RESTORATION OF ELBOW EXTENSION VIA FES IN INDIVIDUALS WITH TETRAPLEGIA

W.D. Memberg and P.E. Crago
Louis B. Stokes VA Medical Center & Case Western Reserve University, Cleveland, OH

Abstract

Functional electrical stimulation of the triceps is a method of restoring elbow extension to individuals with a paralyzed triceps. Activation of the stimulation is achieved either as part of a pre-programmed hand grasp pattern, or via a switch connected to an augmented external controller. Stimulated elbow extension moments in ten arms ranged from 0.5 to 13.3 N•m. Stimulation of the long head of the triceps should be avoided in persons with weak shoulder abduction, since shoulder adduction can be coupled to elbow extension in these cases. Elbow extension neuroprostheses provide statistically significant increases in the ability to successfully reach and move an object, and significantly decrease the time required to acquire an object while reaching.

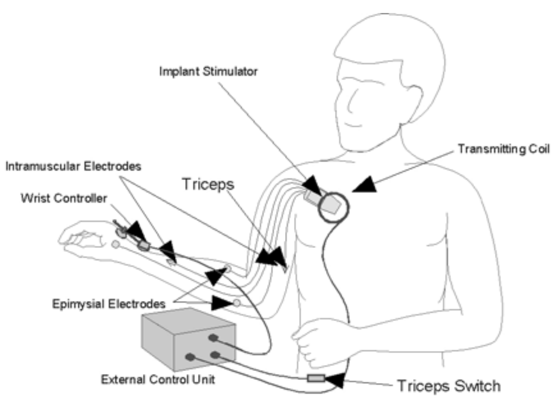

Figure 1. Augmented hand neuroprosthesis.

Introduction/Background

Individuals with tetraplegia at the C5 or C6 level typically have a paralyzed triceps muscle, preventing voluntary elbow extension. This limits their ability to reach overhead or push objects away, reducing their functional workspace. Tendon transfers, orthoses, and FES are interventions that have been used to address this problem. While tendon transfers have the advantage of being always available, they require an available voluntary muscle that has sufficient strength and requires the recipient to learn a new muscle activation pattern. Orthoses typically have poor cosmesis and difficult donning and doffing procedures. For individuals who are already receiving a hand grasp neuroprosthesis, control of elbow extension can be achieved via an incremental augmentation of the neuroprosthesis.

Methods

Elbow extension neuroprostheses [1,2] have been implemented in two ways. One method uses an augmented external controller (Fig. 1), which has a switch that allows the user to activate the triceps independent of hand grasp. When the switch is pressed, triceps stimulation ramps up to a programmed level and remains constant until the switch is pressed again. In the second method (which utilizes an unmodified external controller), the triceps electrode is programmed as part of the hand grasp stimulation pattern. The triceps remains on at a constant level throughout the grasp pattern. In both methods, control of elbow angle was attained by flexing the biceps against the stimulated triceps.

Elbow moments generated by the stimulated triceps were measured either with a custom elbow moment transducer (EMT) [3], or a six-axis force transducer. Elbow moment measurements were made at three or four elbow angles, with at least four trials done at each angle. Triceps stimulation was set to the stimulus level that was used functionally.

A potential drawback of placing an electrode on the long head of the triceps is that, since it crosses the shoulder, it can produce a shoulder adduction moment that may limit a subject's ability to reach if they have weak shoulder abductor muscles. The six-axis force transducer was used to simultaneously measure elbow and shoulder moments produced by triceps stimulation.

An assessment of the effect of triceps stimulation on the controllable workspace was performed by having individuals reach, grasp and move an instrumented 'book' from one location/orientation to another location/orientation [1]. Three near and three far locations at a standard bookshelf height were used. Trials were done with the 'book' either horizontal or vertical, and with the triceps stimulation on or off. Comparisons were made of the success rates and acquisition times with and without triceps stimulation.

Person	ASIA	Int'l. Surg. Classif.	Implant date	Function Date	Functional Duration (months)	Triceps Tendon Transfer
A	C5	O:0	10/97	1/98	36	None
G	C5	O:0	3/98	4/99	21	None
B (R)	C5	O:1	3/97	4/97	45	None
H	C5	O:1	4/00	7/00	6	Biceps
F	C6	O:1	10/98	12/98	25	Post. Delt.
E	C5	OCu:1	4/97	7/97	42	None
I	C6	O:2	8/00	12/00	1	Post. Delt.
C	C6	OCu:2	7/96	8/96	53	Post. Delt.
B (L)	C6	OCu:2	9/97	10/97	39	None
D	C6	OCu:2	9/97	12/97	37	Post. Delt.

Table 1. Arms with triceps electrodes, listed from most impaired to least impaired.

Results

Ten arms in nine neuroprosthesis users (including one bilateral user) that had a triceps electrode were evaluated (Table 1). The average stimulated elbow extension moment with the elbow at 90° for the 10 arms ranged from 0.5 to 13.3 N•m. Seven of the ten arms can extend against gravity with triceps stimulation.

Figure 2. Stimulated elbow extension moment.

Measurements of shoulder adduction moments and elbow extension moments generated during triceps stimulation were made for two of the more impaired subjects (Subjects A and G, Fig. 3). Coupled shoulder adduction was present in both subjects, although it only affected one subject (A) functionally.

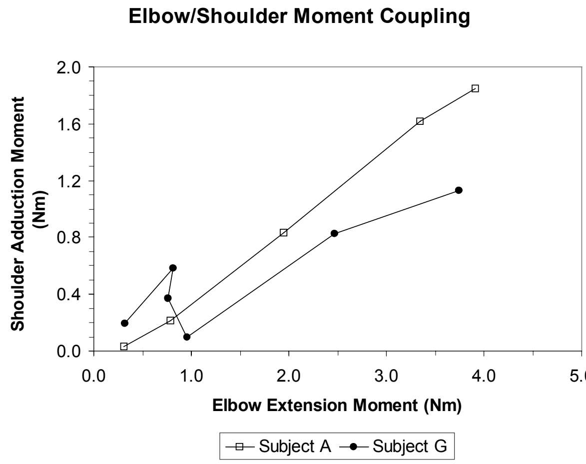

Figure 3. Coupling of elbow extension and shoulder adduction moments.

The quantitative workspace assessment was performed on five arms (Fig. 4). In all five arms, there were more successful trials with the triceps stimulation on than with the triceps stimulation off (Fig. 4a). Acquisition times with the triceps stimulation on were less than with the triceps stimulation off for four of the five arms (Fig. 4b).

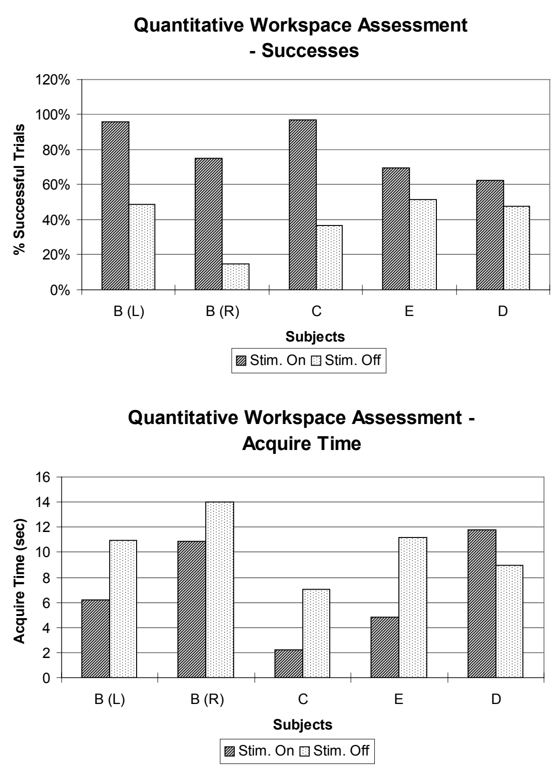

Figure 4. a) Successful completions and b) acquire times for quantitative workspace assessments.

Discussion

Stimulated elbow extension strength did not correlate with impairment level (Fig.2), possibly due to differences in denervation patterns, electrode locations and frequency of exercise. Of the 3 subjects with the least moment generated, one (H) had significant triceps denervation, one (I) was just starting his post-surgical exercise regime, and stimulation was limited in one (D) to avoid recruiting neighboring muscles.

As shown in Figure 3, triceps stimulation produced shoulder adduction moments in both individuals who had similar impairments due to higher injury levels. The subject with the higher shoulder adduction moment (subject A) was unable to oppose the adduction moment and perform functional reaching activities. The other subject (H) was able to perform functional reaching activities, but it is unclear whether that was because the shoulder adduction moment was less, or because his voluntary shoulder abductor muscles were stronger than those of subject A. Selectively stimulating the lateral or medial head of the triceps and avoiding the long head should prevent shoulder adduction in future implementations in the weak C5 tetraplegic population.

The increase in the success rate for the quantitative workspace assessment trials with the triceps stimulation on was statistically significant for each subject (chi-square test, $p<0.05$). The average acquire time with the triceps stimulation on was significantly lower in three arms [B(L),C,E] (unpaired t-test, $p<0.01$), was not significant for one arm [B(R)], and was significantly higher for one arm [D] ($p<0.05$). It is likely that the reason for the poorer performance in these last two subjects was due to a poor hand grasp, which made the acquisition task difficult. The individual with strongly coupled shoulder adduction (subject G) was unable to perform the task due to the shoulder adduction.

Conclusions

Elbow extension neuroprostheses have been successful in providing elbow extension in individuals with a paralyzed triceps, and the triceps is now a commonly used electrode site for the commercially available FreeHand™ system. A stimulated triceps increases the functional workspace and decreases object acquisition time. It has also been shown elsewhere [2] that functional task performance improves with triceps stimulation.

As shown in subjects A and D, improvements can still be made in selective stimulation of the lateral and medial heads of the triceps muscle to avoid shoulder adduction or stimulation of neighboring muscles. Methods of increasing the elbow extension moment are being investigated to assist individuals with tetraplegia in performing weight shifts and sliding transfers.

References

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