THE APPLICATION OF EXTERNAL POWER AND CONTROL TO ORTHOTIC SYSTEMS

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Summary

Research and development carried out at Rancho Los Amigos Hospital during the past ten years have provided external power to upper-extremity orthotic structures which provide patients volitional functional activity within the area of a wheelchair lapboard. Two power sources have been used. The first was pneumatic in the form of carbon dioxide; the second and present power system is elecricity. Sixteen patients have been fitted with the Rancho Electric Arm with tongue switch control. These units are used on quadriplegic patients who have totally flail upper extremities. In addition to controlling the arm, the tongue switch provides the patients with volitional wheelchair control and enables them to regain mobility and independence.

Introduction

The incidence of polio in the United States rose to a peak in 1952, when 58,000 new cases were reported. In the more severe cases the majority seldom survived for any extended period of time since there was little knowledge available on how to treat these patients.

One of the first major developments to increase the survival rate of polio patients was the respirator, initially called the iron lung. Within these devices, patients with respiratory failure could be kept alive indefinitely. Advances in the medical care and treatment of polio also increased the survival rate. After a decade of these improvements, institutions were filled with patients requiring a lifetime of care and there was still no end to the polio epidemic. At that time, the daily cost to care for this type of patient in an institution was approximately $68.00 per day. Because we are all human beings, it was obvious that the uninfected population owed these unfortunate people any benefits that technology could provide. This public impetus started several programs around the

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world to investigate the application of external power to orthotic bracing. After a decade of applied clinical research at the Rancho Los Amigos Hospital, external power and control systems have been developed which permit volitional control of the joint motions in the upper extremities of quadriplegic patients. These systems range from a single power unit, as is used on a handsplint for prehension, to total replacement of a flail arm with seven joint motions, as in the Rancho Electric Arm. These systems are now applicable and available to patients all over the world and offer increased daily functional ability to all, even the most severely afflicted.

Research Accomplishments

Since 1958, the efforts of a clinical team at Rancho have been directed toward developing an external power and control system for paralyzed upper extremities. Two power sources (pneumatic and electric) have been used functionally on patients. Different types of actuators, controls, and various auxiliary components which are necessary to each system also have been developed to functional stages of use. Present research efforts are being directed toward refined control systems which will enable the patient to make volitional motions in space with a minimum of conscious effort.

The application of external power and control systems to patients afflicted with functionl muscle losses formally began at Rancho Los Amigos Hospital in March of 1960 with funds provided by the Vocational Rehabilitation Administration. Prior to this time, little work had been done to develop externally powered orthotic devices. Basic handsplinting, both static and dynamic, had been achieved with limited support from the National Foundation for Infantile Paralysis. The use of external power was stimulated by patients who had useful arm motions but lacked functional prehension. An investigation of forms of stored energy and an observance of the gas-powered prosthetic devices already in use in Heidelberg, Germany, influenced our decision to use pneumatic power in the low pressure range (from 50 to 90 psi). Pistons and bellows initially were attached to the flexor hinge handsplint as activators. While they worked fairly well, they did not appear ideal for this purpose, since they were originally designed for industrial use. After theoretical and practical research, the McKibben artificial muscle became the actuator used extensively for prehension. This "muscle" was designed by Dr. McKibben and developed for large-scale use at Rancho Los Amigos Hospital. An entire preumatic system is shown in Figure 1.

During this same time, and orthotic device known as the mobil arm support shown in Figure 2, (ball bearing feeder) was being used with great success on patients who had residual arm muscles and trunk motion. These units supported the arm against gravity and permitted whatever remaining muscle function the patient had to be used for functional activity within the range of the device. As more higher level lesions were treated, the type of patient soon reached a degree of paralysis where their operation of the device became marginal. It was obvious that these patients would require the help of external power if they were to accomplich functional

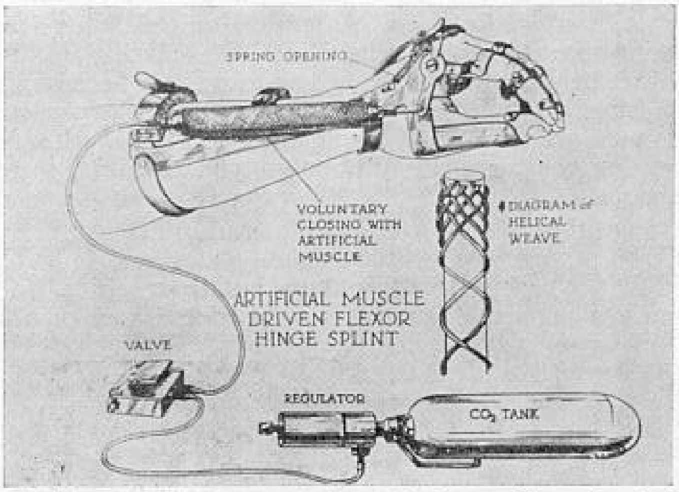

Fig. 1. A pneumatic system used on the flexor hinge handsplint.

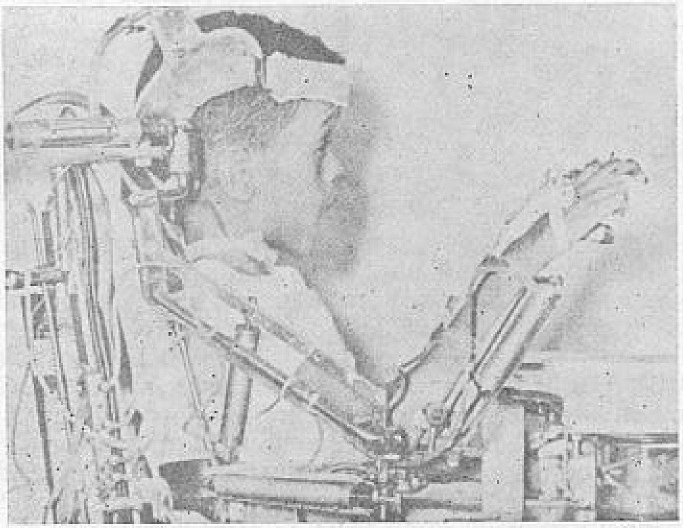

Fig. 2. Mobil arm support.

arm motions. The first attempts to fill this need utilized the mobil arm support as a bracing structure and the artificial muscle as the power actuator. The unit worked to a limited degree, but its limitations pinpointed the faults of the artificial muscle when it was used for any motion other than prehension. Its excursion was restricted to 30% of its original length and it had a variable force curve beginning at a valve of about two and one-half times the pressure times the cross-sectional area, and diminshing to zero at the end of its excursion. For these reasons the piston-type actuators were chosen for arm motion.

It took another four years to up-grade the pneumatic system (Fig 3.) into a structure with seven joint motions. It had been determined that seven was the minimum number required to produce functional arm movement within the restricted area of a lapboard placed on a wheelchair. These seven joints included two joints at the shoulder, two at the elbow (one flexion/extension and the other humeral rotation), forearm rotation, wrist flexion and hand prehension.

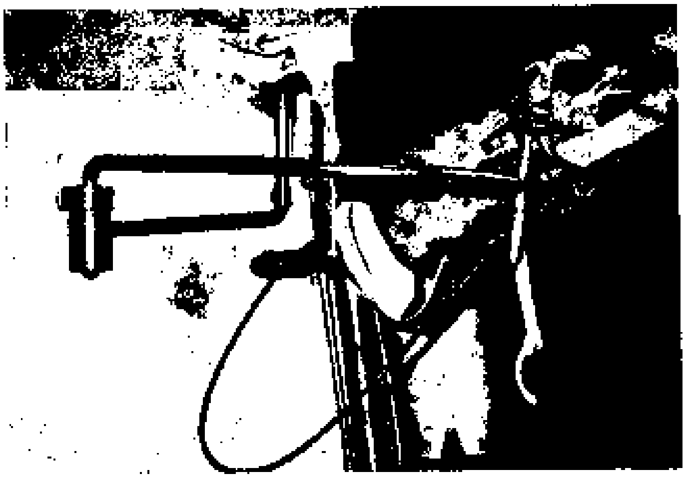

Fig. 3. Pneumatic arm and control.

Two types of valves were used for controls (Fig. 4). The first was a spool valve activated by a sliding motion, such as the action used on a shoulder harness. The second was a poppet type activated by a levelmotion rotating around a pin joint. With both these units the patient could throttle the gas supply and thereby achieve a degree of velocity control. Four patients were fitted with this device unilaterally, and one patient bilaterally.

It must be re-emphasized that patients fitted with a total arm replacement of this type are quadriplegics who spend most, if not all, of their time in bed. When they get up, they are wheelchair-bound.

Mobility in their wheelchairs formerly was possible only if they had someone else push them from place to place. Even after first electric wheelchairs became available, it was impossible for these patients to manipulate the controls. Eventually, where an extremity or head motion was available to operate a joystick, the control boxes could be relocated to fit each patient's muscle motion capability. This was by far one of the greatest advances in applying external power to patients' use. Few other appliances have provided more satisfaction to patients. Their newly-acquired volitional mobility was one of the first degrees of independence most of these patients had experienced for a long time. Further refinements to these control systems made wheelchair operation feasible even for high level quadriplegics.

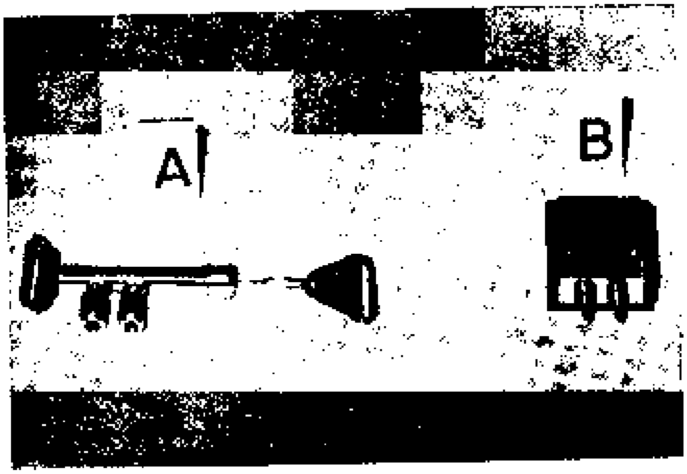

Fig. 4. Slide and lever valve.

This burgeoning demand for powered orthoses necessitated that a comprehensive evaluation be made of power sources. Our patients' arms were operated by pneumatic power, while the wheelchair operated on electricity. Why use two power sources on one wheelchair when the wheelchair batteries alone could provide enough power for both objects? It was apparent that the entire system could be simplified if the arm were electrically powered. Replenishing the power supply also was easier in the case of electricity. After basic studies of power requirements and joint structures, a laboratory model of an electric arm was fabricated. The first arm (Fig. 5) was tested on a patient in the laboratory, and the faults and undesirable features of the arm were itemized.

The most glaring fault was in the control. The seven joint motions of the arm required 14 channels of control. Four additional channels are required to operate a wheelchair, making a total of 18 channels. In our efforts to establish source of controls, we wanted to select a site as universal as possible so that custom fittings would not be necessary. Use of the tongue to operate the control switch was finally selected since it met most of the control requirements.

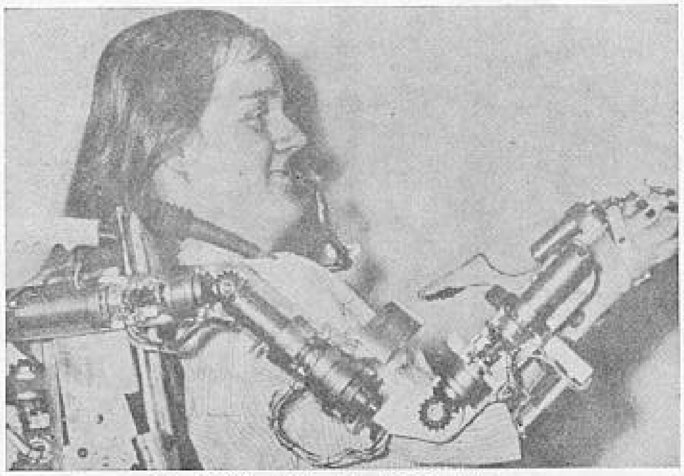

Fig. 5. First Model of Electric arm.

The first tongue switch (Fig. 6) consisted of multiple levers, spring-loaded to center. They provided bidirectional motion through closed contacts on leaf springs. The unit was covered with latex rubber for insulation and waterproofing. Early laboratory testing of this device indicated that it had a great potential as a multi-channel control device if patients accepted the idea of using the tongue to operate it. When they did, an all electric system became a reality. The initial prototype structure and a tongue switch was built and became operational.

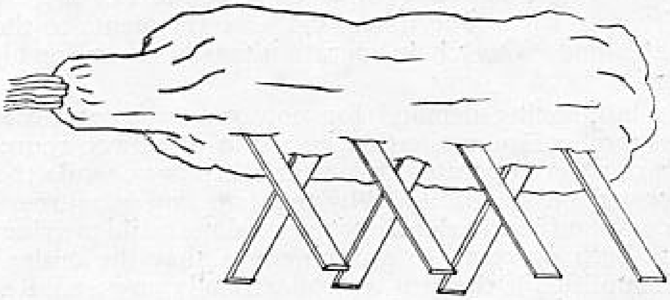

Fig. 6. First model of tongue switch.

The testing of these early units furnished useful data from which to design and improve the next unit constructed for functional patient use. The following joint structures of the arm (Fig. 7) were incorporated:

1. Shoulder rotation (about a vertical axis).
2. Shoulder flexion and extension.
3. Humeral rotation (rotation axis through center of arm).
4. Elbow flexion and extension.
5. Forearm pronation and supination (rotation about long axis of the forearm).
6. Wrist flexion and extension.
7. Prehension.

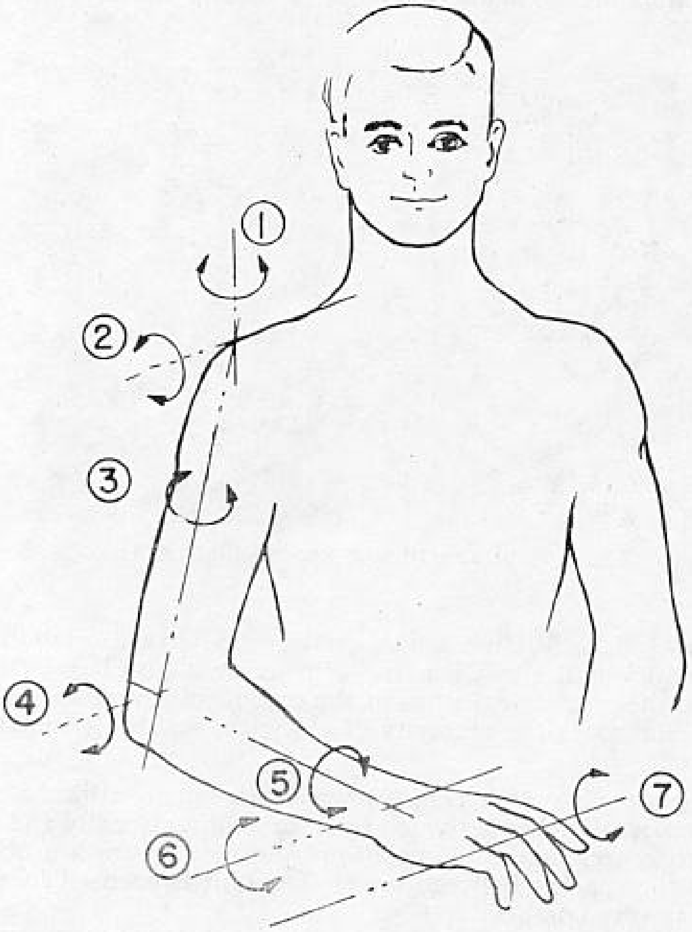

Fig. 7. Rancho Electric Arm.

This joint structure was basically the same as that used on the pneumatic arm except that the joint rotation about the humerus and forearm occur around the long axis of the arm. This more closely approximates anatomical motion and reduces nearly to zero the relative motion between the arm and the bracing structure. The arm unit itself (Fig. 8) consits of the first five joints, beginning at the shoulder and ending at the forearm. Three of these joints are worm gear drives with output speeds of about 4 rpm and capabilities of 150 inch lbs. payload torque at stall. The humeral and forearm joints are spur gear drives with 30 and 15 inch lbs. output torque respectively, and about the same output speed as the worm gears. The last two joints (wrist and prehension) are on the hand-splint and are remotely operated with prosthetic cable and housing. The actuators are permanent magnet 12 volt DC motors with planetary gear heads. All five joints of the arm have a friction drive system which will slip when the arm meets a given resistance or runs into the mechanical stops at the end of joint motion. This precaution eliminates the necessity of electrical end limit switches on the joints.

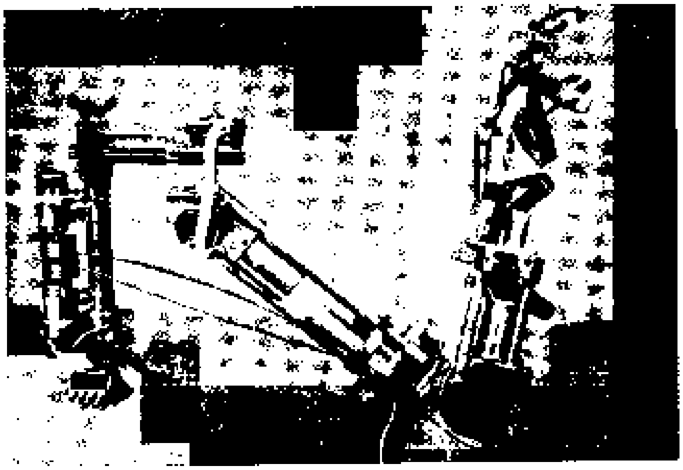

Fig. 8. Joint structure of Rancho Electric Arm.

The tongue switch (Fig. 9) was designed to utilize a double bank of microswitches activated by levers bidirectionally and spring loaded to center at the off position. Alternate levers are offset to increase the spacing between levers. The unit is encased in a housnig and is very compact.

By October of 1964, the new models of the Rancho Electric Arm with tongue switch control had been completed and were ready for patient fitting. A patient was selected and a two-month trial period of fitting and adjusting of the unit began in the laboratory, concurrent with patient self-training. When the test period was finished, the patient, shown in Figure 10, was discharged from the hospital and she has remained an outpatient. This fitting took place nearly five years ago and the equipment is still being used extensively by the patient.

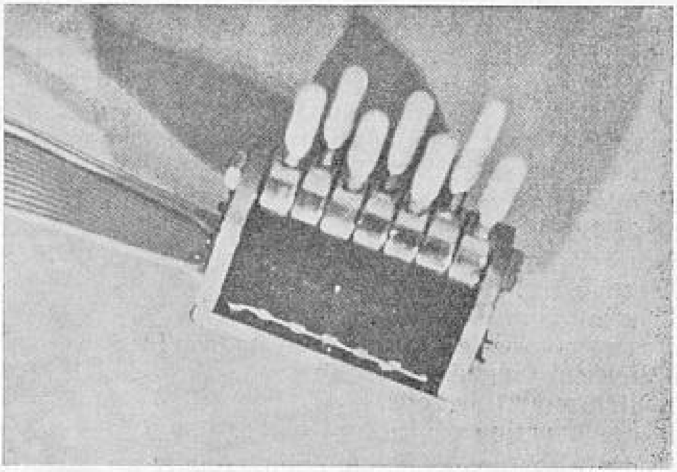

Fig. 9. Tongue switch control.

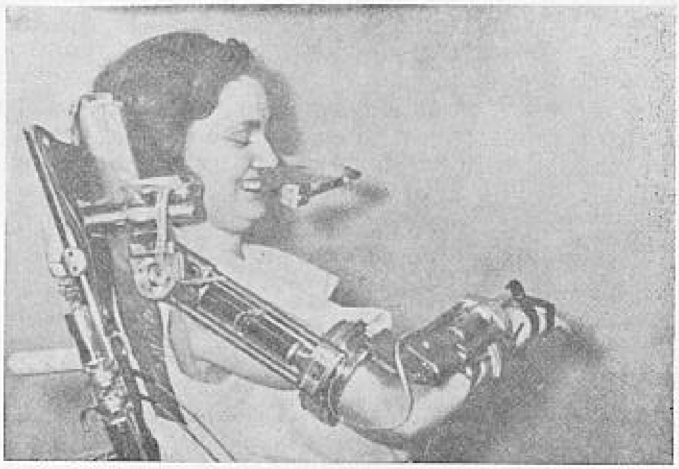

Fig. 10. First patient fitting of electric arm.

To date, 16 electric arms have been fitted to patients within the Los Angeles area. All are outpatients. Four more units have been fitted at other institutions in the United States. Ten additional units are being used by other research groups through the United States who are working on various types of control systems.

It seems appropriate to review the total components that comprise this type fitting as well as to indicate their approximate costs.

The first item which must be acquired is an electric wheelchair. We have used the Everest & Jennings chair exclusively and all our component parts are designed to fit it. The chair is ordered without the standard joy stick control but with an extra six feet of control cable. Two-inch foam seats and back cushions are recommended. This chair costs about 900 American dollars.

The following equipment must be mounted on the electric wheelchair:

1. Relay control box with crossover switch.
2. Electric arm mounting bar.
3. Five joints of electric arm.
4. Dynamic wrist and prehension handsplint.
5. Motorized tongue switch unit.
6. Switch mounting rods.
7. Interconnecting cables and plugs.

All these parts are available commercially and sell for 2,350 American dollars. The mounting and fitting of the Rancho Electric Arm is described in a fitting manual using a step-by-step procedure, and can be carried out by any technician. The handsplint must be custom fitted to the patient by a qualified orthotist.

Conclusions

The Rancho Electric Arm with tongue switch control is no longer a research tool or a demonstration device. It has undergone four-and-one-half years of patient use and now can be considered a standard fitting. Mounted on an electric wheelchair, the two units provide the patient with volitional mobility and functional arm activities in the vicinity of the wheelchair lapboard. This type of fitting can be made anywhere in the world today if an orthotist is available to fit the handsplint to the patient.

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