Prosthetics and Orthotics International, 1982, 6, 17–20

Upper limb prosthetics for high level arm amputation

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Abstract

The paper covers the analysis of residual stump and upper body motions and their involvement in the patients' manipulatory functions. Attention is given to prosthetic techniques that do not restrict the residual motions. A single cable controlled hybrid arm prosthesis is presented with different individual cases. The kinetic structure and the control of prosthesis vary in each case to meet the individual manipulatory characteristic of the patient. The universal unconventional technique is presented which has modular possibilities seen from the kinematic point of view.

Introduction

In the last two decades development in arm prosthetics has focused on the application of external energy sources. There was great hope invested in the outcome of this work and resources were directed to support it. The rehabilitation practitioners however are very sceptical as they think of it as "research for research sake" and remember multi-functional arms which were noisy, machinelike, heavy and difficult to control. On the other hand attempts to restore manipulatory functions in cases of bilateral high level arm amputations, with a conventional body power approach, lead to completely unsuccessful solutions. Those patients are simply knitted together with different harnesses and straps. The worst conclusion from this controversy was the statement, that everything possible in the application of body power had been achieved and that progress in arm prosthetics would only come from the application of external power.

The consequence of this was that in the last decades work on body powered prosthetics did not attract attention and support. The above controversy has a more general background related to the question of what should be the appropriate strategy in rehabilitation engineering. To use as an example the loss of manipulatory functions caused by limb amputation, the question arises what is the correct role for technology in such a case? Should technology be used for substituting for lost functions or instead of this, should it be used only for supporting the residual manipulatory functions. These alternatives are not only different verbally, but mean quite different approaches. When supporting the residual functions, these functions cannot be treated as an unimportant remnant and must in no way be restricted by the applied technology.

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Provision of manipulatory functions

Two of the three basic components of upper limb function, depicted in Figure 1, gripping and positioning, can be, with some degree of adequacy, substituted for by technology but the manipulatory component, which is in fact the fine coordinated, multi-axial, movement cannot as yet be restored by some prosthetic system. The only possibility is to provide a new function involving the residual part of the biokinetic chain

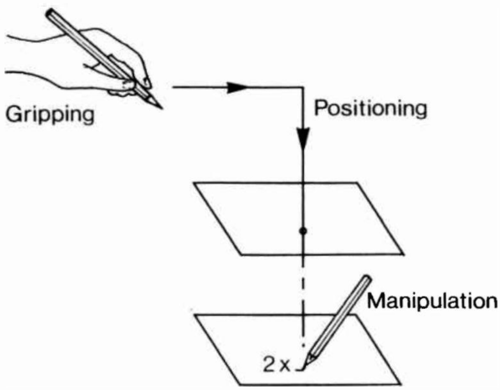

Fig. 1. Components of typical manual activity.

of the upper limb and even the whole body (Fig. 2). These manipulatory functions can be performed by the arm-stump, shoulder girdle, thoracolumbar spine, and in case of bilateral shoulder disarticulation, by the cervical spine, as well as by the lower limbs. The most important condition for using this compensatory potential for manipulatory purposes is careful application of the technology needed for the restoration of gripping and positioning functions. The restrictions on stump and upper body movement must be minimized. There are two elements in such restrictions—the socket with the suspension and the control harness. The socket-suspension, in some cases of arm amputation, can be avoided by application of the revolutionary technique of angulation osteotomy (Marquardt and Neff, 1974; Marquardt, 1975). There is an essential difference between the above two types of restriction. The restrictions caused by the socket-suspension are passive in character, they act like simple range-of-motion limiters. On the other hand, the control harness restricts the stump and shoulder girdle motions in an active way, due to the interference or overlapping of manipulatory motions with prosthesis control movements. In most practical situations forward-flexion of the arm overlaps with flexion of the prosthetic elbow or operation of the terminal device. The only way to avoid this difficulty is by a radical simplification of the control harness and possibly by reducing it to a single strap, running over the shoulder girdle. It is possible to meet this demand by better use of the physiological control capabilities of upper body motions.

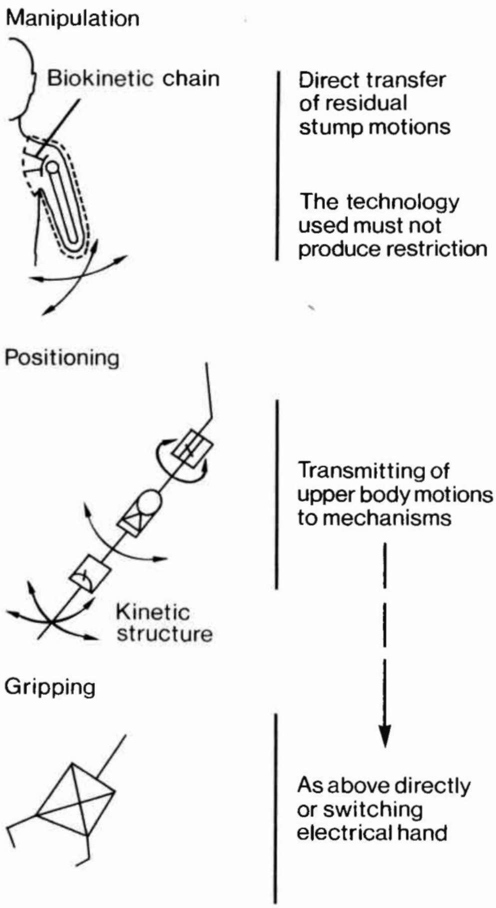

Fig. 2. Functional components of arm prosthesis.

Single cable control of hybrid arm prosthesis

In the past, body motions have been seen only as the mechanical energy source for driving the prosthetic mechanisms or alternatively as a control signal source for activating pneumatic or electric switches and mechanical locks etc. The new concept in the proposed hybrid—single cable controlled arm prosthesis—is the simultaneous powering and controlling of the prosthesis by means of only one body motion. This is possible due to the existence of many physiological control loops, external as well as internal. They offer the patient full control over the force, displacement, velocity and acceleration of the shoulder abduction movement, which is the most powerful motion within the amputee's upper body. This excellent control of body power and the application of this concept is the main reason for suggesting that body power may be seen in a new light when thinking about the future development of upper extremity prosthetics. Failure to recognize and apply the physiological capabilities of body power is the main reason for unsuccessful development in this field, in spite of the revolutionary development of technology. Basic biomechanical research will be needed before the potential capabilities of this system (some of which are summarized in Fig. 3) can be widely applied. Considering the advantages of electrical power in arm prosthetics, one application is obvious. The low power requirement for gripping and the ease of control of electrical power, indicated the application of an electrical hand in the hybrid arm prosthesis. The diagram of the prosthesis (Fig. 4) presents the concept of single cable control. The one upper body motion flexes the forearm, locks the elbow joint, switches the electrical hand in closing-opening and the same cable can control another function, for example the locking of a pronation/ supination joint etc. These possibilities have not yet been fully applied to our present prosthesis.

The presentation in Figure 4 is not very clear and convenient for visualizing the multi-function prosthesis. As we are using only three types of conventional arm prostheses, there is no necessity for presentation of the prosthesis structure.

The introduction of multifunction hybrid arm prostheses having many variations of kinetic structure, as well as different types of control, necessitates a diagrammatic presentation which identifies the functional characteristics.

The proposed new presentation of prosthetic structure and control is achieved by overlapping two diagrams. The first is the kinematic chain, built up of prosthetic segments, represented by straight lines connected with three types of kinetic linkages as shown in Figure 5. The second diagram (Fig. 6) displays the functions of the control cable when applied to the previously presented kinematic chain. Figure 7 shows the hybrid arm prosthesis using the newly introduced symbols. The principle of the single cable control of a hybrid arm prosthesis was developed in Poland (Ober and Piatek, 1977). The hybrid system is now available through Viennnatone, Austria.

A further example of innovation in arm prosthetics, making the use of the prosthesis more efficient and easy, is the device for adjustment of control cable length. Normally when standing, the patient makes use of the full range of forearm flexion, about 140°. The

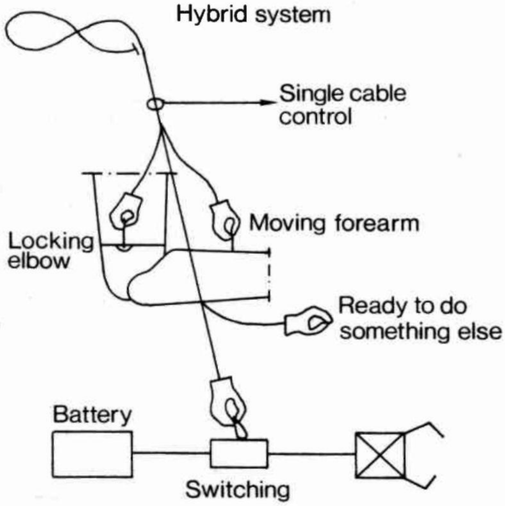

Fig. 4. Single cable multifunction control.

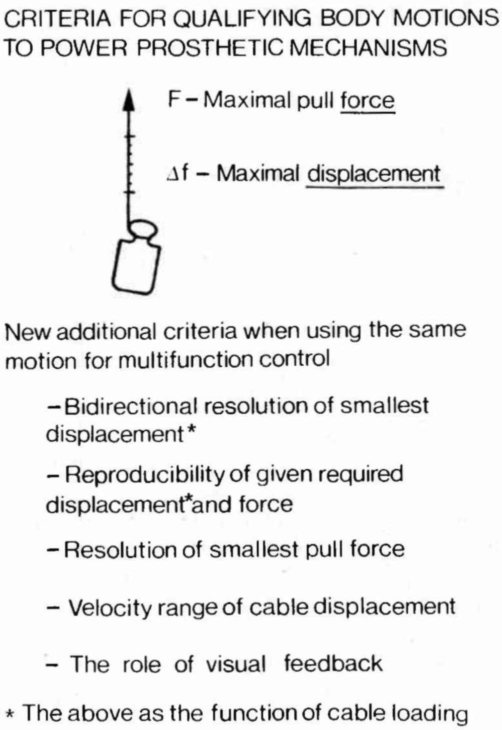

Fig. 3. Body power evaluation parameters.

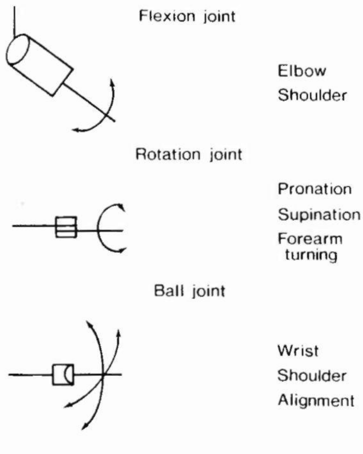

Fig. 5. Kinetic components of arm prosthesis.

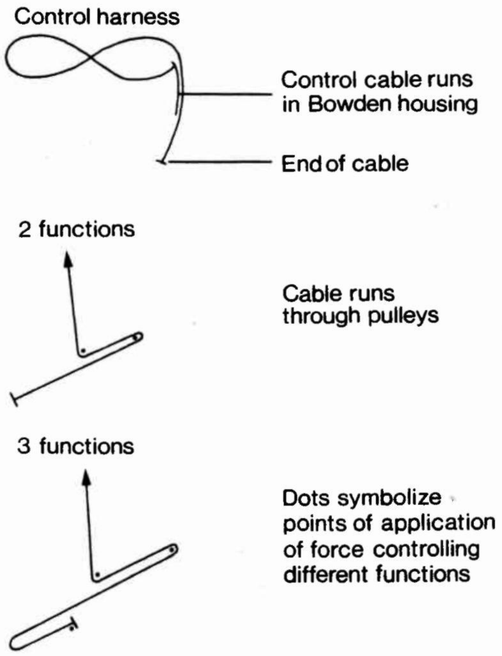

Fig. 6. Diagrammatic presentation of control harness.

situation changes when the patient is sitting working on a table surface. In this case forearm extension is limited by the table surface to about 50° and consequently nearly 70% of cable displacement is not used, however every time the patient operates the elbow, as well as controlling the grip, he must "take up" the unused, loose

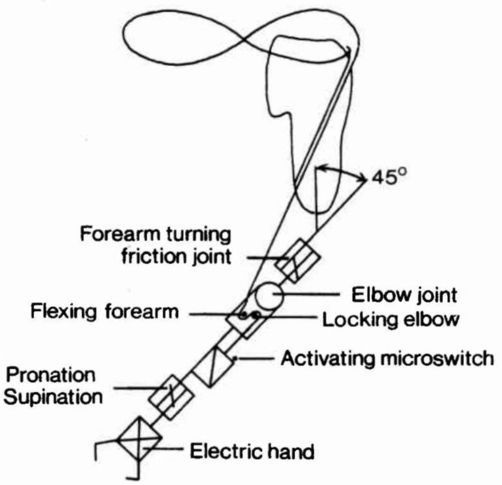

Fig. 7. Diagram of single cable control hybrid arm prosthesis.

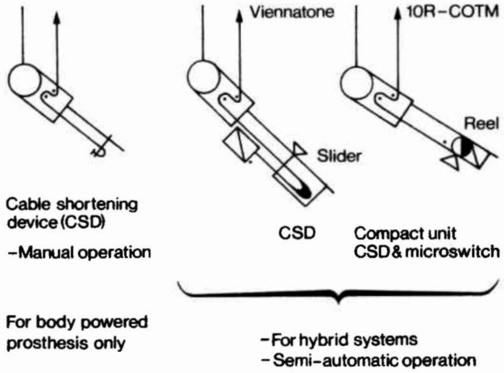

Fig. 8. Manual and semi-automatic operation of cable shortening device.

portion of the cable. The patient thus operates the prosthesis close to the end point of control movement. This is very inconvenient especially when sitting. A cable shortening device has been developed which takes up the loose portion of the cable. This is operated by hand or semiautomatically as shown in Figure 8.

Summary

The paper deals with the application of stump and upper body movement to manipulatory functions for the arm amputee. A system is proposed which ensures that the residual motions will not be restricted by the applied technique. A single cable controlled hybrid arm prosthesis is presented adaptable to different individual cases. The kinetic structure and the control of the prosthesis are different in each case, to meet the individual manipulatory characteristic of the patient. This universal unconventional technique which has modular capabilities from the kinematic point of view is presented, along with the design considerations which have a secondary role.

REFERENCES

Marquardt, E. and Neff G. (1974). The angulation osteotomy of above-elbow stumps. *Clin. Orthop.*, **104,** 232–238.

Marquardt, E. (1975). Osteotomia kątowa kikuta ramienia. Mat. z Kurso-Konferencji pt. "Protezowanie typu czynnego po amputacjach w obrębie kończyn górnych". PWN, Warszawa—Poznań, 37–51.

Ober, J. K. and Piatek Z. J. (1977). One-cable control of the mechanical elbow with flexion—extension and locking. *Pros. Orth. Int.*, **1(1),** 19–20.