FUTURE DEVELOPMENTS IN EXTERNALLY POWERED
ORTHOTIC AND PROSTHETIC DEVICES

VERNON L. NICKEL and WORDEN WARING, LOS ANGELES, UNITED STATES OF AMERICA

From the Rancho Los Amigos Hospital, Downey, California

Anyone who has worked with severely paralysed patients is well aware of the tremendous possibilities of the application of external power in increasing functional activity. This is particularly true in relation to the upper extremities because the degree of disability resulting from loss of function in both upper extremities far exceeds a corresponding loss in the lower extremities. For this reason the focus of attention, in so far as the use of external power is concerned, has been directed primarily to the upper extremities. Although progress has been fairly slow, a significant number of patients have already benefited markedly and the technological results to date encourage those of us working in this field to predict much greater achievements in the near future.

The ultimate goal is to provide the patient with the most natural motion possible. Attempts must be made, therefore, to find better power sources, to refine the control systems and to improve the mechanical design and performance of the device itself. The efforts at present being made in these fields offer great promise and should lead to even more advanced concepts.

POWER SOURCES

Up to the present time compressed gas (CO₂) has been considered the most effective source of power and has been used successfully in conjunction with cylinders, pistons and the helical weave artificial muscle. The initial experimental work with electrical motors was considered a failure, but with the advent of smaller, more powerful electric motors attention has again turned to electrically powered devices. These have a particular advantage for wheelchair patients in that a single source of power supplies energy for both the wheelchair and the upper extremity device. Newer, lighter, rechargeable batteries now make these devices even more convenient for the user at home.

Present research is based on the concept of using surgically implanted electrodes to stimulate the muscle. When a patient has a muscle in a functional area partly or even completely denervated, but not yet severely atrophied, it is theoretically possible for these muscles to perform useful mechanical function, provided electrical stimulation can be efficiently applied. We expect to see considerable exploration of this technique in the near future.

CONTROLS

Regardless of the source of external power used in any particular case, the problem of providing voluntary control remains. The present controls are usually of the "on-off" type, whether valves for CO₂ or switches for electrical control are utilised. Proportional control would be much superior, because velocity of movement or the amount of force supplied to an object could be controlled. One difficulty with the present mechanical or electrical controls is the delay from the time the patient desires to make a movement to the time that the switch (or valve) is moved and finally the desired movement is begun. In order to reduce this delay, any of various mechanical transducers (strain gauges for example) may be placed at convenient sites on the body. Then a slight residual movement could trigger a "power boost," as in the power steering of a car; or other phenomena under voluntary control may be used.
A number of investigators are using myoelectric activity as a source of signals to control the application of power. It is our expectation that a great expansion of this type of investigation will occur in order to establish the conditions under which it could be most effective. It involves problems associated with picking up of the myoelectric signals. Various methods of electrode attachment are being assessed.

If these electrodes are placed on the surface of the skin, artifacts must be reduced or eliminated; distinction must be made between signals from the desired muscle and signals from nearby muscles (unless these two have identical phasic activity for the tasks involved); electrode placement must be reasonably reproducible; and an electrode and paste system compatible with the physiology of the skin must be used. If electrodes are placed within the body and wires are taken out through the skin, problems of infection, wire breakage and tissue reactions to a foreign body arise. If the electrodes are completely implanted, body reaction is important, and sturdiness, reliability and constancy of location pose problems. Probably no one of these three techniques will be best in all cases.

Voluntary control signals, even of the proportional type, should in most cases be used to effect changes in position rather than to define a position; that is, the device should have an automatic hold (whether at one end of its range or in its current position when signals are absent) so that it does not require continued exertion by the patient to maintain it in its position. These same considerations apply to prosthetic hooks and joints as well as to functional braces.

If a rather versatile orthosis or prosthesis is used many separate control sites will be needed. Then the patient must be trained to use the various controls (for example, tongue switches) and in the techniques of using several controls at one time to obtain a single combined movement rather than a sequence of movements about different axes. Part of the success here will come with the patient's skill and part with care in the designing and placing of the separate controls. Some special training in the control of individual muscles and parts of muscles may also be required. Studies of this nature are in progress at several institutions.

Since there is, in general, no simple correspondence of one muscle to one function, the use of pattern recognition techniques (developed by electronics research and used with computers) may provide a successful way to distinguish the patient's attempts to make a variety of different movements. For such pattern recognition, special simplified and miniaturised apparatus is needed; it would be impractical to have a number of individuals reliant upon a single large digital or analogue computer for their moment-to-moment actions.

As the advantages and limitations of myoelectric control become more clearly defined, and as electrode technology is further refined, exploratory work with neuroelectric signals will become more important.

More extensive attempts will be made to associate particular electroencephalographic patterns with particular intended movements. Decoding the EEG signals will not be done easily, nor will the distinctiveness of patterns be adequate for reliable controls unless some "breakthrough" is made in the fundamental understanding of how the EEG patterns are generated and to what physiological or mental activities they relate.

MECHANICAL DESIGN

Although great advances in the mechanical design of both upper and lower extremity devices have been made, we expect further refinements in both fields. Sturdiness, comfort and cosmetic appeal will be improved with no increase in weight; furthermore, mechanically possible motions of the devices will be more accurately related to physiological and kinesiological axes and patterns. "Vectorial" or "integrated" control will become significant; that is, instead of making a sequence of movements on separate axes, the newer control systems and improved mechanical design will give a single composite motion in the desired direction.

THE JOURNAL OF BONE AND JOINT SURGERY
FUTURE DEVELOPMENTS IN EXTERNALLY POWERED ORTHOTIC AND PROSTHETIC DEVICES

PERFORMANCE

In order to relieve the patient from detailed control of each successive movement, one school of thought is developing programmed control, either using magnetic tapes on a computer or building a "reaction loop" performance into the device. The opposite school believes that there is danger of the device driving the patient, and emphasises that the patient must at all times have detailed control of his device. There is already evidence that these opposite views are approaching each other.

It seems likely that one of the most fruitful fields for exploration is this "man-machine" interface: how much automatic programming is desirable? What sort of controls are most suitable so the patient can at all times know he has control of the device? To what extent is flexibility of function to be built into the device, and to what extent is variety allowed in the surroundings?

PATIENT ACCEPTANCE

A most important factor in the success or failure of a particular orthotic or prosthetic device is the attitude of the patient. We have considered above merely the physical and technological problems now being explored as improved devices are being developed. But perhaps one of the most important problems is in the field of psychology. If it is assumed there is no basic change in human nature in the next few years, acceptance of future devices will depend primarily on whether or not the devices give distinct and definite advantages to the patient in the kind of activities in which he is interested.

CONCLUSION

Future devices will be more reliable, although more versatile and complex. They will require less attention and maintenance, but more skill when maintenance or repair is necessary. They will require less training of the patient before he can use them successfully and will be more immediately responsive to his wishes, giving smooth, integrated movements, varying with the intensity and direction of his effort.

The work of this paper was supported by a research grant, number RD-1655-M-64, from the Vocationa Rehabilitation Administration, Department of Health, Education and Welfare, Washington, D.C., 20201.