Electrical Response and Electromyograms of Upper-Extremity Muscles in Quadriplegics

by

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INTRODUCTION

This study is intended to determine the feasibility of electrical stimulation of forearm muscles in quadriplegics and their use as power to drive hand-forearm orthoses. Specifically, an attempt was made to answer the following questions:

1. What is the nature and distribution of paralysis in those muscles of interest from the orthotic point of view?

2. Can denervated (lower motor neuron) muscles be comfortably, safely and usefully electrically stimulated?

3. Can innervated but paralyzed (upper motor neuron) muscles be comfortably, safely and usefully stimulated?

The idea of using an electrically stimulated weak or paralyzed muscle to power or drive splints or braces has been applied in the past. Liberson (1) and Gracanin (2) stimulated the peroneal nerve in hemiplegics to aid in dorsiflexion

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of the foot. In this laboratory, Long (3) devised the electrophysiologic splint for use on the forearm muscles of quadriplegics. Experimental work in this area is in progress; Steinberger (4) attempts to maintain denervated muscle in functional condition by continuing intermittent stimulation with intramuscular electrodes. Surface stimulation is used routinely in several European paraplegic centers (5); continuous electrical stimulation is applied to entire muscle groups to maintain activity and muscle volume until recovery occurs or until it becomes clear that the lesion is irreversible and complete. Crochetiere (6) and others at Case Institute of Technology have investigated the feasibility of controlled electrical stimulation of paralyzed muscle. Vodovnik (7) has published data on the efficiency and pain response to different currents. It has been our early clinical impression that applications of electrical stimulation in upper extremity orthotics are not effective in providing useful prehension, even within a splint. The electrophysiologic splint earlier described in this laboratory has never been successful clinically, as reported by Long and Masciarelli. We felt it necessary to review the basic electroneurophysiology of the forearm muscles to determine retrospectively the factors which might be responsible generally for the apparent failures, and to determine whether the electrical stimulation method could be improved.

MATERIAL AND METHOD

Eight patients with traumatic quadriplegia were chosen at random. Their injuries were as recent as three months at the time of initial testing, and as old as six years. In three patients, it was possible to repeat testing several months after initial testing. All patients had a clinically complete, permanent cord transection at the levels given in their histories. All patients had almost symmetrical involvement of both arms; therefore, all testing was done on one arm only. None of the patients had reconstructive forearm-hand surgery. All patients had good range of motion in the arms tested, except one (E. B.) who had moderate spasms and tightness, with slightly restricted passive range of motion.

No attempt was made to correlate findings with anatomic details of injury, X-rays, or method of treatment, such as laminectomy.

The following tests were done on each patient:

1. Manual muscle test: Only muscles testing fair or less were used for further electrical testing.

2. Electromyography: To demonstrate presence or absence of evidence of denervation.

3. Strength-duration and strength-frequency curves: To demonstrate presence or absence of denervation, the degree of denervation, if present, and to compare the findings with EMG evidence.

A TECA constant current chronaxie meter was used. No effort at elaborate skin preparation was made, such as sandpapering or cleaning the skin with ether. The muscles tested were selected on the basis of their usefulness for hand-forearm orthoses. The muscles most frequently tested were biceps, extensor carpi radialis, extensor digitorum, flexor digitorum profundus or superficialis.

No attempt was made objectively to determine whether an electrically stimulated, paralyzed muscle is efficient enough to be of practical value; however, the clinical observations and impressions gained during the testing, regarding strength, consistency of response, and fatigue are reported.

The diagram (Table 1) shows the possible combinations of strength-frequency curves and EMG findings. Absence of denervation evidence on EMG with fairly normal strength-duration/strength-frequency curves indicate an upper motor neuron lesion. Denervation on EMG, with denervation type strength-duration/strength-frequency curves proves the lesion to be low motor neuron. EMG evidence of denervation combined with fairly normal strength-duration/strength-frequency curves indicates a mixed upper motor neuron/lower motor neuron lesion.

Chronaxies were considered normal at any value falling under 1 millisecond.

Following is the list of patients tested:

(Motor level indicates lowest spared segment.)

1. T. L.:
   Car accident 11–24–65, age 19
   Fracture-dislocation C5–6
   Motor Level: C6, biceps good plus extensor carpi radialis fair, otherwise zero
   Tested: Eleven months following injury.
2. T. M.:
   Diving accident 7–11–66, age 24
   Dislocation C4-5
   Motor Level: C4, biceps trace, otherwise zero
   Tested: Four months and ten months following injury.
3. D. B.:
   Car accident 9–4–66, age 20
   Fracture-dislocation C4-5

		ELICITED RESPONSE	
		NORMAL	DENERVATED
EMG	NO DENERVATION	UMN	–
	DENERVATION	MIXED	LMN

TABLE 1

	TOTAL	UMN	MIXED	LMN
T.L.	4	1		3
J.M.	2		1	1
D.B.	3		2	1
H.S.	3		2	1
E.B.	2	1	1	
W.H.	3		2	1
D.P.	5			5
P.C.	3	2		1
TOTAL	25	4	8	13

TABLE 2

Motor Level: C4, all zero including biceps

Tested: Three months and eight months following injury.

4. H. S.:

   Diving accident 6–10–63, age 15

   Fracture-dislocation C4-5

   Motor Level: C4, all zero including biceps

   Tested: Three years and five years following injury.

5. E. B.:

   Fell hitting forehead against table edge 9–2–66, age 48

   No bone injury demonstrated

   Cord injury C4 level

   Motor Level: C4-5, biceps poor minus, otherwise zero

6. W. H.:

   Diving accident 6–6–61, age 15

   Fracture-dislocation C5-6

   Motor Level: C5, biceps good minus, otherwise zero

   Tested: Six years following injury.

7. D. P.:

   Assaulted 12–10–67, age 44

   Fracture-dislocation C6–7

   Motor Level: C7-8, biceps normal, triceps trace extensor carpi radialis good, flexor carpi ulnaris trace otherwise zero

   Tested: Three months following injury.

8. P. C.:

   Car accident 5–22–65, age 22

   Fracture-dislocation C5-6

   Motor Level: C6, biceps normal, extensor carpi radialis fair minus, otherwise zero

   Tested: Three years following injury.

FINDINGS

Table 2 shows the statistical distribution of the upper motor neuron, mixed, and lower motor neuron lesions. In the total of 25 muscles tested 4 were upper motor neuron lesions, 8 were mixed lesions, and 13 were lower motor neuron lesions.

The chronaxie values are shown in Table 3. They fall in line with the appearance of the curves and the classification of the muscles, with two exceptions: 1) one high chronaxie in a mixed muscle and 2) too low chronaxie values in lower motor neurons muscles.

The strength-duration and strength-frequency curves are clear cut and consistent on repeated testing, immediately and at a later date. There are only a few areas really suggestive of a "kink" in the strength-duration curves; these are disregarded since these muscles are not reinnervating and the "kinks" are probably artefacts.

The motor points more or less coincided with those given in motor point charts, but this was not entirely consistent. Motor points were usually quite critical and a matter of a few millimeters. Spill-over to other muscles was often

	TOTAL	U M N	MIXED	L M N
T.L.	4	0.4		40.0
				50.0
				50.0
J.M.	2		0.14	10.5
	2		1.8	?
D.B.	3		0.23	?
			0.17	
	3		0.23	1.75
			?	
H.S.	3		0.55	0.28
			?	
	3		0.25	?
			0.3	
E.B.	2	0.06	0.32	
W.H.	3		0.4	?
			0.3	
D.P.	5			8.0
				10.2
				10.0
				?
				?
P.C.	3	0 5		0.76
		0.25		

TABLE 3

	BICEPS			TRICEPS			E C R			E D C			FLEX. DIG.			F C U			1st D I		
	U	M	L	U	M	L	U	M	L	U	M	L	U	M	L	U	M	L	U	M	L
T.L.						+	+					+			+						
J.M.			+								+										
			+								+										
D.B.			+								+				+						
			+								+				+						
H.S.			+								+				+						
E.B.			+								+				+						
		+								+											
W.H.		+				+					+										
D.P.						+						+			+			+			+
P.C.									+	+			+								
		2	3			3	1		1	2	4	2	1		4			1			1

TABLE 4

pronounced. This may have been aggravated by the use of a large pad for the reference electrode. Spread along nerve trunks peripherally was present, especially in testing the biceps. It was consistently difficult to obtain good strength-duration curves in the triceps and extensor carpi radialis muscles.

Most patients had no sensation and therefore no discomfort, but those with even slight sensory return complained of pain or at least discomfort, especially with increasing current. For instance, D. P. was unable to tolerate strength-frequency curve testing in the finger flexors and first dorsal interosseus. In this case there was minimal muscle reaction in the comfortable range of current, but considerable discomfort with currents capable of eliciting satisfactory contraction. Skin reddening occurred regularly in the vicinity of the motor point, especially after long testing due to difficulty with the motor point.

Table 4 shows the distribution of the lesions in the different muscles. Those muscles most useful for clinical use in orthoses, using electrical stimulation, such as biceps, finger flexors and finger extensors, were heavily mixed, or lower motor neuron lesions. It was observed that near normal chronaxia values and good strength-duration curves did not necessarily mean that the muscles were clinically useful for electrical stimulation. Many such mixed muscles showed poor muscle bulk, strength, endurance or excursion. Fatique occurred, particularly in muscles with poor response on prolonged testing.

CONCLUSION

Lower motor neuron muscles cannot be electrically stimulated to orthotically useful function in this series of patients. Upper motor neuron muscles react easily to electrical stimulation, but are relatively rare in traumatic quadriplegia. Some mixed muscles show fairly good strength-duration curves, sometimes almost approaching upper motor neuron muscles in their reaction. Most others are closer to a lower motor neuron muscle in their reaction. Some show relatively high chronaxie values in spite of good shape of the curve, suggesting high current requirements, possibly leading to pain and/or burns, if functional contraction levels are to be reached.

These findings strongly suggest that electrical stimulation will not form a suitable source of driving power for the paralyzed muscles of quadriplegics in general. Isolated instances of specific, stimulatable muscles may occur, but practical use of electrical stimulation in multi-joint systems seems impossible. Work on the serial stimulation of denervating muscle, beginning immediately after injury, should be pursued to see if this apparently impossible situation can be changed by stimulation therapy.

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