Prosthetics and Orthotics International, 1979, 3, 155–156

Prosthetics and orthotics in Latin America*

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Latin America can be divided into four parts. Bordering with the United States is Mexico, next there is Central America then the Northern and Southern parts of South America. Europeans tend to be concentrated in the South where there are many Germans, British, French, Italians and Danes. The further North you travel the more you meet the Indians and their culture and the more you encounter different attitudes.

Throughout Latin America there are three different types of services for the amputee: private shops or laboratories, state supported laboratories and government controlled laboratories. Patients can also be divided into three groups:

1. Patients who are financially independent; these usually obtain services from private prosthetic/orthotic laboratories or travel abroad for treatment.
2. A very large group of middle or working class patients who are covered by insurance or social security as well as receiving support from their families; they are normally sent to a state supported laboratory, such as my institution, for service. This type of assistance is provided by the majority of the Latin American countries. (In some hospitals or rehabilitation centres where social security services are provided, doctors—mostly physiatrists, issue prescriptions for prostheses or orthoses and send their patients to places from a list of private or government laboratories. The final checkout is done in the institution where the prescription is issued, usually without the participation of the prosthetist.)
3. The great majority of patients are in the low income group and they generally use the services of the government prosthetic/orthotic laboratories at the Rehabilitation Centres.

Many of the patients in the third group fail to take good care of their stumps, due to lack of training, following discharge from hospital. When they come to the Rehabilitation Centre their stumps are often in very bad condition with contractions, heavy subcutaneous tissue, neuromas etc. Consequently, many patients have to start protracted pre-prosthetic treatment or undergo revision surgery. However, the indigent patient cannot afford to pay for a long course of treatment as his income is very low and, because there is no birth control, his family may be large. As a result the patient may insist that the prosthesis be finished quickly so that he can return home and resume supporting his family. Many of these patients will return to the clinic due to changes in their stump. They will complain that the prosthesis was improperly fitted, and insist on getting a new prosthesis. This situation is very common in most of the Latin American countries and results in much wasted time and material. It would be very useful if prosthetic clinics could be attached to the orthopaedic hospitals, but this will be difficult to arrange. It would also be very helpful if more of the new amputees could be fitted with rigid dressings. The use of a temporary pylon prosthesis would also greatly benefit the patient and I am very happy to note the work that is being carried out elsewhere on temporary sockets for the primary amputee. We are particularly interested in the lightweight polypropylene prosthesis. Many Latin American countries are producing this material and the new prosthesis may partially answer our problems of low budgets and difficult

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*Based on a paper presented at the ISPO International Course on Above-knee Prosthetics, Rungsted, November 1978.

importation of sophisticated materials. At the moment nearly eighty percent of all amputations are carried out at above-knee level and only a very small number are below-knee, we would like to see that changed.

In some cases patients are unable to pay for the prosthesis. Many patients from rural areas have to travel a long way to the specialized services, which are usually located in the capital cities, and do not have enough money to pay for food and accommodation while being treated. When his funds run out, the patient may have to abandon treatment and return home perhaps without his prosthesis.

In order to solve these problems the governments have assigned an annual budget to the Rehabilitation Centres, including the prosthetic/orthotic departments. However, due to scarcity and failure to provide the centres with regular supplies of materials and the fact that the prosthetic/orthotic services do not have an independent renewable budget, it is still difficult for many patients to get a prosthesis made. We are trying to have a separate budget for the prosthetic/orthotic laboratories so that we can get a little closer to a good prosthetic service. Another problem faced by patients is the difficulty of finding a job; it is easier for some amputees to inspire compassion by showing their stumps or crippled limbs and begging for support.

In spite of the incorporation of the prosthetic/orthotic services in the Rehabilitation Centres, technical difficulties arise because these services are managed by physiatrists who are not skilled in amputee care. The surgery itself is carried out by orthopaedic surgeons. Another problem which requires attention is that the prosthetist/orthotists are not recognised as professionals by the medical staff and their opinions with regard to prescription formulation and prosthetic management are not accepted.

In my twenty years experience in training prosthetists in Latin America I have observed that they are highly qualified and have great interest in their profession. Unfortunately the administrative authorities are still reluctant to recognize them as professionals despite the fact that two permanent schools exist for paramedical staff in rehabilitation; both of which are recognized by the Ministry of Health and the Ministry of Education.

The problems of the prosthetists start when they graduate. The Departments of Personnel and Administration usually classify prosthetists as technicians because they work in a workshop. This unhappy situation results because, although the governments spend large sums training prosthetists, they fail to classify them accordingly; in addition, the salaries paid are inadequate. Consequently many prosthetists change their job in favour of a better position and the prosthetic/orthotic services are undermanned. In some Latin American countries only limited training is provided to meet the most urgent needs of the service. In the rural areas and other places with poor access to services use is made of simple devices made in the community from local materials.

It is worth mentioning that despite the difficulties and obstacles good results have been obtained in certain aspects of the service. This progress is related to improvement of the teaching system which began with the training of resident rehabilitation doctors in prosthetics and orthotics and the introduction of simple, inexpensive methods, using local material to avoid expensive importation of materials and components.

New ways of solving the problems outlined are being applied. A prosthetic/orthotic educational programme has been organized through the Pan American Health Organization for doctors dealing with cardiovascular disease, orthopaedics and rehabilitation. The programme is concerned with the importance of preserving articulations, especially the knee joint; the use of immediate rigid dressings, early prosthetic fitting, stump shape, prescription and information on developments related to new materials and designs. The School of Prosthetics/Orthotics of the New York University Post Graduate Medical School has co-operated with PAHO, WHO and the Member Governments in programming and implementing these courses.

Prosthetics and Orthotics International, 1979, 3, 157–162

Ideas on sensory feedback in hand prostheses

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Abstract

Development of systems for sensory feedback in hand prostheses has not been as successful as that of modern prosthesis control systems. The discrepancy is partly caused by an insufficient analysis of the concept of sensory feedback and by neglect of knowledge on the physiology of kinesthesis. In the present paper modern theories on physiologic kinesthesis are briefly summarized and the implication of these theories on the development of prosthesis sensory feedback systems are discussed. It is concluded that the future development of sensory feedback systems for hand prostheses should be directed towards increased utilization of the physiologic kinesthesis resulting from operation of the prosthesis control systems. This can be obtained by further development of the control systems. One promising approach in this direction is the use of a proportional control signal based on signal acquisition through pattern recognition of multiple myoelectric signals. Development of artificial systems for feedback should be restricted to situations when feedback emerging from the prosthesis control is insufficient. The importance of simplicity and reliability of feedback systems is stressed as well as the necessity to maintain prosthesis self-containment even after application of a feedback system.

Introduction

The development of control systems for motorized prostheses based on detection of myoelectric signals has been rapid and successful following the first use of such systems in the late nineteen fifties (Battye el al., 1955). Clinical success with powered prostheses has been reported (Schmidl, 1973; Lewis et al., 1975; Herberts et al., 1978), but other authors have expressed doubts about the value of these devices (Mooney, 1976). Beyond doubt, many patients using myoelectrically controlled prostheses have been pleased with them, despite several limitations in the prosthetic function (Herberts et al., 1979). A generally recognized drawback in powered prostheses in comparison to conventional cable-operated devices is that the lack of feedback makes control outside the field of vision very difficult. In addition, the control of strength in the grip is insufficient. These findings have led to attempts to develop artificial feedback systems for use in myoelectric prostheses (Kato, 1970; Mann, 1973; Clippinger et al., 1974; Prior & Lyman, 1975; Rohland, 1975; Shannon, 1979). Most feedback systems described up to now have not reached a development stage allowing routine clinical use outside the laboratory. Clinical follow-up has been reported in only small series. Measurements of the performance of amputees using powered prostheses with feedback show that it is close to their performance with conventional cable-operated grips (Mann & Reimers, 1970). The purpose of this paper is to discuss some basic clinical and physiological principles relevant to feedback in externally energized prostheses. Possible fields for future research in this area are indicated.

The concept of sensory feedback

A hand prosthesis is mainly a machine to replace the prehension of the lost hand. The loss of a hand, however, also implies the loss of an important sensory function. The full sensation of a normal hand, as pointed out by Moberg (1964), is a very complex quality which does not lend itself easily to replacement by artificial devices. Sensory feedback is not intended to replace normal hand sensation. We think that sensory

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feedback in prosthetics should have the same meaning as feedback in control engineering; i.e. a way to compare the output of a machine with the input (Fig. 1). Feedback is an aid to increase the accuracy of the control system and of prehension, Therefore, the term "artificial touch" is inadequate and may lead development of prosthetic feedback systems in wrong directions.

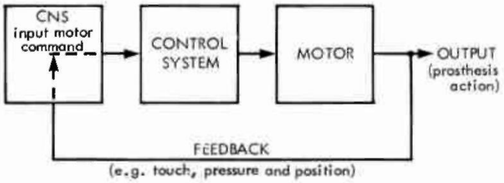

Fig. 1. Concept of feedback as discussed in the text.

In order to effectively enhance control of the prosthesis the sensory feedback should consist of several components. One component is kinesthetic information about position, movement and force in the prosthesis joints, i.e. proprioceptive feedback. Another component is information about the effects of the action of the prosthesis on the outside world; i.e. somatosensory feedback concerned with, for example, force in the grip and detection of slippage of handled objects. Most feedback systems developed today convey somatosensory information only. The somatosensory part of feedback information can not replace proprioceptive information and vice versa. The special importance of feedback concerning handling of objects in the grip has been pointed out by Forchheimer et al., (1978).

Existing feedback systems

Feedback systems for externally powered prostheses have been used since the early nineteen sixties (Tomovic & Boni, 1962). Most systems have employed some kind of artificial stimulation controlled by a transducer situated in the grip of the prosthesis. The block diagram of Figure 2 illustrates some different solutions of the feedback problem as described in the literature. The most commonly used artificial feedback systems have worked with vibratory stimuli (Alles, 1970; Mann, 1973) and electrical stimulation (Kato, 1970; Clippinger et al., 1974; Reswick et al., 1975; Rohland, 1975; Anani et

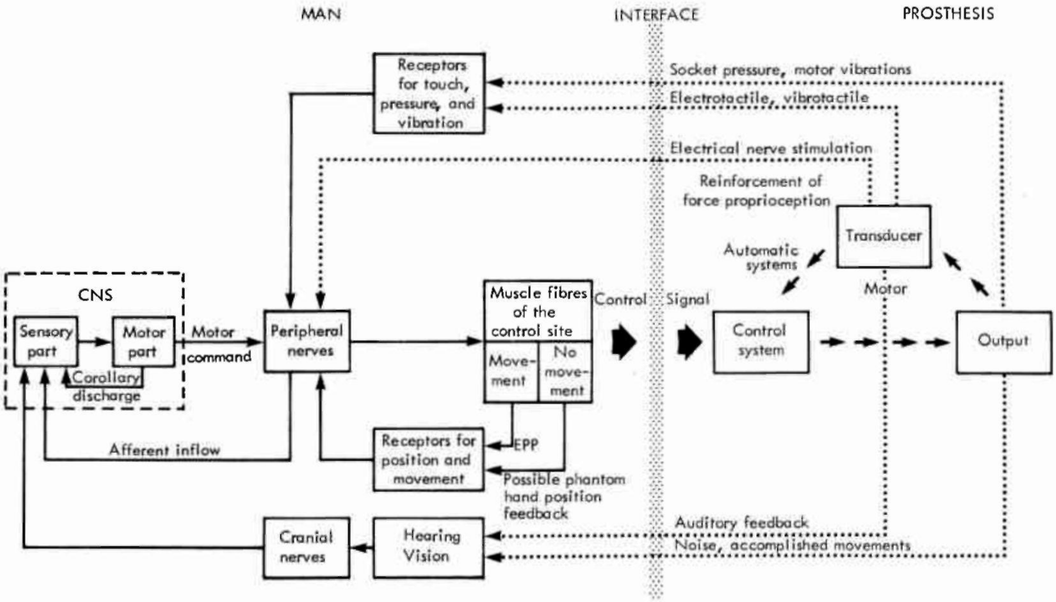

Fig. 2. Different means of providing feedback from externally powered prostheses.

al., 1977; Shannon, 1979). The clinical application of artificial sensory feedback systems has often been unsuccessful (Reswick et al., 1975; Mooney, 1976; Reswick & Nickel, 1977). Rejection of systems has been caused by technical problems such as fragility, interference with the control systems and lack of miniaturization. It is obvious that in some applications the need for a feedback system has not been present, which of course, has led to rejection.

Kinesthetic mechanisms and prostheses feedback

Aids for the handicapped designed to take advantage of physiologic mechanisms will have a greater chance of being accepted by patients than devices based on entirely artificial grounds (Herman, 1973; Hirsch & Klasson, 1974). This is especially true of the complicated myoelectric prostheses that include a feedback system. In the design of such devices thorough knowledge of kinesthetic mechanisms in man is mandatory for success. Mann (1973) and Simpson (1974) described feedback for prostheses using the physiologic signals that result from the actions of the human body necessary to control the prostheses. Clinically this has resulted in the most attractive and successful systems so far described. Practical experience with such devices shows the need to take physiologic kinesthetic mechanisms more into consideration in the future development of feedback systems.

Physiologic kinesthesia and forearm amputation

The knowledge of neural mechanisms behind the sensing of muscular effort and the sensing of position has been revised during the nineteen seventies. Previously, it was widely believed that the sense of position was based entirely upon information from joint and skin afferents (Rose & Mountcastle, 1959). Indirect evidence is now against this view. Investigation of cat knee joint receptors has not revealed the presence of any receptors capable of signalling absolute joint angles (Clark & Burgess, 1975). Sense of position is not affected by total joint replacement (Grigg et al., 1973). In addition, it was shown by Goodwin et al., (1972) that artificial stimulation of muscle spindles induces illusions of movements. This indirect evidence opposing the traditional views on kinesthesia led to a re-evaluation of the classical experiments concerning the sensing of movement and position when finger movements were performed with blocked skin and joint sensors. Through such experiments it has been convincingly shown by Gandevia & McCloskey (1977) that the sense of position has its neural mechanisms partly in muscle spindles. By performing weight-matching tests, McCloskey & Gandevia (1978) have shown that the estimation of heaviness and the sense of effort have their neural mechanisms largely in the central nervous system.

Substantial parts of the tendons and muscles executing movements of the normal hand and fingers are left intact after a hand amputation. The new evidence presented above leaves no doubt that these remaining structures contain receptors responsible for important components of the sensing of position and movement in the normal hand. The information from these receptors is also available to the amputee as is the sensing of effort.

These physiologic facts should be taken into consideration in the design of prosthesis feedback systems.

Sensing force and effort

The force proprioception system developed by Mann (1974) for the Boston arm works with the sensing of effort accompanying the muscle work at the control site necessary for generating myoelectric signals. A negative feedback signal proportional to the force resisting the movement is added to the myoelectric signal that controls the prosthesis. When the prosthesis is loaded an increased myoelectric signal is required to achieve movement. The result is an augmentation of the sensing of effort of the muscles at the control site. Such an augmentation is necessary to make the force clearly perceivable. Since the sensing of effort has its neural mechanisms in the central nervous system, it can be assumed to be influenced by signals originating from different muscles relevant to one specific movement (Herman, 1973). Such a convergence can explain why previous attempts to utilize the sensing of effort for prosthesis feedback purposes without strong augmentation have been disappointing. In these attempts subjective sensations resulting from activity in single muscles only have been applied. Single muscle activity is an unphysiologic phenomenon and probably lacks cortical representation (Radonjic & Long, 1970). Therefore, if the control of prostheses can be related to physiologic movements rather than to actions in single muscles, more feedback information can be expected to emerge from the control system.

Hand prostheses controlled by pattern recognition of multiple myoelectric signals have been described by, among others, Herberts et al., (1973). The pattern recognition approach permits control of the prosthesis through and integration of signals from several muscles relevant to one specific movement. It is therefore plausible to assume that a proportional control signal derived from signal processing according to the pattern recognition method should yield significant amounts of information about effort and force. Our preliminary data support this hypothesis.

Sense of position

Muscle afferents have been shown to play a significant part in the perception of movements (Mattews, 1977). In a clinical follow-up study of unilateral below-elbow amputees using myoelectric prostheses we found that all non-congenital amputees (35 patients) had a distinct phantom image (Table I). All the patients except two stated that they could easily move the perceived phantom and that they could feel how the phantom was moved. The neural basis for the perception of movement of the phantom image is considered to lie in the muscle afferents from the distal part of the amputation stump (Henderson & Smyth, 1948). Control of prostheses using the pattern recognition method is based on the principle that specified movements of the phantom hand shall result in corresponding movements of the prosthesis. Our preliminary data show that it is to a certain extent possible to relate a proportional control signal achieved through the pattern recognition method to specified positions of the phantom hand. Therefore it seems reasonable to postulate that the sense of movement and even the sense of position of the phantom hand can be used to convey prosthesis feedback. Further development of the prosthesis control systems for feedback purposes is, however, necessary if this goal is to be achieved.

Table I
Features of phantom perceptions in 35 unilateral, non-congenital below-elbow amputees.

	No. of patients
Presence of phantom perception	
Constantly	26
Can be evoked	9
Ability to perform distinct movements with phantom hand	
Yes	33
No	2
Length of phantom extremity	
Equal to non-amputated side	16
Shorter than non-amputated side	13
Can not tell	6
Extent of phantom extremity	
Complete hand	21
Parts of hand	4
Variations in extension	8
Unknown	2
Pain in phantom	
None	24
Mild, occasional	6
Severe	5

Extended physiological proprioception

A different way to utilize the physiologic actions at the prosthesis control site was described by Simpson (1974). In prostheses designed for amelic children the movements and the positions of the clavicle are translated to movements and positions of the prosthesis. Through this proportionality between the movements of the clavicle and the prosthesis the angle of the prosthesis in space can be determined by the normal kinesthetic mechanisms of the child. The brain will then very easily adapt to the length of the terminal segment (the prosthesis) in much the same way as the golfer will adapt to the length of his club. The phenomenon is called extended physiological proprioception (EPP) and gives the amputees significant amounts of feedback information in addition to excellent efferent control.

Areas for future research

Future approaches to feedback in hand prostheses should be directed towards the design of systems which can be included in self-contained prostheses. The importance of self-containment for patient acceptance is clearly documented (Childress, 1973). The experiences of Mann and Simpson indicate that feedback systems based on the physiologic actions necessary to control the prosthesis are consistent with high patient acceptance and with prosthesis self-containment. The new evidence on neural mechanisms underlying kinesthesia gives further support to the opinion that development of control systems providing feedback information as well will lead to success. One promising approach in this line of research is the use of pattern recognition of multiple myoelectric signals to generate a proportional control signal.

In accordance with the discussion above, a proportional control signal derived from several muscles with relevance to one specific movement should yield substantial amounts of force proprioception in addition to sensing movement and possibly also sensing position.

Even if important feedback information can be achieved from a properly designed control system, it is necessary to leave room for systems working with purely artificial stimulation as well. Such stimulation is needed to convey the somatosensory components of kinesthesis. In the design of purely artificial sensory systems it is equally necessary not to endanger self-containment and reliability of the whole prosthesis system. From this point of view electrical stimulation seems to have advantages over mechanical or auditory stimulation. Electrical stimulators can readily be miniaturized, their energy consumption is low, and they are reliable. If the electrical stimulation is applied to the nerves of the amputation stump the sensations will be felt by the amputee in specific parts of the phantom image (Anani et al., 1979). This creates a convergence of feedback and control functions to the phantom image. Such convergence can be expected to increase the accuracy of prosthesis control (Weissenberger & Sherridan, 1962).

Acceptance by the patient is the only important criterion to determine if an effort to replace a lost function with an artificial device is successful. Patient acceptance is a complicated concept which is not determined only by technical and cosmetic characteristics of the rehabilitation aids. Social and economic factors are equally important in addition to the psychologic attitude of the amputee towards his handicap (Höök, 1976). This means that complicated rehabilitation aids can never be prescribed without a thorough analysis of the psychologic and socio-economic situation of each individual patient. However, in order to meet the requirements of most patients, rehabilitation aids must be reliable, easy to use, and inconspicuous. Therefore, the aim in designing prosthesis feedback systems must be as much to maintain prosthesis self-containment and self-suspension as to provide significant amounts of feedback information.

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