Paraplegia (1972), 10, 3-10

Proceedings of the Second Scientific Meeting of the International Medical Society of Paraplegia at Edinburgh on 27th to 28th July 1970

CONTROL SYSTEMS FOR UPPER EXTREMITY FUNCTION IN TRAUMATIC QUADRIPLEGIA

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COMPLETE lesions of the cervical spinal cord result in severe paralysis of the upper extremities. Ninety per cent. of these lesions occur at the C5, C6, or C7 neurological level. Injuries at different levels result in varying severity of paralysis; however, the pertinent factor which is common to all levels is inadequate finger-thumb prehension.

The most common neurological level of injury is the C6 functional level. The patient with this functional level has strong active shoulder abduction, elbow flexion, and wrist extension, but no voluntary wrist flexion and no finger extension or flexion.

The wrist-driven flexor hinge hand splint (fig. 1) employs the principles of a second-class lever incorporated into a parallelogram (Nickel *et al.*, 1963). This splint provides reciprocal flexion of the MP joints via extension of the wrist. The thumb is stabilised as a post and prehension is achieved. Patients with a functional C7 neurological level have stronger shoulder, elbow and wrist musculature (including wrist flexors), but have no finger flexors. This type of patient lacks the finger-thumb prehension which a wrist-driven flexor hinge hand splint can provide.

Patients with a higher level of lesion resulting in a C5 neurological level do not have wrist extensors. They are left with only weak deltoid, biceps and brachialis muscles for shoulder abduction and elbow flexion. This type of patient needs external power to provide prehension through hand splints.

Early attempts to harness outside power borrowed materials and principles from prosthetics. A prosthetic hook was attached to a palmar cuff and powered by a prosthetic cable using the opposite shoulder abductor as the power supply (fig. 2). If a patient has fixed contractural deformities of the hand, this hook may be the only orthotic device available for his use; however, it is a poor substitute for finger-thumb-palmar pad prehension. The artificial muscle designed by McKibben which consists of a rubber bladder encased in a helical nylon weave (fig. 3) and inflated by carbon dioxide provides smooth flexion and extension of the MP joints (Nickel *et al.*, 1963). This muscle's disadvantages are that it (1) requires an airtight system, and (2) depends upon the wear characteristics of the rubber bladder and a readily replenishable source of carbon dioxide.

With the advent of small solid-state electric motors and rechargeable nickel cadmium batteries (Nickel *et al.*, 1969), power sources for hand splints became more reliable and longer wearing. The combination of a flexor hinge hand splint

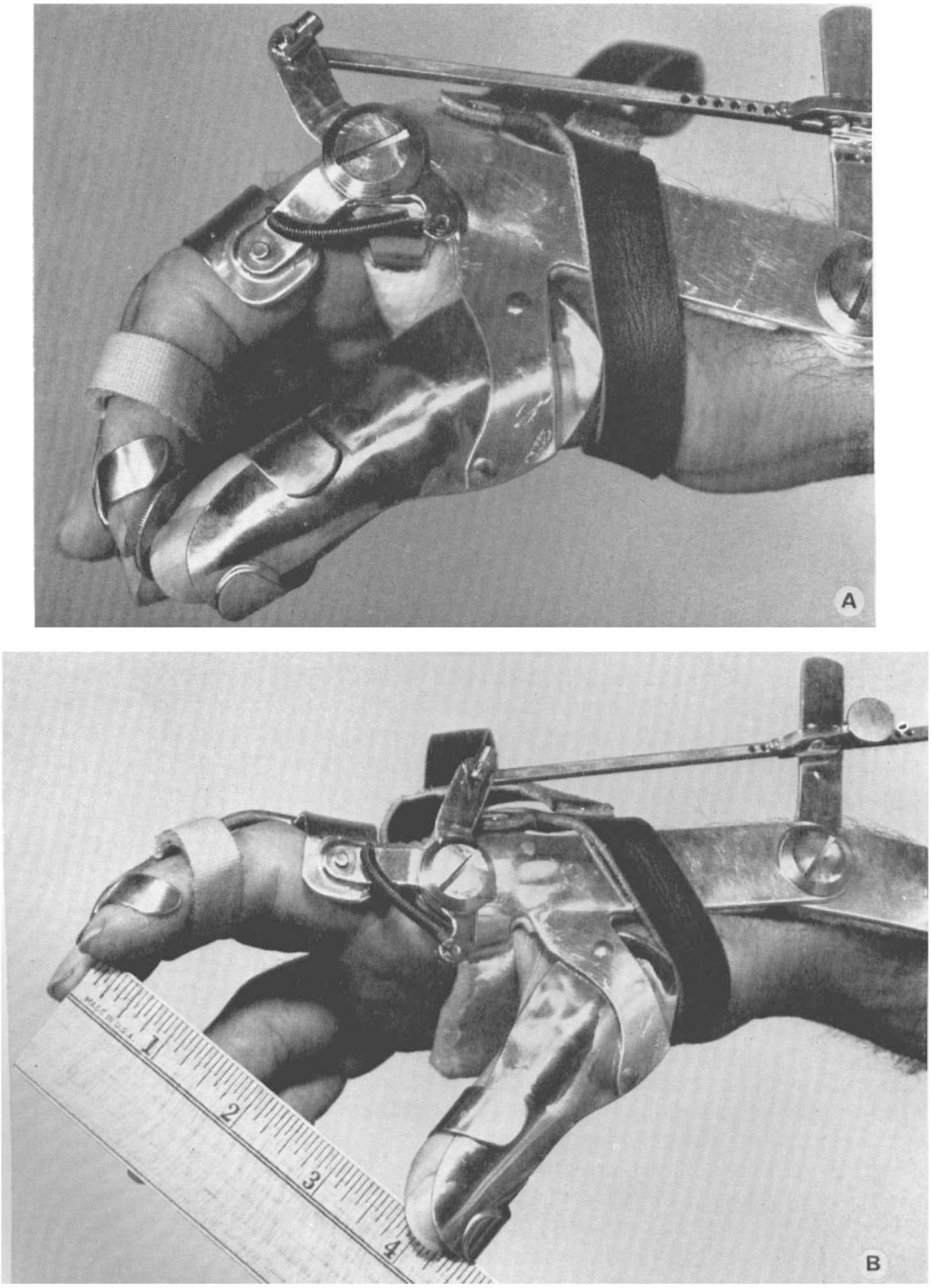

FIG. 1 (A) and (B)
Wrist-driven flexor hinge hand splint.

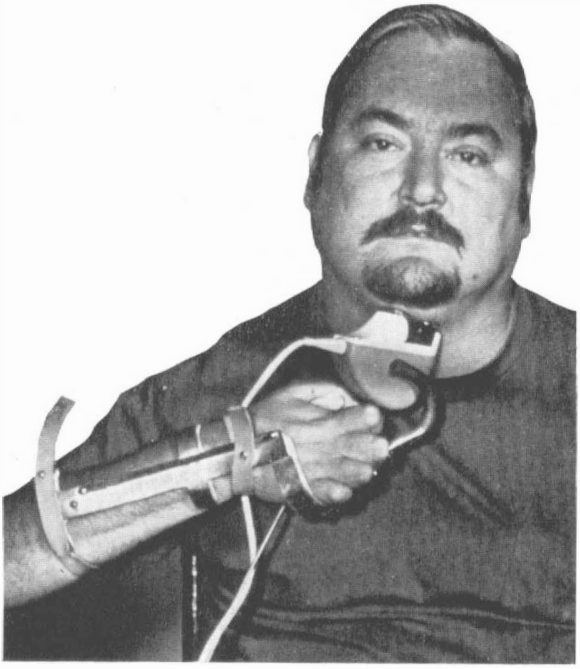

FIG. 2
Power-controlled system with addition of a prosthetic hook.

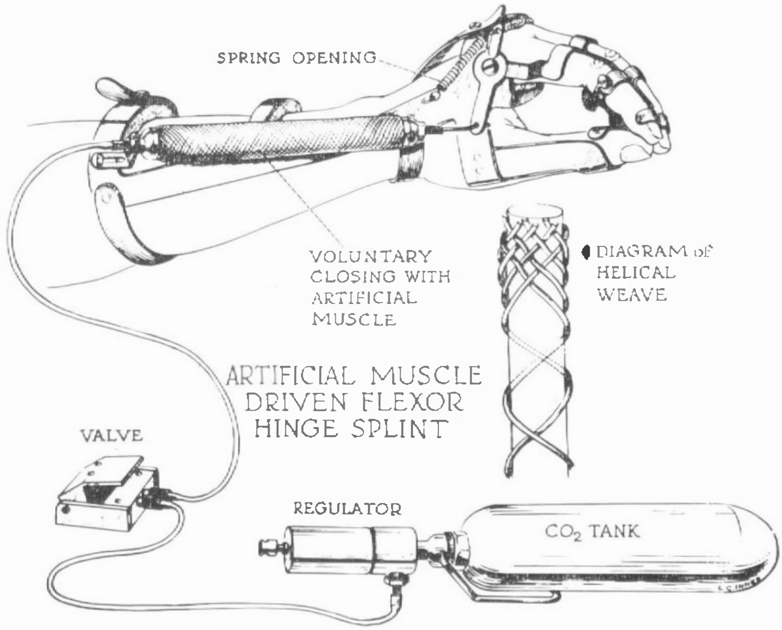

FIG. 3
Use of the McKibben artificial muscle.

and an electric motor now enables the physician to provide pinch for any person with traumatic quadriplegia. The biggest problem of externally powered hand splints is to achieve smoothness of operation. Today's control systems cannot satisfactorily provide smooth movement.

MICROSWITCH CONTROLS

The simplest and most reliable control presently available is a three-position microswitch (fig. 4) with positions for off, closed and open, which can be controlled

FIG. 4
Microswitch control.

by shoulder elevation or head motion (Allen *et al.*, 1969). To operate this device requires delicate, finely coordinated movement that is not available to most quadriplegic patients with poor trunk balance. Since the tongue is perhaps the most agile muscle of which the quadriplegic has full control, tongue switches of small microswitches can be coupled to control several devices, including the hand splint and wheelchair. Seven microswitches on a bank played by the tongue can control an entire external arm orthosis. This latter arrangement again has the disadvantage of being simple on-off switches requiring multiple motions for combined coordinated movements of the arm.

The major research endeavours at Rancho Los Amigos Hospital concentrate on improving the controls of the externally powered hand splints (Karchak *et al.*, 1969). Several prototypes of experimental control devices being developed are described below. These devices are fitted to only a few select patients and cannot be considered functional at the present time; neither are they the usual controls that are routinely fitted to our patients.

INTRAORAL TRANSDUCER CONTROLS

To simplify the tongue switch, intraoral transducers mounted on a dental-type bridge can control an external orthotic device by telemetry, thereby eliminating

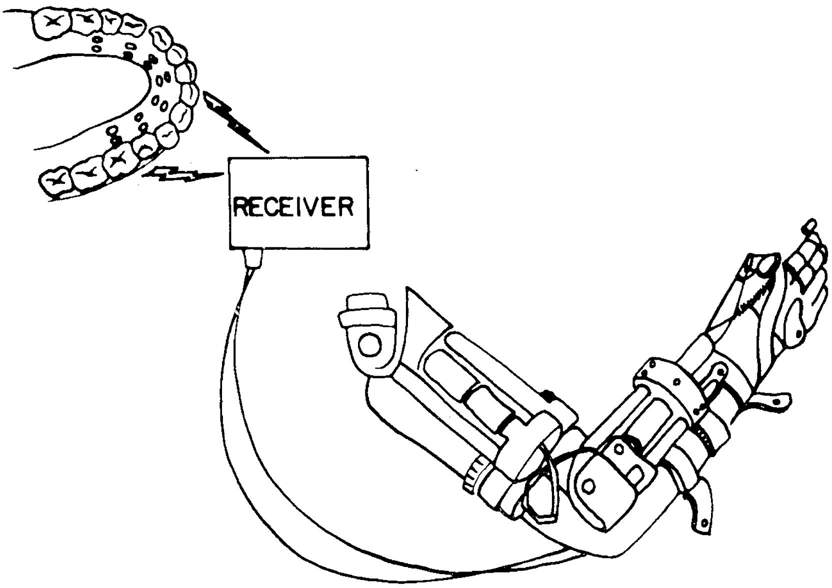

FIG. 5
Intraoral transducer control.

wire circuitry (Bontrager *et al.*, 1969). The intraoral appliance is similar to a dental retainer plate (fig. 5). Pressure-sensitive transducers are activated by the tongue, and the signal is telemetered to the motors which power the upper extremity orthosis.

OCULAR CONTROLS

Ocular control systems which have been designed as a back-up safety system for the astronauts on the Apollo programme may be used to control external orthotic devices by lateral motion of the globe in the orbit. Switching is accomplished by interference of an infrared beam from the eyeglasses frame played on the sclera. When the pupil moves into the ray of the beam, the switch is closed and the motors activated.

COMPUTERISED CONTROLS

Rendezvous end-point (Allen *et al.*, 1962) which would incorporate the combined activity of all motors at one time to move a hand through space to a predestined destination is feasible through computerised motion. To date, the technical requirements of the computer have not been substantially miniaturised to make this motion practical. Surface-to-air rockets have sophisticated miniaturised computers which will guide a rocket through a predestined end-point; however, to have a missile or a hand decelerate and stop at a predestined end-point requires much more technical computation.

MYOELECTRIC CONTROLS

The system that has had the most clinical trial and holds the greatest promise for widespread clinical applications in the near future is the myoelectric control system (fig. 6). Surface electrodes pick up myoelectric signals from muscles that

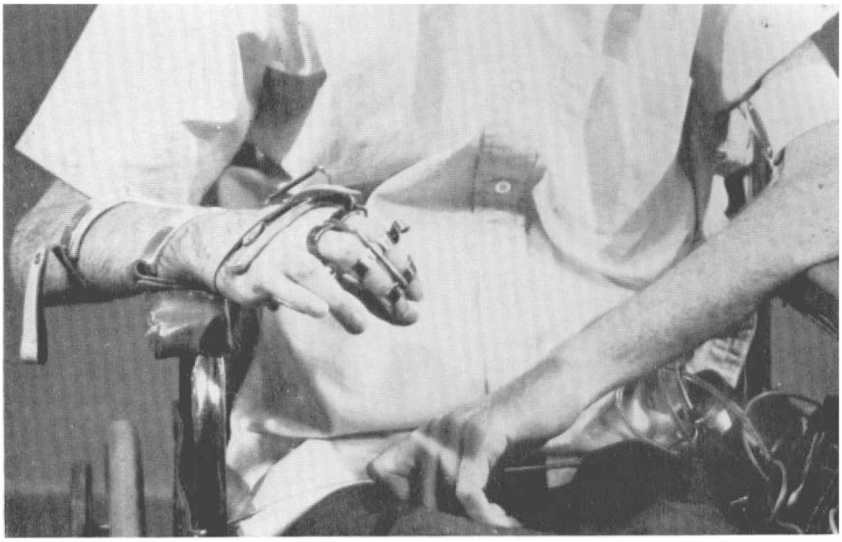

FIG. 6
Myoelectric control system.

are normally innervated. These signals then control the externally powered motor for the hand splint. Myoelectric controls have the disadvantage of typing up a muscle that would be functional for other activity. Also, if the control muscle is inadvertently contracted, the hand splint may either open or close by mistake. These disadvantages seem insignificant compared to the ease of control without the use of microswitches. Just a short period of training is needed to teach patients muscle control.

INTERNALLY IMPLANTED NERVE STIMULATORS

In the quest for better control of paralysed muscles, implanted nerve stimulators may supplement the patient's own muscle for the upper extremity functions of prehension and grasp. These controls have been designed and manufactured in cooperation with Medtronics Corporation, manufacturers of cardiac pacemakers and carotid sinus stimulators. The internal implanted nerve stimulators incorporate a surgically implanted electrode around the nerve and a wire lead to a receiver which is buried subcutaneously (fig. 7). The external device consists of a pulse generator, rheostat switch, and transmitting antenna. When the antenna is placed over the subcutaneous receiver and the pulse generator is turned on, the stimulus across the skin barrier is picked up by the implanted receiver and causes stimulation of the motor nerve, which in turn causes contraction of the muscle(s) it supplies.

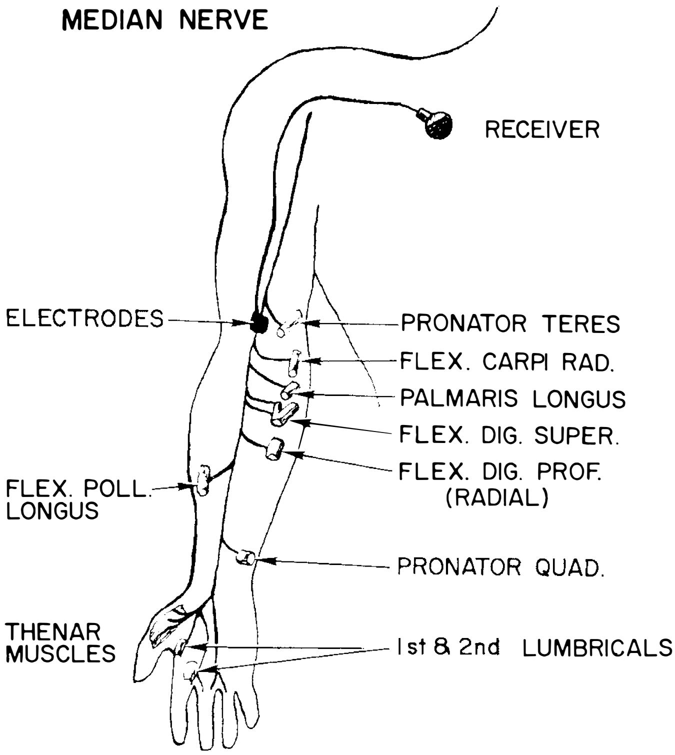

FIG. 7
Use of internally implanted nerve stimulators.

Implanted nerve stimulators have the dual benefits of supplying function for paralysed muscles as well as of maintaining muscle tone and neuromuscular endplate function.

CONCLUSIONS

Prehension grasp can be provided to any patient who has paralysis of the upper extremities if he has not been allowed to develop contractural joint deformities. If the patient has strong wrist extensors, the reciprocal flexor hinge hand splint will provide palmar pad prehension. If the patient does not have wrist extensors, externally powered devices can substitute for his wrist extensors.

Present-day control systems are quite cumbersome. Smoothness of operation awaits more refined control systems which are being developed. Ultimately, internally implanted nerve stimulators hold the promise of marshalling paralysed muscles into use for improved function of the paralysed upper extremity.

REFERENCES

ALLEN, J. R., KARCHAK, JR., A. & NICKEL, V. L. (1962). Design and application of external power and control orthotic devices. *Mech. Engineering*, **84**, 52-54.

ALLEN, J. R., KARCHAK, JR., A. & NICKEL, V. L. (1969). Orthotic manipulators. Presented at Third International Symposium on External Control of Human Extremities, Dubrovnik, Yugoslavia.

BONTRAGER, E., SCOTT, I., UTLEY, B., NICKEL, V. L. & ASH, M. (1969). Intra-Oral Control Systems. Presented at Third International Symposium on External Control of Human Extremities, Dubrovnik, Yugoslavia.

KARCHAK, JR., A., ALLEN, J. R. & NICKEL, V. L. (1969). The application of external power and controls to orthotic systems. Presented at Third International Symposium on External Control of Human Extremities, Dubrovnik, Yugoslavia.

NICKEL, V. L., KARCHAK, A. & ALLEN, J. R. (1969). Electrically-powered orthotic systems. *J. Bone Joint Surg.*, **51-A**, **2**, 343-351.

NICKEL, V. L., PERRY, J. & GARRETT, A. L. (1963). Development of useful function in the severely paralyzed hand. *J. Bone Joint Surg.* **45-A**, 933-952.