Independent-Control Harnessing in Upper-Extremity Prosthetics

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FUNCTIONALLY, the well-designed and well-constructed body harness for an upper-extremity prosthesis serves a twofold purpose: first, it helps to hold the prosthesis in place; second, it transmits body power for operation of the prosthesis.

For shoulder-disarticulation amputees and for high above-elbow amputees, the provision of an adequate functional harness presents a challenging problem particularly with respect to power transmission and control. The problem is especially difficult in the case of shoulder-disarticulation amputees because of the lack of a control source from humeral motion, which is the major source of power and control in the case of above-elbow amputees. The typical prosthesis for shoulder-disarticulation amputees utilizes shoulder motions and chest expansion.

In the present limited state of the art of prosthetics, there are three minimal operations to be controlled in an upper-extremity prosthesis: lifting of the forearm, operation of the terminal device, and management of the elbow lock.

Here in the United States, the usual harnessing method for shoulder-disarticulation and above-elbow amputees utilizes the so-called "dual-control" system *(1,2,3)*. Lifting of the forearm of the prosthesis and operation of the terminal device are so linked mechanically that a single control motion (shoulder motion in the case of shoulder-disarticulation amputees, arm flexion in the case of above-elbow amputees) produces either operation, depending on whether the elbow is locked or unlocked.

In shoulder amputees, operation of the elbow lock must be managed by various special arrangements; for example, elevation of the shoulder, expansion of the chest, or use of the chin to nudge the elbow-lock control. In above-elbow amputees, operation of the elbow lock in a dual-control system depends upon extension of the humerus and depression of the shoulder.

In a triple-control system, operation of the terminal device is separated from lifting of the forearm of the prosthesis. Triple control has been a recognized method of harnessing upper-extremity amputees for many years, and standard harness patterns providing triple control can be found quite readily in prosthetics literature *{1,2,3)*. However, triple-control harnessing in actual application is seldom seen in the United States, although it is used extensively in Germany and elsewhere. A possible reason for lack of use in the States is that in early trials it was difficult for the patients to operate the controls independently.

Recent experiments at Xorthwestern University in fitting bilateral shoulder-disarticulation amputees have resulted in a harnessing system that provides acceptable function using standard components. Success with some five or six cases renewed interest in "independent-control" harnessing for above-elbow amputees.

In describing this experimental harnessing for bilateral shoulder-disarticulation amputees and above-elbow amputees, the term "independent control," rather than "triple control," is used in order to avoid confusion with the standard harness patterns for triple control.

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BILATERAL SHOULDER-DISARTICULATION AMPUTEES

The limited availability of control sites constitutes a serious restriction on the effectiveness of a harnessing system for bilateral shoulder-disarticulation cases. Shoulder motions are available on both sides, and chest expansion can be utilized. However, there may be only sufficient control motions to obtain acceptable function from one prosthesis. In this event, activities which require the use of two hands, such as eating with a knife and fork, are necessarily precluded.

Major consideration is given to operation of the terminal device and lifting the forearm of the prosthesis. In addition, the elbow lock must be operated and the functions of wrist and shoulder positioning should be supplied.

Although there is but one prosthesis, two shoulder sockets are used. On the side of the amputee on which the prosthesis is suspended, the socket must, provide weight-bearing at the top. This socket may be fitted well down toward the lower edge of the rib cage in order to provide good stability. The other socket, or shoulder cap, is designed specifically to provide independent control of the terminal device, and it is made as small and as light as possible (Figs. 1 and 2).

SHOULDER JOINT

A passively adjustable shoulder joint is essential for ease in putting on a coat, for positioning the prosthesis so that it does not interfere when sitting in an armchair, and for positioning the prosthesis for eating, writing, and similar tasks. Humeral abduction and flexion may be combined in a single axis joint. The friction plate shown in Figure 2 includes two wedge-shaped discs ("Wilson-Riblett wedges") which can be rotated during the preliminary fitting to provide the optimum plane of motion

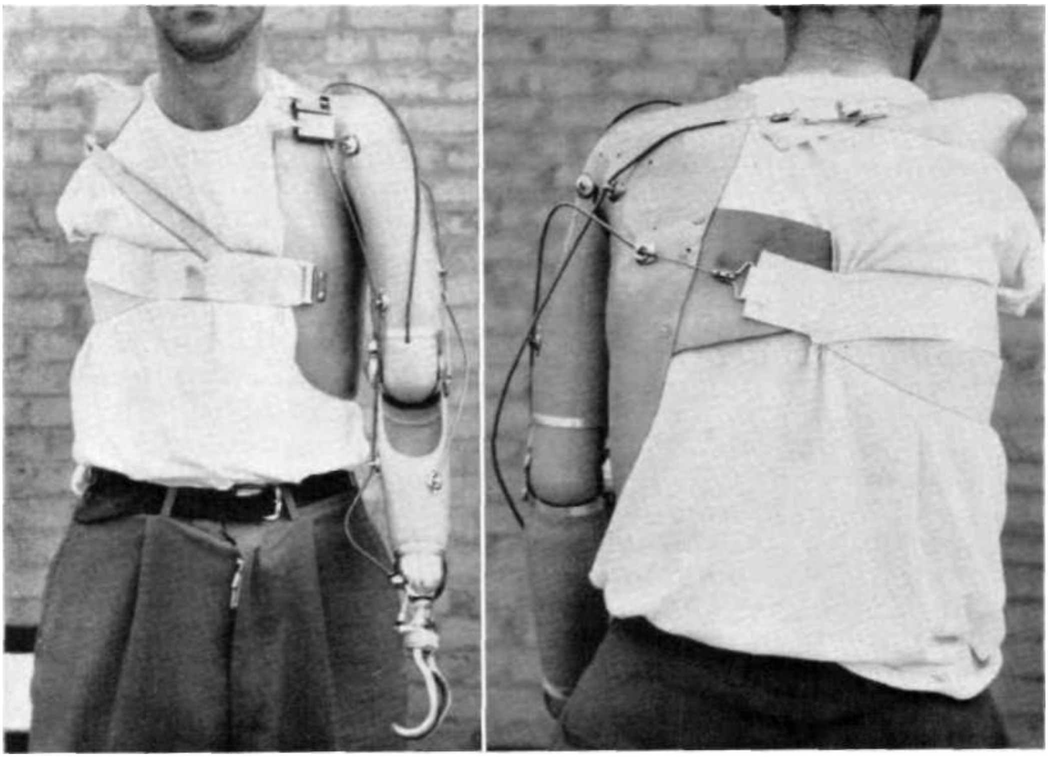
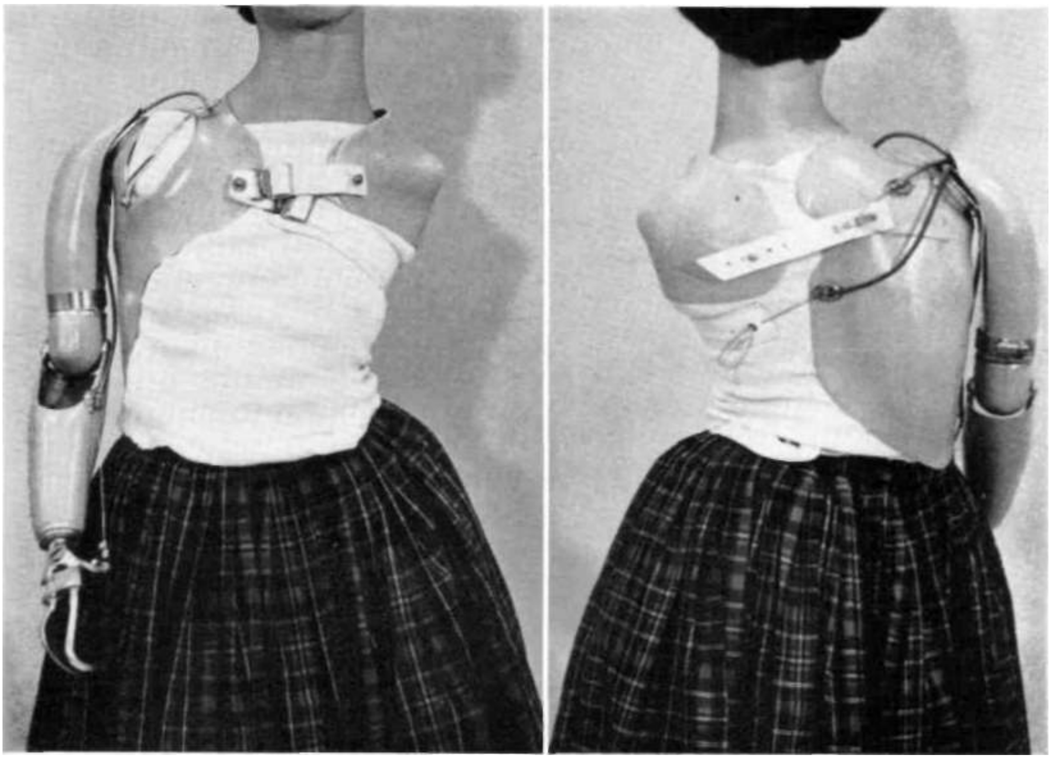


Fig. 1. Shoulder disarticulation on the right and humeral neck amputation on the left. Amputation followed electrical burns.



Fig, 2 Bilateral amelia with scoliosis and short left leg.

for the shoulder joint (Fig. 3). When this is obtained, they are locked into position. The amount of friction can be regulated by a self-locking nut and washer which hold the assembly together.

Forearm Lift

Because the weight-bearing socket has been extended downward over the rib cage, the chest strap may be positioned around the center of the rib cage where maximum excursion can be obtained. The harness pattern shown in Figure 1 uses chest expansion in series with scapular abduction of the prosthesis-fitted side to lift the forearm The forearm lift cable terminates in a swivel fitting at the lift tab. Since excursion is usually limited, the lift tab should be positioned close to the elbow joint. II this is not possible, a pulley may be titled to double the effect of the excursion. But. of course, such an arrangement doubles the input toree requirement In Figure 2. the forearm lift cable is fitted internally in a special groove cut in the locking quadrant ol the elbow unit

Terminal Device

With the chest strap fastened about the middle ot his rib cage, the amputee is free to move the scapula of his nonprosthesis-bcaring shoulder. Thus, a small shoulder cap. carefully lilted to the scapula, can provide independent control o! the terminal device. An anterior elastic strap is usually required to hold the shoulder cap in position. In Figure 2, the available excursion was limited, and therefore a step-up pulle\ was necessarv in order to achieve full opening of the terminal device,

Elbow Lock

Since operation of the elbow lock requires a relatively small amount of excursion and force, there are several ways in which it can be accomplished. The patient shown in Figure 1 origi nally was fitted with a cable which ran from the elbow lock, around a pulley high on the

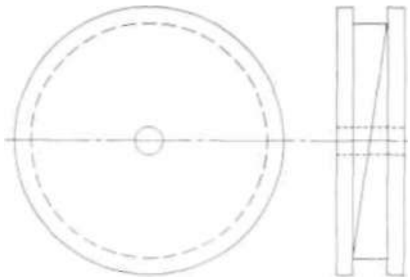


Fig. 3. Schematic drawing showing principle of "Wilson-Riblett wedges."

shoulder, and thence down to a waist belt, so that shoulder elevation was used, alternately, to lock or to unlock the elbow. Later, this was replaced by the nudge control (Fig. 1), which the amputee preferred.

For the patient shown in Figure 2, the prominent acromioclavicular joint was utilized by cutting a hole in the anterior part of the socket and positioning a lever so that forward motion of the clavicle moved the lever forward and downward to develop tension in the elbow-lock cable.

WRIST UNIT

A standard passive wrist-rotation unit, which permits pre-positioning by the amputee, was provided in both cases (Figs. 1 and 2).

For many tasks, such as toilet care, wrist flexion is important. Flexion can be provided by building it into the prosthetic forearm (Fig. 2), or by using a nudge control and Bowden cable to operate the lock on a standard wrist-flexion unit (Fig. 1). In the latter case the lock for the wrist-flexion unit is operated by relative motion between cable and housing. In this application the cable is stationary and the housing pushes to open the lock. To achieve this, the cable guides must be drilled out to allow the housing to slide freely. The inner cable passes through a hole drilled in the locking lever on the wrist-flexion unit and is anchored to a post screwed to the cover of the wrist unit (Fig. 4). When the wrist unit is unlocked by pressure on the nudge control, tension in the terminal-device cable will cause the wrist to flex. If the terminal-device cable is relaxed, gravity will cause the wrist to extend. Thus a measure of active wrist flexion is obtained.

CAPABILITIES AND LIMITATIONS

The harnessing arrangement just described provides reasonably acceptable prosthetic function without the use of perineal straps. Independent control of the terminal device apart from operation of the elbow allows maximum opening of the terminal device in all positions of elbow flexion and improves the performance rate, since it is not necessary to lock the elbow before using the terminal device. Also, there is no tendency for the terminal device to open when the elbow is being flexed.

The amputee who is a skilled foot user may be able to put on or take off the prosthesis without assistance, particularly if Velcro straps are used (Fig. 2). If the amputee is not a skilled foot user, assistance is required in fastening the chest strap snugly.

The prime objective in fitting this type of prosthesis to a severely disabled amputee is to provide at least a minimum of self-sufficiency in public. Problems of self-dressing are complex, and their solution can scarcely be achieved without the use of external power and devices which have not yet been developed.

ABOVE-ELBOW AMPUTEES

The same three minimal operations (namely, operation of the terminal device, lifting of the forearm, and management of the elbow lock) must be controlled in the prosthesis for a unilateral above-elbow amputee. To avoid restric-

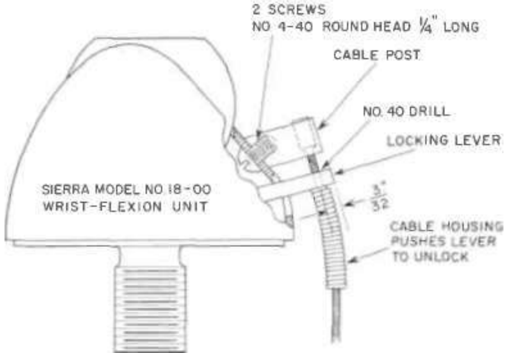


Fig. 4. Modifications of wrist-flexion unit for use with nudge control. Refer to Figure 1.

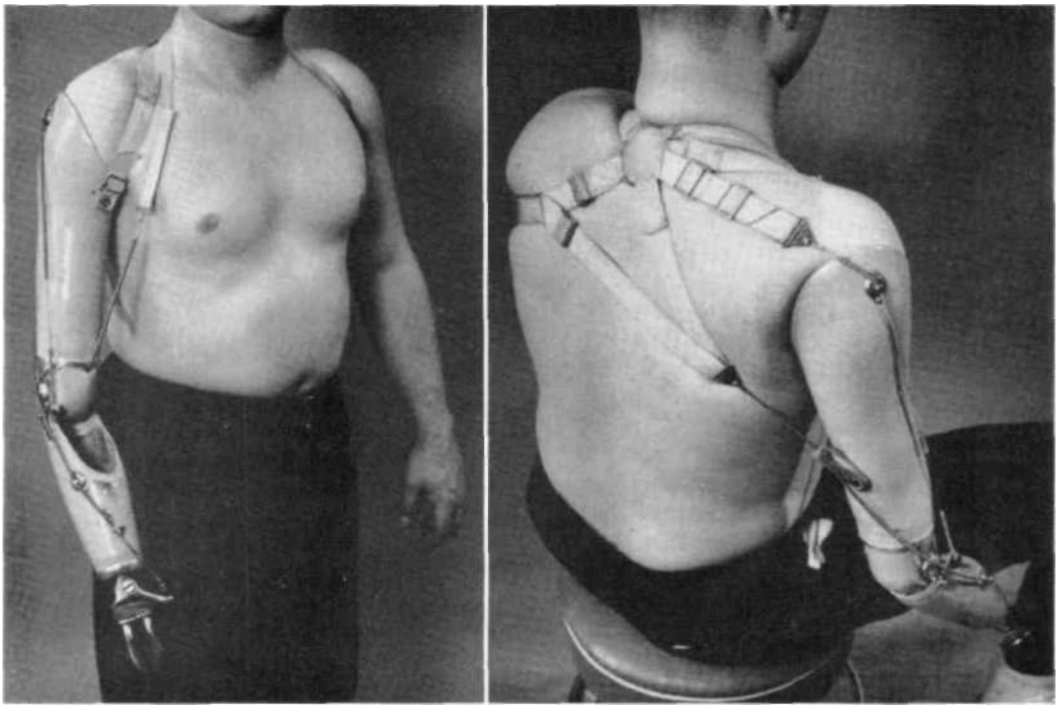


Fig. 5. Congenital above-elbow amputee fitted with independent control. Scapular abduction is used for fore-arm lift.

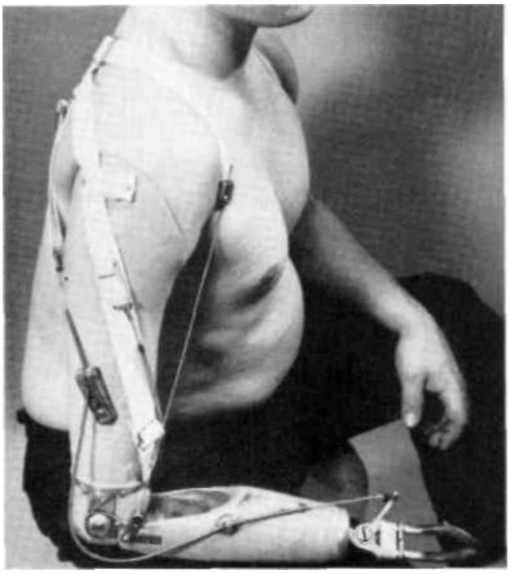


Fig. 6. Same amputee as shown in Figure 5 fitted so the shoulder depression is used to lift the forearm.

tion of the sound arm, the axilla loop of the harness should provide stabilization only. Hence the shoulder motions available for prosthetic use are those that remain on the amputated side. These are scapular abduction, humeral flexion, and humeral abduction. It is conceivable that humeral extension and humeral abduction could be harnessed, but an entirely different harnessing configuration would be required. As in the case of the shoulder-disarticulation amputee, shoulder elevation can be used only in conjunction with a perineal strap or a firm waistband. Most above-elbow amputees can separate scapular and humeral motion, and the harnessing described here is specifically designed to utilize this independent control.

In this harnessing system, lifting of the forearm of the prosthesis is activated by scapular abduction. The anchor point is a ring held in the center of the back by the axilla loop. The reaction point is attached high on the socket, so as to be independent of humeral flexion. If the reaction point is placed centrally near the top edge of the socket, rotation is minimized and humeral abduction can be used to increase the excursion. The cable is passed through the reaction point and terminates in a swivel at the forearm lift tab, the length and position of which should be carefully adjusted to make full use of the available excursion. (The cable housing at the reaction point serves only as a cable guide.) The suspension strap and elbow-lock strap are attached as shown in Figure 5, the configuration being essentially the same as that used in the Northwestern University dual-control ring-type harness.

Humeral flexion and abduction are harnessed to provide operation of the terminal device. Experiments indicate that the harness pattern shown in Figure 5 is preferable to that in which the control cable is attached solely to the harness ring. A Bowden cable is used, with the housing anchored on the humeral section and on the forearm in a manner similar to that of a standard below-elbow fitting, so that operation of the terminal device is independent of flexion of the elbow.

Optimum results are obtained when the shoulder motions are used in combination. Maximum lift of the forearm is achieved when the humerus is abducted at the same time that the scapula is abducted. This means that the elbow is held close in to the body as the forearm is lifted—a motion that is not ideal for certain tasks, such as switchboard operation. Scapular abduction also tends to affect the terminal-device cable. Thus, when the elbow is held in full flexion, there may be some tension induced in the terminal-device cable, making it difficult to hold the hook closed without locking the elbow. Conversely, the hook is very easy to open fully in this position.

Three amputees have been fitted with this type of harness and have been wearing it routinely for several months. In addition, one bilateral amputee has been fitted with dual control on one arm and independent control on the other. All the subjects had been users of prostheses. They learned the basic controls with about an hour's training and became proficient at the end of a week.

This harnessing provides excellent terminal-device function throughout the full range of elbow flexion, without locking or even stabilizing the elbow. Since the terminal device is independent of the forearm lift, there is no tendency for the hook to open when the forearm is being raised. However, near the point of full flexion, the interaction of the harness straps does require considerable effort to avoid opening the hook. Moreover, the force available for lifting the forearm is adequate only for the lightest loads.

After several months' wear, one of the amputees rejected the harness and was refitted with a different type of independent control (Fig. 6). The operation of the terminal device was left unchanged, but the forearm-lift and elbow-lock straps were interchanged so that shoulder depression was used to raise the forearm, and scapular abduction to operate the lock. This seemed to provide greater force for lifting the forearm, provided the humerus is not flexed more than about 20 deg. Operation of the terminal device appeared to be slightly improved. The amputee is still wearing the prosthesis routinely.

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