MANAGEMENT OF THE PERSON WITH HIGH-LEVEL BILATERAL ARM AMPUTATIONS

J.E. Uellendahl* and C.W. Heckathorne**
* Prosthetic/Orthotic Clinical Services, Rehabilitation Institute of Chicago
** Rehabilitation Engineering Research Program,
Northwestern University Medical School, Chicago, IL

INTRODUCTION

Over the past ten years, the Prosthetics Clinical Services Department of the Rehabilitation Institute of Chicago has treated thirty-six (36) persons with bilateral arm amputations. Of these, twenty-three had sustained high-level bilateral limb loss. High-level is defined as the absence of a functional physiological elbow joint. In some cases the anatomical elbow is present, but the joint is impaired and non-functional necessitating a prosthetic elbow joint. This accumulated clinical experience has been augmented by significant input from the Northwestern University Rehabilitation Engineering Research Program in Prosthetics and Orthotics. Guided by a fitting philosophy that has evolved over this period, our combined efforts have resulted in considerable success in the rehabilitation of this most severely impaired group of persons with arm amputations.

GENERAL PHILOSOPHY

Our goals are to enable the person to become independent in activities of daily living and to promote participation in vocational and avocational pursuits. Toward those ends, we provide prostheses, other adaptive equipment, and training with an emphasis on maximizing manipulative function.

Unlike the person with a unilateral arm amputation, the person with bilateral amputations does not have the option of compensating for the inadequacies of a prosthesis by use of an intact physiological arm. Therefore, we have approached the design of high-level bilateral arm prostheses by considering how diverse prosthetic components might be configured to complement each other's function (and supplement each other's deficiencies) so as to serve the intentions of the user. We consider the bilateral prostheses not as artificial arms, but as tools to extend the physical capabilities of the user.

To maximize manipulative capability and provide complementary function, our prosthetic designs incorporate multiple actively-positioned components in a hybrid configuration (combining body-powered and electric-powered components). In general, the dominant prosthesis of the bilateral pair is configured with all mechanical, cable-actuated components while the non-dominant side incorporates either all electric or hybrid componentry [1].

DOMINANT SIDE

Body-powered, cable-actuated position control offers a number of benefits over electronic systems which control component velocity, such as switches and myoelectric controllers. Perhaps most significant among the benefits of body-powered position control is the close coupling of the user and the prosthesis resulting from the control cables and associated harness. Body movements and forces are transferred directly to the prosthetic components such that the cable and its harness serve as a bi-functional link providing both control and feedback of position, velocity, acceleration, and forces [2]. The extension of the user's physiological proprioception via the control cable reduces the mental effort required in positioning and using the prosthesis.

In the selection of mechanical components, we favor positive-locking units over components that utilize friction to maintain their position [1,3]. Positive-locking components, when unlocked, are considerably easier to re-position than are friction components. Furthermore, when the components are locked, the entire prosthesis becomes an extension of the user's body through which the user can exert forces without concern that a component might slip.

To provide for a wide range of prehensor orientations, we utilize both wrist rotation units and wrist flexion units. These components, together with the mechanical elbow and split hook prehension device, are arranged so that a single control cable can be used to position the components [4,5]. This arrangement is referred to as the "four-function forearm set-up" or "four-function control system". It is a mechanically refined and modularized version of a control system pioneered by George Robinson and Jim Caywood. The elbow, wrist rotation unit, and wrist flexion unit are held in place by mechanical locks. Whenever one of these components is unlocked, action on the control cable affects the position of that component. When all three components are locked, action on the control cable operates the split hook prehension device.

NON-DOMINANT SIDE

Although the dominant prosthesis is generally favored for object manipulation because of the physiological coupling, the performance of the prosthesis is limited by the user's force and excursion capabilities. These limitations particularly affect prehension force and live lift capacity. The non-dominant prosthesis is generally configured with a combination of electric-powered and body-powered components that have characteristics not found in the dominant prosthesis. Not only does this approach complement the function of the dominant prosthesis, it also conserves body excursion for use by the dominant side and reduces or eliminates problems of cross coupling of control between the two prostheses.

The body-powered split hook is best suited for fine manipulation, but an electric-powered prehensor offers powerful grip force which is achieved with minimal effort by the user. Additionally, an electric-powered prehensor can maintain very low forces for handling delicate objects with no sustained effort on the part of the user. Low prehension forces using a voluntary-opening body-powered split hook can only be maintained with constant force on the control cable. A prehensor with a shape and design different from the split hook also enables the user to handle a wider variety of objects.

The cable-actuated wrist rotator on the dominant side has an active rotational range of about 130° due to the routing of the control cable to the split hook prehensor. By providing an electric powered wrist rotator on the non-dominant side, the user is able to perform continuous wrist rotation when needed. Furthermore, the motorized wrist rotator is able to produce sufficient torque to turn some handles and valves, which could not be done with the body-powered rotator.

If the subject has bilateral shoulder disarticulations [3] or a combination shoulder disarticulation and trans-humeral level amputation, an electric-powered elbow is generally incorporated into the non-dominant prosthesis. Figure 1 illustrates an exception to this guideline. In this case, the subject had established good ballistic control of an uncabled mechanical elbow during previous prosthetic fittings. Only the lock control, actuated by chest expansion (or scapular adduction) was harnessed.

If the person has bilateral trans-humeral level amputations and adequate excursion and strength, a body-powered elbow is generally used on the non-dominant side, as well as on the dominant side, see Figure 2. The combination of body actuation of the elbow and electronic actuation of an electric-powered wrist rotator or prehensor affords the user the option of simultaneous, coordinated operation of two components. For example, if the prehensor and wrist are myoelectrically controlled and the elbow is body-powered, the user could flex the elbow and supinate the wrist simultaneously while eating.

Even in the case of bilateral trans-humeral amputations, we have made exception in the configuration of the non-dominant prosthesis. Several persons with long residual limbs bilaterally have been fit with body-powered four-function control prostheses on both sides and with excellent results [4,5]. Two of these individuals chose this arrangement over the hybrid control with which they also had experience.

Figure 1: Client with a left trans-humeral amputation and a right shoulder disarticulation. The left side (the dominant side) is fit with a four-function body-powered prosthesis (unfinished at time of photo).

On the right side, a switch-controlled Otto Bock electric hand is operated using shoulder elevation. His right Hosmer E-400 elbow is positioned with ballistic motion, so no control strap is harnessed. A lock control for the elbow is harnessed and is operated by chest expansion (scapular adduction).

Figure 2: Client with bilateral trans-humeral amputations. On the left side, he has a four-function body-powered prosthesis with an excursion amplifier.

On the right side, he has a hybrid configuration. The right Otto Bock elbow with AFB is body-powered. The Motion Control ProControl system is used for proportional, sequential myoelectric control of the Otto Bock prehensor and wrist rotator. Myoelectric signals are obtained from remnants of the biceps and triceps.

PROTOTYPE PROSTHESES

In view of the unique presentation of each person and the plethora of possible component combinations, it is our opinion that the ultimate usefulness of the proposed design can only be fully evaluated through the use of a prototype. The prototype prosthesis is an indispensable tool in the development of optimal prosthetic design and component selection. Often patients and payers will not fully appreciate the subtle functional advantages of one system over another. Trial of the proposed components will often allow all parties concerned to jointly reach the same conclusions regarding component selection, leading to better acceptance and ultimately a better outcome. Critical to the success of this approach is the availability of all component options and the technical ability to mix and match components from different manufacturers. The foundation of the prototype prosthesis is a well fitted evaluation interface. The components to be evaluated are attached to the interface and adjusted appropriately in order to allow for a field trial that is fairly representative of function with a finished prosthesis. This process has proven to be essential in the identification of the most appropriate componentry and has offered the client, a process where they can have significant input into their prosthetic rehabilitation.

CONCLUSION

The principles outlined have served as a useful and proven template for the design of high-level bilateral prostheses. However, one should not be constrained by rigid interpretation of this fitting philosophy, but should consider it a useful starting point. Allowances must be made for situations when physiological limits, additional disabling conditions, established functional patterns, or personal preference of the client suggest modification of the general scheme and selection of components and control methods outside the basic approach. Such situations demonstrate the importance of using prototype prostheses and of addressing the unique needs of each individual.

Throughout the design and rehabilitation process, it should be born in mind that the functional and cosmetic needs of these clients far exceed our present technology. It has been our experience that the most important elements in the success of any particular person are the ability of that person to accept their radically altered circumstances and the motivation to adapt and problem solve as they meet the challenges of their continuing life.

ACKNOWLEDGEMENT

The participation of C.W. Heckathorne and the Northwestern University RERP in Prosthetics and Orthotics has been made possible through grants from the National Institute on Disability and Rehabilitation Research (NIDRR), U.S. Department of Education.

REFERENCES

1. Childress, D.S., Krick, H., Heckathorne, C.W., and Uellendahl, J., "Positive-locking components and hybrid fitting concepts for persons with high level bilateral arm amputations", Proceedings of the Twelfth Annual RESNA Conference, 296-297, 1989.

2. Heckathorne, C.W., "Manipulation in unstructured environments: Extended physiological proprioception, position control, and arm prostheses", Proceedings of the International Conference on Rehabilitation Robotics, 25-40., 1990.

3. Meredith, J.M., Uellendahl, J.E., Heckathorne, C.W., Krick, H.J., and Wu, Y., "Bilateral shoulder disarticulation: Self-care and use of complementary hybrid prostheses", Proceedings of the Myoelectric Control Symposium, University of New Brunswick, 153-158, 1993.

4. Uellendahl, J., and Heckathorne, C., "Prosthetic component control schemes for bilateral above-elbow prostheses", Proceedings of the Myoelectric Control Symposium, University of New Brunswick, 3-5, 1993.

5. Uellendahl, J., Meredith, J., and Wu, Y., "Prosthetic fitting and self care skills in a bilateral above-elbow traumatic amputee", VHS video, Rehabilitation Institute of Chicago, 1992.