

Use of shoulder flexors to achieve isometric elbow extension in C6 tetraplegic patients during weight shift

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The anterior deltoid muscle has been found to be active during elbow extension in normal volunteers and in C6 tetraplegic patients lacking a functional triceps. Using surface electromyography (EMG) on normal volunteers and on patients with spinal cord injury (SCI) at the C6 motor level, we evaluated whether the anterior deltoid and biceps brachii muscles are active during closed chain elbow extension in a simulated weight shift position. Thirteen normal volunteers performed isometric contractions at 5 submaximal levels of force ranging from 4–25 kg. Six SCI patients performed isometric contractions at force levels of 20%, 40%, 60%, 80% and 100% maximum voluntary contraction (MVC). Surface EMG over the right biceps, triceps, and anterior deltoid muscles was recorded for each participant and the root mean square (rms) electromyographic activity level for each muscle was determined at each level of force. Statistical analyses using repeated ANOVA with Tukey HSD post-hoc tests were performed for each level of force. The results indicated increasing rms activity of the triceps and anterior deltoid muscles with increasing force in normal volunteers to a significant degree ($P < 0.05$). SCI patients showed significant increasing activity of the anterior deltoid with increasing force, but showed minimal triceps rms activity. In both groups, the biceps showed minimal rms activity. SCI patients exhibited significantly greater rms activity of the anterior deltoid at low force compared with normal volunteers. The results suggest that the anterior deltoid aids in isometric elbow extension during a simulated weight shift maneuver.

Keywords: elbow joint; electromyography; muscles; self care; tetraplegia

Introduction

A complete spinal cord injury (SCI) at the sixth cervical level (the C6 level) results in partial or complete paralysis of the elbow extensor.¹ Because the triceps is the primary elbow extensor, presence of a functional triceps is believed to be a critical determinant in the ability to perform activities of daily living such as wheelchair maneuvering and transferring.^{2–4} However, patients suffering an SCI at the C6 level are said to be able to isometrically extend their elbows in a closed kinetic chain to assist in wheelchair transfers despite having a complete lack of triceps activity.^{5,6} A closed kinetic chain is defined as a limb position such that the terminal part of the extremity meets with resistance which restrains its free motion.⁷

Investigating the activity of muscles contributing to extension of the elbow in a closed kinetic chain can

assist efforts to improve the lives of C6 tetraplegic patients. Muscles do not act as simple isolated elements, but as an integrated synergic system.^{8–10} Understanding the synergic relationships between muscles is important for evaluating the arm and shoulder muscles that can be used in elbow extension in the presence of a non-functioning triceps muscle.

Prior studies identified some shoulder muscles that are active in isometric closed chain elbow extension. Zerby *et al*¹¹ found the anterior deltoid and upper pectoralis muscles to be active during isometric elbow extension occurring during a bench press. Zerby and associates suggest that these muscles, acting as shoulder horizontal adductors,¹² contribute to isometric elbow extension. Marciello *et al*¹³ report that the same occurs in C5–C6 SCI patients who also lack a functional triceps. The purpose of this study is to demonstrate that the anterior deltoid and biceps brachii can achieve an elbow extension force during a simulated weight shift attempt. These muscles function as flexors of the shoulder² and may contribute to elbow extension in a closed kinetic chain. The same reasoning was used by Inman¹⁴ who determined by surface electromyography (EMG)

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recording of muscle activity during walking that the gluteus maximus, a hip extensor, aids in knee extension during walking.

The present study also employed surface EMG in its design. Giroux and Lamontagne¹⁵ and Turker¹⁶ pointed out that surface electrodes are sufficient for recording overall muscle activity. Yang and Winter¹⁷ demonstrated that surface EMG is a reliable indicator of isometric contractions. Root mean square (rms) of the EMG is used to quantify isometric muscle activity because it is an accurate gauge of muscle tension in the absence of muscle fatigue.^{18,19}

Method

Two groups of individuals participated in this study. The control group consisted of non-paralyzed volunteers and the SCI group consisted of patients with spinal cord injuries at the C6¹ motor level. All participants gave informed consent prior to testing. EMG activity of the right anterior deltoid, biceps brachii, and triceps muscles was measured as the participants performed isometric elbow extensions.

Control group

This group consisted of 13 normal volunteers, nine males and four females ages 19 to 43 years (mean 26 years). Each volunteer was screened to verify absence of pain in the shoulder and arm. During testing, the volunteers were seated in a wheelchair of the following dimensions: seat length, 38 cm; seat width, 44 cm; seat height, 44 cm.

Force of contraction was measured with a myometer with a range of 0–30 kg (Penny & Giles Transducer Ltd. Dorset, England). The transducer was fastened to the right side of the wheelchair in the space between the wheel and the side edge of the seat and secured in place with adhesive tape. Both wheels of the wheelchair were locked and anchored in place by binding one of its spokes to the chair's frame with adhesive tape. The transducer was oriented to measure downward force exerted by the subject (Figure 1).

SCI group

Six male patients with spinal cord lesions at the C6 level were solicited for participation in the study. Four of the six patients had previously participated in related studies by Zerby *et al.*¹¹ and Marciello *et al.*¹³ Patient ages ranged from 21 to 53 years (mean 33 years), and the time since injury ranged from 3 to 23 years (mean 10 years). Each patient received \$25 compensation, as well as free valet parking and a meal pass at the hospital cafeteria. A manual muscle test (MMT)²⁰ was performed on the following muscles: elbow flexors, elbow extensors, shoulder flexors, shoulder extensors, horizontal shoulder adductors, shoulder adductors, and wrist extensors.¹² Patients were also questioned about their levels of functional

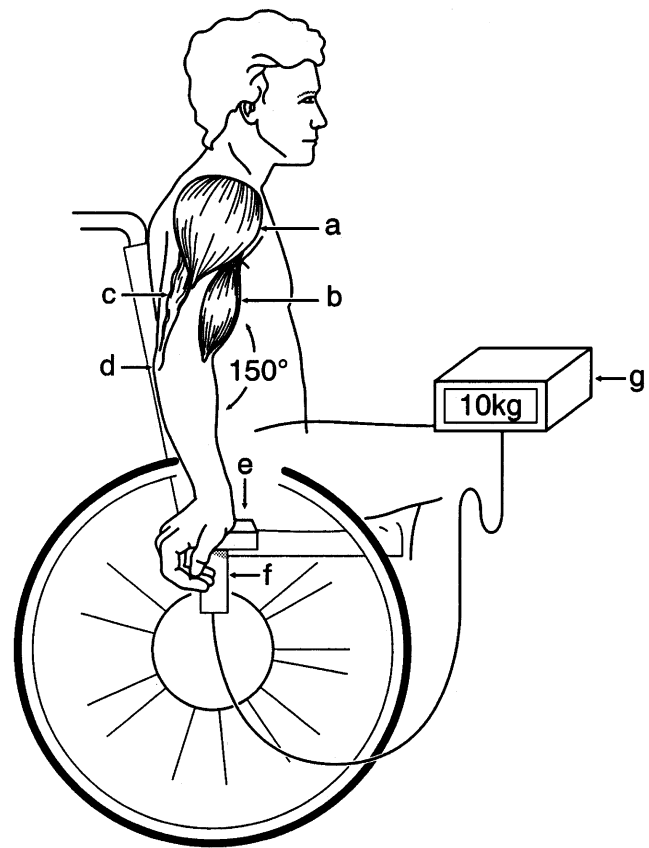


Figure 1 Position of anterior deltoid (a), biceps (b), and a weak triceps (c) are shown. Anterior deltoid contraction results in flexion of the shoulder resulting in extension force at the elbow (d) because the hand is fixed at (e). The force transducer (f) measures downward force resulting from extension of the elbow and displays a readout of the digital myometer (g)

independence using the method described by Hamilton *et al.*²¹ This method uses a seven point scale (1 = total assistance; 7 = independence) to evaluate patients' level of independence in various activities of daily living.

Patients remained seated in their own wheelchairs during EMG testing. Force of contraction was measured with a myometer and transducer identical to the ones used in the control group. The transducer was fastened beside each patient's wheelchair in a position as similar as possible to the position used in the control group. The transducer was inserted through a 4 cm hole in the end of a wooden board (58 × 6 × 2 cm). The board was clamped to a chair beside the patients' wheelchairs and brought into position.

Both groups

Figure 1 illustrates the test position for all participants. They were seated in their respective wheelchairs, with the transducer placed at the level of their ischii. When

necessary, a pillow was placed behind their backs to prevent them from sliding back in the seat. Participants were instructed to hold their right arms in the sagittal plane, with the elbow flexed at 150 degrees and the wrist supinated. Care was taken to ensure that each participant sat with an erect posture and that their arms remained in the indicated position. Upon contraction, participants pushed inferiorly with the thenar and hypothenar eminences against the transducer. This motion is designed to simulate a weight shift maneuver.

Each participant attempted a maximum voluntary contraction (MVC) during two practice contractions. Testing in the SCI group consisted of five contractions at each of five force levels: 100%, 80%, 60%, 40% and 20% MVC. Two subgroups were identified within the control group. In subgroup A ($n=6$), the volunteers reached an MVC between 20–25 kg. This subgroup was instructed to perform contractions with force levels of 20, 16, 12, 8 and 4 kg. In subgroup B ($n=7$), the volunteers reached an MVC greater than 25 kg and were instructed to perform contractions with force levels of 25, 20, 15, 10 and 5 kg. Table 1 summarizes the tested force levels for all groups. Participants watched the digital readout of the myometer in order to achieve the required force level. A 1–2 min rest period was provided between contractions. A 500 msec period of EMG for each trial at the desired force level was isolated for analysis.

An electromyographic record of muscle activity for each participant was made using a bipolar bar electrode with 10 mm discs and 20 mm inter-electrode distance. A 750 mm lead and 2 mm plug were used for signal detection (Teca). Surface electrodes were chosen because they are less invasive than wire electrodes and would not deter potential study participants.¹¹ Conductivity gel was used on the electrode leads (Graphic Controls, Buffalo NY, #10-008). EMG signals in the 20–500 Hz bandwidth¹⁶ were amplified and monitored on a Nicolet Viking device equipped to convert raw EMG activity to root mean square (rms). (Nicolet Biomedical Instruments, Madison WI, 1989, #870254).

The participants' skin over the right anterior deltoid, biceps brachii, and triceps muscles was cleansed with alcohol. Electrode contacts were cleansed with alcohol and covered with conducting gel before being attached to the skin with plastic surgical tape. Right side muscles were chosen to minimize effects of cardiac electrical activity.¹¹ For measuring shoulder flexors, the active recording electrode was placed over the acromioclavicular joint. For measuring elbow extensors, the active recording electrode was placed over the lateral head of the triceps muscle, midway between the acromion and the olecranon. For measuring elbow flexors, the active recording electrode was placed on the most prominent aspect of the belly of the biceps muscle. Reference electrodes were placed 20 mm distal to the recording

Table 1 Individual forces of contraction (kg) for each force level

Force level:	1	2	3	4	5	
Normal subgroup A ($n=6$)	4	8	12	16	20	
Normal subgroup B ($n=7$)	5	10	15	20	25	
SCI patients	1:	1	2	3	4	5
	2:	1	2	4	6	8
	3:	1	2	4	6	8
	4:	2	4	6	8	10
	5:	2	4	6	8	10
	6:	1	2	4	5	6

Subgroup A = normal volunteers with MVC of between 20–25 kg. Subgroup B = normal volunteers with MVC of greater than 25 kg. Force levels 1–4 represent 20%, 40%, 60% and 80% respectively of force level 5

electrode and in line with the direction of the muscle fibers. The ground electrode was placed just proximal to the antecubital fossa over the biceps tendon.

Data analysis

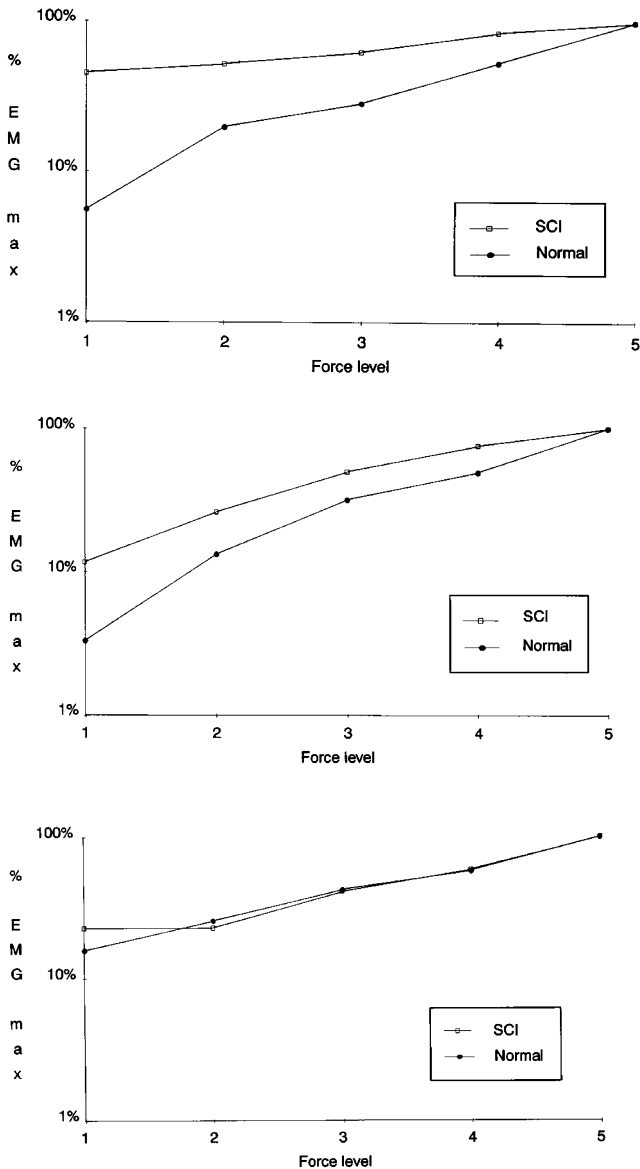
The mean rms electrical activity for each 500 msec period was computed by the Nicolet Viking. Five trials were performed for each of five force levels, totalling 25 trials per muscle. Similar trials were repeated for each of the three muscles tested. Mean rms values were computed for each participant at every level of force. For each muscle tested, the mean rms at each force level was normalized by expressing it as a percentage of the mean rms at the highest force level. We refer to this ratio as %EMGmax. Note that the highest force level used for computing %EMGmax is not identical to the MVC in the control group. The mean %EMGmax value was calculated and one standard deviation of these values was obtained in both the control and SCI groups. The %EMGmax values for each muscle were plotted and are shown in Figures 2–4. Because the relationship between %EMGmax and force level is exponential, the %EMGmax values are expressed on a logarithmic scale.

Results

Electromyographic testing

The triceps and anterior deltoid muscles showed steady and significant ($P<0.05$) increases in mean rms (Table 2) and %EMGmax (Figures 2 and 3) as the applied force increased, in both the control and SCI groups. Results obtained at all five force levels were found to be significantly ($P<0.05$) different from each other for mean %EMGmax.

In addition, the biceps muscle in both groups also showed steady and significant ($P<0.05$) increases in mean rms (Table 2) and %EMGmax (Figure 4) with increasing force in both groups. For most participants,



Figures 2–4 %EMGmax vs force level for triceps (Figure 2–top), anterior deltoid (Figure 3–middle), and biceps (Figure 4–bottom). Y-axis is on a logarithmic scale. %EMGmax is the mean rms at each force level, expressed as a percentage of the mean rms at the highest force level (level 5). Increases are significant ($P < 0.05$) in the three muscles tested

however, the rms values for the biceps muscle were considerably lower than the values for the deltoid and triceps muscles at equivalent forces (Table 2).

Manual muscle testing (SCI group)

All patients demonstrated normal (grade 5) elbow flexors. Grades for the shoulder flexors, shoulder abductors, shoulder adductors, shoulder extensors, wrist extensors and elbow extensors ranged from 4–5. Grades for elbow extensors ranged from 0–1.

Table 2 Mean rms values for each force level

Force level:	1	2	3	4	5
Normal subgroup A					
BI:	10	34	71	106	161
TR:	21	108	113	231	427
AD:	5	33	88	149	442
Normal subgroup B					
BI:	42	67	72	90	169
TR:	16	47	88	125	211
AD:	8	51	119	180	354
SCI group					
BI:	7	6	14	20	38
TR:	15	36	39	44	49
AD:	35	119	214	311	417

BI=biceps; TR=triceps; AD=anterior deltoid. RMS=root mean square (microvolts) of the amplitude of electromyographic activity

Functional independence measures (SCI group)

Most patients reported independence with the activities of daily living of eating, grooming, bathing upper body and dressing upper body. However, all patients reported requiring varying degrees of assistance in wheelchair transferring, bathing lower body and dressing lower body.

Discussion

The data show that the anterior deltoid muscle is active in extension of the elbow in a closed kinetic chain. The significantly increasing rms amplitude of the anterior deltoid with increasing force in both the control group and the SCI group (Figure 3) provide evidence not only that the anterior deltoid is active during elbow extension, but also that it can exert increasing force on demand. As expected the triceps muscle was active during elbow extension in control group members but only minimally so in SCI patients (Table 2). These findings are consistent with those of Zerby *et al*¹¹ who reported that the anterior deltoid was active during elbow extension in normal people while performing a bench press. The findings also confirm those of Marciello *et al*¹³ who reported the same to be true for spinal cord injured patients.

The anterior deltoid's ability to create an extension force is dependent upon the closed kinetic chain in which it operates. With the hand restrained against a stationary support (the force transducer and wheelchair frame), contraction of the shoulder flexor cannot result in free movement of the arm (Figure 1). Instead, the hand remains in position while the humerus moves forward, resulting in extension at the elbow joint. This is the mechanism that allows the anterior deltoid to produce the isometric extension force recorded in the SCI patients in this study.

Initially we hypothesized that the biceps brachii, also a shoulder flexor, contributes to elbow extension in a similar fashion, but our results did not support

this hypothesis. Presumably, this negative response occurs because the biceps acts principally as an elbow flexor and thus cannot function as an elbow extensor.

A possible explanation for the small amount of biceps activity recorded in the study (Table 2) is that while participants did in fact produce slight contractions in their biceps muscles during isometric extensions, the biceps participated as an antagonist to elbow extension. If this explanation is correct, the biceps would modulate the extension force produced by the anterior deltoid and triceps muscles by creating a force in the opposite direction. Gordon and Ghez²² showed that both the biceps and triceps muscles activate to modulate force during isometric contractions at the elbow joint. It is possible that, despite our efforts in this study to isolate activity only during pure extension, participants were continuously adjusting the extension force by contracting both their agonist and antagonist muscles. Supporting this possibility is the particularly small biceps rms in the SCI group, since the relatively weak extension force produced by this group would minimize the need for opposing involvement by the biceps.

Other muscles such as the latissimus dorsi and pectoralis may have been active in our contraction study. These muscles could be the focus of future investigations of muscle synergy.

Sources of error

We recognized that our use of surface electrodes introduces a potential source of error into the experiments. Crosstalk, or electrical activity recorded from muscles not directly targeted under the surface electrode,¹⁶ was a concern. A significant amount of the activity we recorded on the EMGs, particularly over relatively inactive muscles, may have been due to conduction of electrical activity from other muscles. For example much of the EMG recorded over the biceps muscle in our experiment may have been crosstalk from the anterior deltoid or triceps. In addition, some of the deeper muscles of the arm, such as the coracobrachialis which acts as a shoulder flexor,² were probably active during contractions, thus contributing to the surface recordings. Additional studies using double-differential or branched-electrode techniques of surface EMG recording^{16,23} would be required to affirm or deny these potential sources of error.

Another possible source of error in our experiment may have been muscular fatigue in the participants. Because rms increases with fatigue,¹⁹ the recordings of muscle contractions made during the later stages of the experiment may have been exaggerated because of increasing muscle fatigue.

Another consideration is that while the force measurement in the control group could easily be related to the triceps muscle, some of the force in the SCI group could have been related to patients' weight leaning on the extended arm on the transducer. We feel this component was minimized by keeping the

arm at a 150° angle, forcing the contracting muscles to support the weight. Nonetheless, the weight of the arm itself resting on the transducer probably contributed to the force measurement, especially in the SCI group.

Theoretical considerations

The synergic mechanisms controlling muscle activity studied in this report have emerged in recent years to be much less straightforward than was once believed. Buchanan²⁴ suggests that multi-articular muscles are so complex that only one optimal pattern of recruitment exists that provides maximum force yet requires minimal energy expenditure and tissue strain. Karst and Hasan²⁵ propose that the muscle activation patterns can be predicted using only a few simple variables, such as initial and final joint angles for a given movement.

Other investigators describe the motor system as being divided into discrete groups of task-oriented motor units that are optimized for specific actions.^{9,10,26} The motor system would then tailor the recruitment of different motor units to the task at hand. If this is true, muscle activation patterns could extend to a much more intricate level than the whole-muscle activity recorded in this study.

In regard to SCI patients, the question arises as to whether the mechanisms controlling muscle synergy are altered in any way following loss of control of certain muscles. Neural plasticity, or the ability of the nervous system to adopt to a changing environment,²⁷ has been examined in SCI patients²⁸⁻³⁰ and amputees.³¹ The investigators have found enlarged cortical maps of motor output and greater excitability of motor pathways to muscles rostral to the level of injury. It is not as yet clear how this motor reorganization occurs or even whether it occurs at cortical and/or subcortical levels. It seems logical to assume, however, that the observed changes in these patients reflect an ability for the CNS to modify its control of muscle synergies to compensate for lost muscle function.

An example of this sort of modification in muscle synergy may have occurred in our study when we found that SCI patients had greater activity of the anterior deltoid muscle than did normal controls at low elbow extension force. This difference may be explained by the observation that normal people, who are able to involve their triceps in the contraction, can distribute the contraction load among the participating muscles in such a way as to rely more heavily on the triceps muscle at lower forces. As the force of contraction increases, the load could be redistributed to allow the shoulder flexors to take on a greater share of the total force. SCI patients, who are unable to use their triceps, compensate by activating the shoulder flexors at all force levels. The result is a disproportionately larger participation of the shoulder flexor muscles at low force levels in the SCI group.

The SCI patients in this study reported varying degrees of functional independence despite having similar MMT scores. A possible factor is that patients with greater functional capacity are those who have been able to train their synergic muscles to compensate for the loss of triceps control. A better understanding of this compensatory mechanism could help caretakers harness the natural plasticity of the nervous system more effectively. This would allow enhanced training and strengthening of compensatory muscles in spinal cord injured patients, with an ultimate improvement in their functional abilities.

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