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A single case study: myoelectrically controlled exoskeletal mobilizer for amyotrophic lateral sclerosis (ALS) patients

W. F. SAUTER, G. BUSH and J. SOMMERVILLE

The Hugh MacMillan Medical Centre and Sunnybrook Medical Centre, Toronto

Introduction and clinical pathology of Amyotrophic Lateral Sclerosis (ALS)

Amyotrophic Lateral Sclerosis (ALS) also known as Lou Gehrig's disease is the generic name for progressive muscular atrophy and bulbar palsy. It refers to all disorders of the cortico spinal pathways which are characterized by progressive muscle weakness. After multiple sclerosis, ALS is the most common purely neurological disorder (Janiszewski et al. 1983). Information available from the ALS Society indicates that the most common age of onset is 55 years.

Literature shows that the incidence of ALS is 1-2 per 100,000 population. There are, however, geographic pockets where this figure doubles (Sarnia, Ontario) or even jumps 100 fold as on the island of Guam in the Pacific (Guamainian ALS) (McLachlan, 1988).

To date, no etiological or epidemiological factors that could be linked to ALS have been found nor is there any cure for the disease.

A major feature of ALS is that a mentally alert person who is accustomed to being active and independent becomes trapped in a weakened body. As a result of the disease, people lose the motor functions of their muscles and limbs. This report concerns itself with the loss of muscle power in the upper extremities which, in the advanced stages of the disease, leaves the arms of 16% of these patients virtually flail, except for limited weak grasp (Beggs, 1988). While these patients retain full sensation, reach and grasp become impossible and most normal activities of daily living cannot be performed any longer.

In the past, significant efforts have been made to improve the functionality of the upper limb amputee through the provision of externally powered prostheses (Lewis et al, 1975; McLaurin, 1975; Prior & Lyman, 1975). It might well be that upper limb amputees were targeted because their problems were relatively easy to resolve and the resulting improvements were often dramatic. The real need however, certainly in degree of disability, is in the authors' opinion much greater among persons with flail limbs. One of the outstanding efforts to provide assistive hardware to the quadriplegic and post polio group was the Ranchos Los Amigos "Golden Arm" (Nickel et al, 1964). Mounted on the back of a wheelchair, the orthosis was powered by nine different electrical actuators and controlled by a bank of tongue switches. The device was complex, expensive and difficult to don. The tongue switch control was less than hygienic and difficult to combine with eating and drinking. The device is no longer in use and no new developments that would benefit persons with bilateral flail arms have been reported.

This paper reports on the provision of an externally powered, myoelectrically controlled forearm lift and prehension device for a person with a flail arm.

Patient profile

On initial examination, this 31 year old male showed nearly flail arms with very poor hand function. He was, however, able to walk a few steps when pulled up to standing and given a walker. His speech was slurred and his vital functions reduced. Three years previous to referral to the myoelectric clinic he was diagnosed as having ALS. He is married and living at home, with a supportive wife who has to go to work.

All correspondence to Mr. W. F. Sauter, Coordinator, Myoelectric Prosthetic Service, Rehabilitation Engineering Department, The Hugh MacMillan Medical Centre, 350 Rumsey Road, Toronto, Ontario, M4G 1RB, Canada.

In discussion with the team and patient, self-feeding was rated as the greatest need followed by being able to access a computer keyboard. It was decided jointly that an attempt be made to fit his left arm.

Control system

Before embarking on the design and fabrication of the orthosis, the problem of how to control hand prehension and forearm lift had to be addressed. It was decided that to be effective, the mode of control chosen had to be unaffected by normal body movement or sway, as well as other functions such as eating or speech. The control function had to be easy to produce, while having an acceptable degree of reliability and repeatability. Suck and puff switches, tongue switches and head attitude controls were excluded because of their interference with eating and drinking. In the search for control modes and control sites, it became evident that only the upper facial muscles of ALS patients remain unaffected as the disease progresses. It therefore seemed reasonable to use the occipito-frontalis muscle group as the signal source for an electromyographic (EMG) control system.

With the patient seated a jogger's head band was used to hold two Otto Bock* surface electrodes in place just above each eyebrow. A jogger's headband was used because the patient disliked the idea of wearing eye glasses to support the electrodes on his forehead. The electrodes were wired to a battery and a myoelectric hand. The patient was shown how, with separate left and right frontalis muscle contractions, it was possible to open and close the hand. The patient and his wife were shown how to apply the system and were then given the equipment to take home so that the patient could practise on his own.

As predicted, the jogger's headband proved inadequate. Every time the patient perspired, the electrodes would work themselves higher up and away from the control sites. The electrodes were therefore transferred onto a pair of eyeglasses with the ground electrode mounted in the middle across the bridge.

The EMG signals from the frontal part of the occipito-frontalis muscle group were picked up by the 2 electrodes mounted on the eyeglasses and located 7cm from mid-line of the forehead, approximately 1cm above the eyebrow ridge and at approximately 30° of lateral rotation. With the electrodes spaced in this manner, it was possible to avoid involuntary triggering of the system thus preventing inadvertent activation.

A negative cast of the patient's left arm was used to make a full plaster replica of his limb. The resulting positive mould was used to custom form the device. The upper-arm and forearm sections were hinged by spring-loaded (energy storing) elbow joints. The hand prehension splint was powered by an electric dual-action linear actuator. Forearm lift was achieved by an electrical miniature winch winding up a timing belt. Both these devices were made in-house by the centre's mechanical engineering staff. After three weeks of home training, the patient became proficient in generating sufficient signals from either the left or right frontalis muscle, to either open or close his hand. However, in order to operate both hand and elbow with the chosen 2-muscle site system, an electronic mode selector had to be incorporated into the system. The mode selector, normally at rest, responded to a co-contraction from the fontalis muscles lasting at least 0.7 seconds after which the device would switch control from hand to elbow or vice versa. After switching control from the hand orthosis actuator to the elbow winch, the patient could contract the right frontalis muscles to raise the forearm and vice versa. This meant that the orthosis provided 4-degrees-of-freedom for forearm lift and finger opening and closing. The system was powered by a 7.2 volt, 1200 mAh nickel cadmium battery with an operational capacity of 8 hours.

Brace redesign

Whilst this orthosis worked well enough to demonstrate the effectiveness of the approach taken, it was structurally too weak, causing the elbow joints to lose their alignment under load. It also became evident that to enable the patient to feed himself, his arm needed to be held in a position of approximately 20° abduction and 30° of humeral flexion. It was also noted that the patient's gleno-humeral joint tended to sublux under the combined weight of the arm and orthosis. The most

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* Otto Bock Orthopaedic Industries, Cat. #13E60. (Otto Bock Canada, 251 Saulteaux Crescent, Winnipeg, Manitoba, R3J 3C7).

evident short-coming of this orthosis, however, was the lack of pronation-supination to facilitate self-feeding. Therefore, a second device was designed with 6-degrees-of-freedom. This Mark II brace was constructed of sturdy stainless steel uprights of 4mm × 15mm cross section. Two transverse bands of the same material on the humeral section held the elbow joints securely aligned. The forearm section had one sturdy band of 4mm × 15mm stainless steel approximately 30mm distal to the elbow centre. Both elbow joints were equipped with lift assist springs. These energy storing springs were cranked up to balance the weight of the forearm almost completely. In order to achieve pronation-supination, the forearm segment was constructed in such a way as to simulate the movement of the osseous structure of the forearm. The lateral forearm bar was cut off at the proximal third and a piece of stainless steel tubing was welded to it. The tubing formed the bearing for a 6mm stainless steel rod which connected with an aircraft tie rod end to the wrist joint. On the medial side, a similar rod with a tie rod end on each end makes up the forearm section. This arrangement allowed the forearm section of the brace to supinate 45°. The electric elbow winch was mounted to the lateral upright of the humeral section. The winch winds up a timing belt which connects to a stainless steel cable. The cable was sleeved through a bowden housing on the lateral forearm from where it crossed over the forearm to the anchor point on the medial forearm rod. Thus supination was effected by the forearm being raised under power. Because of offset stops on the mechanical elbow joints, pronation was produced when the arm was extended. The fingers of the patient's hand were held in a powered orthosis. A double acting linear screw actuator moved the fingers of the hand against a stationary thumb. Because the patient had full sensation, he could feel what he picked up. The addition of pronation-supination greatly improved the usefulness of the device because the hand was automatically rotated into the appropriate position for picking up food at table level and then bringing it to the mouth.

In addition to fabricating and fitting the orthosis for the patient's upper extremity, it was necessary to hold and support the patient's arm in a position of 20° of abduction and 30° of humeral flexion to accomplish self-feeding effectively. A laminated, lateral body panel held in place with a strap around the waist was used as a mounting base for an adjustable support strut holding the arm out and away. Because of painful subluxation of the glen-humeral joint, it became necessary to fabricate a shoulder saddle which would comfortably support the assembly. Donning and doffing was simplified by having the orthosis, the body panel, the shoulder harness, and the eye-glasses-electrode assembly separate into different units which are applied one at a time. The complete device is shown in Figure 1.

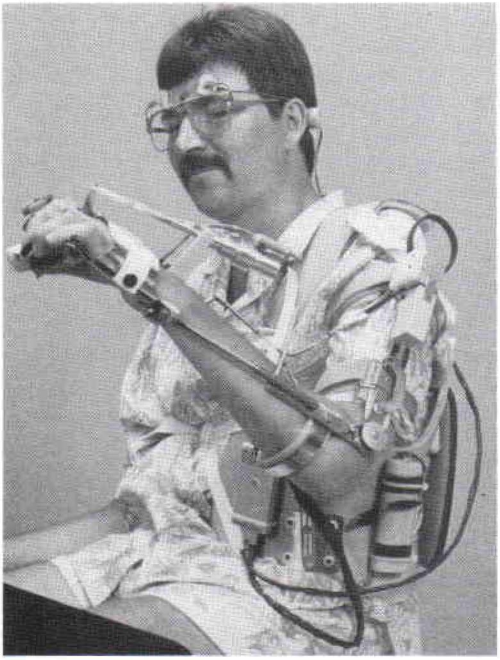
Fig. 1. The complete orthosis being worn by the patient.

Results

It is now 24 months since delivery of the device to the patient. He continues to use the device almost daily. The device has helped him to accomplish various activities of daily living which have enhanced his independence and thus, the quality of his life. He can place a drinking straw into a cup or glass, operate a telephone communications device and operate a T.V. remote control. He can play board games with his children and, most importantly, he can eat solid foods such as a sandwich or fruit that has been previously cut. Since being fitted with the device, the patient has used it to access a computer. Using a word processor, he has completed a book on landscaping. He has also become employed as a part-time bookkeeper because of his ability to access the computer.

It is believed that the positive outcome of this fitting is attributable to several factors. These are:

(a) an enthusiastic and well motivated patient;
(b) wearing the brace on the arm rather than having it attached to the back of the wheelchair;
(c) this orthosis, in contrast to previous complex designs, provides grasp, elbow flexion, pronation and supination with a minimum of hardware and a simple electronic control system. In addition, with some lateral tilt of the torso, the hand can swing in the coronal plane.

The positive outcome of this fitting leads us to believe that the approach taken with this subject could also benefit other people with conditions such as quadriplegia, spinal muscular atrophy or poliomyolitis.

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