheses by holding the terminal devices, one at a time, each with the opposite foot. Thus the arms are left hanging in such position that the stumps can again be inserted into the sockets and the harness slipped back over the head.

Control in the bilateral amputee is at best difficult. Because the number of controls required is doubled, less effective control motions must be brought into use, and independence of control becomes a problem. At present, six control functions, three for each arm, are about all that can be manipulated conveniently and efficiently. Even so, interaction between controls is noticeable.

THE BILATERAL BELOW-ELBOW HARNESS

The easiest way to describe a bilateral below-elbow harness (Fig. 31) is to start by supposing that a unilateral below-elbow amputee has lost his remaining good arm below the elbow and has asked that his old figure-eight harness be used to make the new bilateral harness. The first step would be to cut the axilla loop on what was formerly the sound side. The front portion of the cut strap would then be attached to the inverted Y-suspensor of the new prosthesis. The back portion of the cut strap would be turned back upon itself and attached to a buckle. It thus would become the control attachment strap for the new prosthesis.[9] Arm flexion on either side then gives terminal-device operation.

The cross on the back may be lowered by loosening the inverted Y-straps in front and

[9] While this hypothetical case suffices to describe the harness, it carries the faulty implication that the bilateral harness is simply two unilateral harnesses. No such implication is justified, for, as already pointed out, the functional requirement is magnified many fold, there is the complication of effecting separation of controls, and in addition there is the problem of getting into and out of the harness.

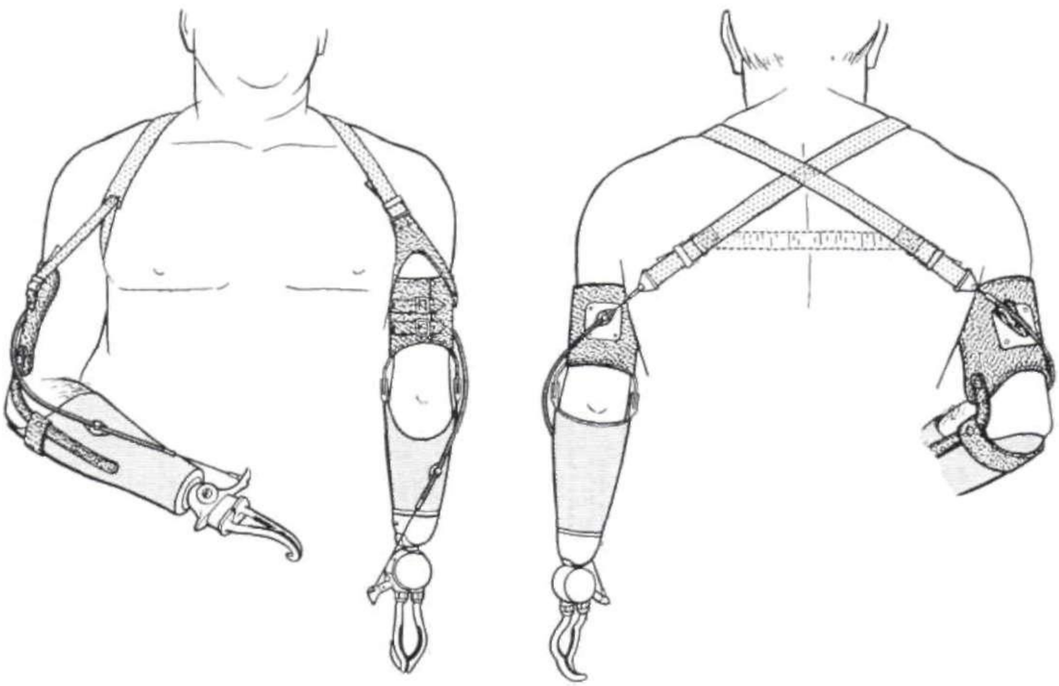

Fig. 31. The bilateral below-elbow figure-eight harness. A webbing inverted Y-suspcnsor with triceps pad and flexible leather hinges is shown on the right side, while a leather inverted Y-suspensor with full cuff and rigid hinges is shown on the left. Similarly, one type of hook is shown on one side and another type on the other. In the bilateral case, prescriptions should be written independently for the two sides with a view toward providing as much utility as possible. As in the corresponding unilateral cases, the choice of cuffs, pads, hinges, terminal devices, and other details is made on the basis of the individual characteristics of the stump for which the prosthesis is intended.

taking up the slack in the control attachment straps. The reverse procedure moves the cross up. Should the cross be too far to one side, it may be moved horizontally by loosening the inverted Y-strap and control attachment strap on that side and taking up the slack on the opposite side.

An important consideration is the choice of materials best suited to the individual case. In Figure 31, the right Y-suspensor is made of vinyon, while the left is made of leather. If the amputee finds that getting the harness on and off is a major problem, then the tendency of leather to maintain its shape makes it easier to slip the stumps through the suspensors. If excessive perspiration is a problem, then vinyon tape may be more suitable.

Although the combination of one leather and one vinyon Y-suspensor is shown in Figure 31 primarily to suggest the two possibilities, it is not inconceivable to consider the arrangement for actual use. In the bilateral below-elbow cases, the choice of cuffs and hinges is made independently for each side on the basis of such factors as stump length, muscular tone, and elbow mobility. In some cases, it might be well to consider using flexible hinges on one side to encourage the use of residual pronation-supination while applying full cuff and rigid hinges on the other to provide stability. A bilateral so fitted would thus have the added versatility provided by an enhanced function of one kind in one arm and an enhanced function of a different kind in the other.

In Figure 31, a wrist-flexion unit is installed on the left prosthesis. Although in exceptional cases the bilateral fitting of wrist-flexion units might be desirable, ordinarily only one flexion device is necessary. When only one wrist-flexion unit is used, amputee preference, or simply prosthetic dominance of one extremity over the other, is probably the best criterion for determining the side to which wrist flexion should be applied.

THE BILATERAL ABOVE-ELBOW HARNESS

The unilateral below-elbow figure-eight harness has been adapted for bilateral above-elbow cases as well as for the bilateral below-elbow amputee. It is essentially the same as for the below-elbow cases but with added suspensory harness and means of operating the elbow locks. A typical pattern is illustrated in Figure 32. If allowance is made for the increased need for function in the bilateral case, then fabrication of the bilateral above-elbow harness is similar to that of the unilateral above-elbow figure-eight pattern. Use is made of the same methods of harness adjustment as in adjusting the harness for the below-elbow bilateral.

Before attempting the fabrication of the bilateral above-elbow harness, the harness-maker must understand the above-elbow figure-eight harness for unilaterals. He should then discuss with his patient any special vocational or personal activities requiring modification of harness design. When the harness is completed, the prosthetist should make it a point to follow up progress in training to make sure that the bilateral amputee can soon become self-sufficient in all necessary activities. If attention is paid to these few details, and if each bilateral amputee is treated as an individual problem, surprisingly good results may be obtained in practically all bilateral cases.

THE BILATERAL SHOULDER-DISARTICULATION HARNESS

Because the bilateral shoulder disarticulation and the bilateral above-elbow/shoulder combination represent comparatively rare and highly specialized instances of upper-extremity amputation, it has thus far not been possible to establish any set harness pattern for these cases. Although in general the bilateral shoulder-disarticulation harness is a sort of combination of two shoulder-disarticulation harnesses for the unilateral, every amputee requiring such harness must have meticulous attention to details in the individual case. In any event, it is obvious that, in the bilateral shoulder-disarticulation amputee, the goal of the prosthetist is to obtain as much function as possible regardless of necessary deviations from ordinary practice. Although experience with extreme cases of this kind has to date been limited, the Case Study at the University of California at Los Angeles

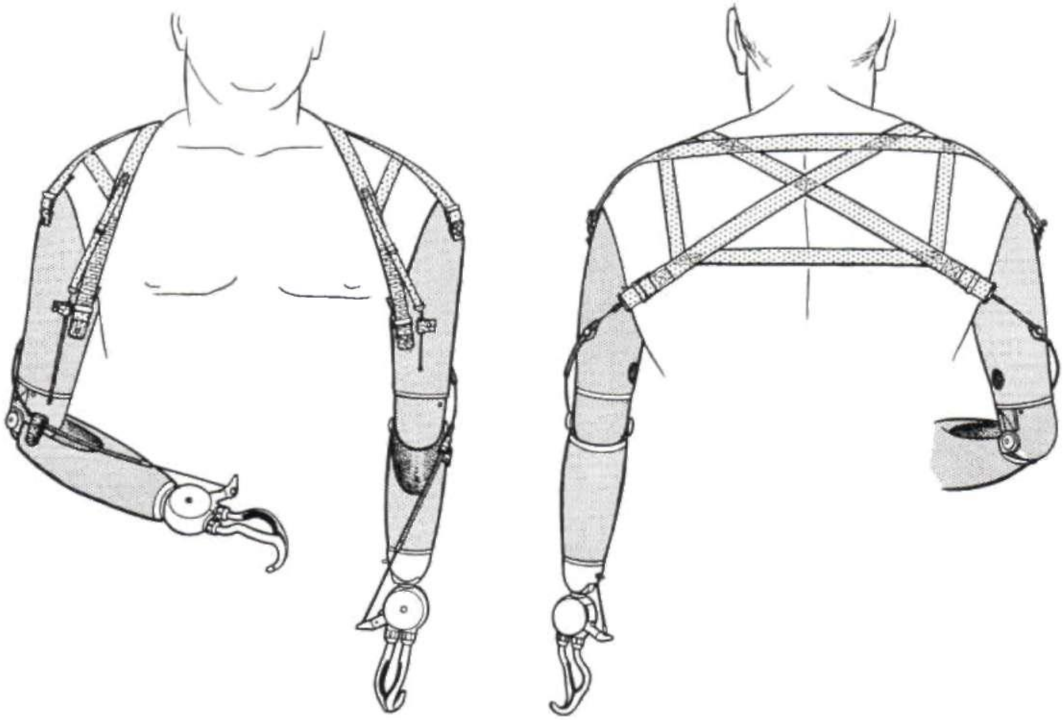

Fig. 32. The bilateral above-elbow figure-eight harness. As in the bilateral below-elbow case, here too the choice of components for the two sides is made independently with regard for individual stump characteristics and with the intention of providing as much useful function as possible.

(page 61) has accumulated some useful information. At present, the knowledge gained at UCLA probably offers the most important guide for management of the individual bilateral shoulder-disarticulation case.

CONCLUSION

To the student of the art of harnessing upper-extremity prostheses, it will now have become perfectly plain that here, as in almost every other published source, the harness designs presented are principally those applicable to the comparatively young, healthy, adult male amputee. Included, furthermore, are only those systems for which there has been accumulated enough clinical evidence to prove their validity for use with presently available arm components. Noticeably missing are special patterns and fabrication techniques for the very young, for the very old, for the debilitated, for the special cases involving other complicating handicaps, and, with two exceptions, for the female.

The reason for this situation lies in the fact that, inspired as it was by the desire to aid the veteran returning from the wars, the Artificial Limb Program, sponsored by the Veterans Administration and the Department of Defense, has quite naturally placed emphasis upon the type of amputee to be expected from the battlefield. But it is not fully appreciated by the general public that there are produced annually from disease or accidents—in the home, on the highway, in the factory—many, many more amputees than are ever produced in military campaigns. Such causes of amputation play no favorites with age or sex.

Fortunately, the basic principles involved in the harnessing of the adult male are more or less fully applicable to the juvenile amputee. Recently, for example, an armamentarium chart defining child amputee types and offering suggestions for prescription for children of age three and a half to ten years has been prepared under the auspices of the Michigan Crippled Children Commission *(18).* Two columns of this reference document are devoted to "harness type" and "control type" respectively. Except for the omission of the below-elbow dual control and of the above-elbow and shoulder-disarticulation triple controls, at every level of arm amputation in the child the recommended harness and control systems are identical with those used for the corresponding level in the adult male. The only significant modifications are concerned with the use of 1/2-in. instead of 1-in. webbing, according to the size of the child, and with the twofold recommendation that the harness be worn over a T-shirt and that the younger children be provided with two harnesses, one to be worn while the other is laundered. Since in general young children do not possess harnessable forces as large as are usually to be had in the adult, the unit stresses produced by the narrower webbing are acceptable to the small child, and hence, following the rule of minimum permissible harness in all cases, it is obviously advisable to use the 1/2-in. material whenever it can serve the small fry satisfactorily. The need of children generally for a frequent change of clothing deserves no further comment here.

In any event, it will be recalled that some twelve-year-olds are actually larger and stronger than some adults, and consequently the determining factor in any given child is his own particular size, which in turn determines whether 1/2-in. or 1-in. material will provide the more comfort. Other features of harness fabrication for children are essentially the same as for adult harnessing.

As for the adult female, generally the harness for the adult male is applicable, with the exceptions that the chest-strap designs usually are not desirable and that commonly more emphasis is placed on cosmesis. Most women, for example, prefer to have a choice of wearing "V" necklines instead of being restricted to Peter Pan collars or other high necklines. The figure-eight harness pattern is adequate for both above- and below-elbow female amputees. In high-above-elbow cases and shoulder disarticulations, the patterns of Figures 27 and 28 usually serve satisfactorily.

Elderly amputees, amputees with multiple limb losses, and those with additional complications such as blindness or deafness all present such highly specialized problems that no single harness pattern can be more than partially satisfactory in all cases. Some evidence seems to indicate that there may even be an age limit beyond which most individuals begin to feel that bothering with an artificial arm at all is no longer worth the effort. But no really scientific evaluation has yet been made of the needs of the aged amputee. Circumstances in the individual case must therefore dictate the course to be taken. As in the case of children, some geriatric patients are healthy, strong. and dynamic; others are ailing, feeble, or lethargic. In the elderly amputee, therefore, as in all special cases, personal factors prevent the recommendation of any generalized harnessing system.

In the two illustrations of typical harnessing for bilateral arm amputees (Figs. 31 and 32), the subjects are shown as having amputations at approximately the same level on the two sides. In actual clinical practice, of course, bilateral arm cases present all possible combinations of above- and below-elbow amputations. In all such cases, the problem of devising suitable harnessing combinations presents a special challenge to the prosthetics clinic team. Similarly, in the case of amputations complicated by other mental or physical handicaps, special assessment of the individual patient must be made to determine, first of all, whether use of a prosthesis is actually feasible and, if so, what if any departures from conventional harness patterns are indicated. In all such unusual instances, the considered judgment of the clinic team is indispensable in the development of a specialized harness pattern suited to the needs and abilities of the individual concerned,

It may now be reiterated that, even in the so-called "standard" cases, it does not suffice to supply a "standard" harness. The reference chart of Table 1 is appended here only for the convenience of the clinic team in selecting the basic kind of harness applicable to any given case. It is, in the end, the responsibility of the

Table 1

HARNESS REFERENCE CHART

Harness Type	*Harness Controls Required*	*Body Motions Available for Operation*	*Advantages*	*Disadvantages*
Wrist-disarticulation single control	Double axilla loop	Arm flexion, scapular abduction	Requires no cuff or hinges above socket	Has limited load-lifting capabilities
Below-elbow figure-eight single control	Simple figure-eight from opposite axilla across back to prosthesis	Arm flexion, scapular abduction, opposite-shoulder flexion	Gives minimum amount of harness for below-elbow amputee	Has limited load-lifting capabilities, causes extreme axillar discomfort in some cases
Below-elbow chest-strap single control	Chest strap, shoulder saddle, and suspension straps	Arm flexion, scapular abduction	Provides greater load-supporting capabilities and improved stability	Requires straps about chest, gives no definite anchor for the control attachment strap so that, upon extreme application of force on control cable, the harness tends to rotate
Below-elbow figure-eight dual control	Simple figure-eight from opposite axilla across back to prosthesis	Arm flexion, scapular abduction, opposite-shoulder flexion	Assists forearm flexion and gives greater range of flexion for very short below-elbow stumps	Has limited load-lifting capabilities, causes extreme axillar discomfort in some cases
Below-elbow biceps cineplasty	Simple suspension on upper arm	Excursion of cineplastic muscle motor	Eliminates shoulder harness, gives improved sense of pressure appreciation, permits operation of terminal device in remote areas (over head, behind back, etc.)	Recommended for selected amputees only
Above-elbow figure-eight dual control	Simple figure-eight harness with optional straps to improve suspension when necessary	Arm flexion, scapular abduction, arm extension	Gives minimum amount of harness, less chance of error in fabrication technique	Has limited load-supporting capabilities, causes axillar discomfort in some cases
Above-elbow chest-strap dual control	Chest strap and shoulder saddle	Arm flexion, limited scapular abduction, arm extension	Provides greater load-supporting capabilities, gives relief for subjects who can not tolerate axillar discomfort of above-elbow figure-eight	Complicated to fabricate, possibility of harness rotating owing to lack of definite anchor
Above-elbow triple control	Chest strap and shoulder saddle	Arm flexion, limited scapular abduction, arm extension	Provides separation of forearm flexion and terminal-device operation	Recommended for long above-elbow stumps only, harness complicated to fabricate, maximum harness and cable control systems
Shoulder-disarticulation scapular-abduction dual control with shoulder-elevation elbow lock	Chest strap and either waist strap or clothing attachment	Scapular abduction, shoulder elevation	Requires no excessive harness, gives good separation of controls, success can be determined at time of fitting, no training problem	Requires clothing attachment or waist band
Shoulder-disarticulation scapular-abduction dual control with opposite-shoulder elbow lock	Chest strap, opposite-shoulder loop	Scapular abduction, opposite-shoulder shrug	Requires harness about the shoulder girdle only	Poor separation of controls (*e.g.*, involuntary locking and unlocking of the elbow), presents training problem, impossible to determine ultimate success at time of fitting
Shoulder-disarticulation scapular-abduction dual control with shoulder-extension elbow lock	Chest strap with elastic suspension leg	Scapular abduction, shoulder extension	Requires a minimum of harness and requires no waist strap or clothing attachment	Limited to subjects with humeral neck, requires coordination of scapular abduction and shoulder extension
Shoulder-disarticulation triple control	Chest strap, waist strap or clothing attachment, opposite-shoulder loop	Scapular abduction, opposite-shoulder shrug, shoulder elevation	Applicable to either type of terminal device, maximum amount of excursion available for terminal device regardless of position of forearm	Requires maximum harness, all three body motions must be good

prosthetist to see that the details are properly custom-matched to the wearer and that, after adequate amputee training, the harness chosen actually fulfills satisfactorily the needs of the wearer for whom it was intended. Less meticulous avenues of approach lead ultimately to failure.

Finally, cognizance should be taken of the understandable circumstance that the harness patterns presented here have all been developed specifically for use with existing mechanical devices. The above-elbow and shoulder-disarticulation systems—the dual-control figure-eight, the dual-control chest-strap, and the triple-control patterns—have, for example, all been designed around existing elbows. Because heretofore the art of harnessing has lagged behind the development of arm components, it has been necessary in recent years to design the harness systems to fit the mechanical parts rather than vice versa. A more logical arrangement would have been first to analyze the available body control motions, to design the harness for maximum utilization of these motions in the least awkward way, and then to design the other parts of the prosthesis in such a manner as to be operable by control patterns best suited to amputee characteristics. Future research in harnessing can be expected to influence redesign of desirable operational characteristics of the mechanical devices now available and to encourage the development of wholly new and improved arm components.

ACKNOWLEDGMENT

With the exception of the photographs and of Figure 12, the illustrations appearing in this article are the work of George Rybczynski, free-lance artist of Washington, D. C.

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