Biceps Brachii Long Head Overactivity Associated with Elbow Flexion Contracture in Brachial Plexus Birth Palsy

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Background: The etiology of elbow flexion contracture in children with brachial plexus birth palsy remains unclear. We hypothesized that the long head of the biceps brachii muscle assists with shoulder stabilization in children with brachial plexus birth palsy and that overactivity of the long head during elbow and shoulder activity is associated with an elbow flexion contracture.

Methods: Twenty-one patients with brachial plexus birth palsy-associated elbow flexion contracture underwent testing with surface electromyography. Twelve patients underwent repeat testing with fine-wire electromyography. Surface electrodes were placed on the muscle belly, and fine-wire electrodes were inserted bilaterally into the long and short heads of the biceps brachii. Patients were asked to perform four upper extremity tasks: elbow flexion-extension, hand to head, high reach, and overhead ball throw. The mean duration of muscle activity in the affected limb was compared with that in the contralateral, unaffected limb, which was used as a control. Three-dimensional motion analysis, surface dynamometry, and validated function measures were used to evaluate upper extremity kinematics, elbow flexor-extensor muscle imbalance, and function.

Results: The mean activity duration of the long head of the biceps brachii muscle was significantly higher in the affected limb as compared with the contralateral, unaffected limb during hand-to-head tasks ($p = 0.02$) and high-reach tasks ($p = 0.03$). No significant differences in mean activity duration were observed for the short head of the biceps brachii muscle between the affected and unaffected limbs. Isometric strength of elbow flexion was not significantly higher than that of elbow extension in the affected limb ($p = 0.11$).

Conclusions: Overactivity of the long head of the biceps brachii muscle is associated with and may contribute to the development of elbow flexion contracture in children with brachial plexus birth palsy. Elbow flexion contracture may not be associated with an elbow flexor-extensor muscle imbalance, as previously hypothesized. The negative impact of elbow flexion contracture on upper extremity function warrants future research in the development of preventive and therapeutic techniques to address elbow flexion contractures in children with brachial plexus birth palsy.

Level of Evidence: Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

The incidence of brachial plexus birth palsy is 0.38 to 4.6 per 1000 live births¹⁻⁵. Although the majority of affected infants recover spontaneously, as many as 34% experience long-term sequelae, including skeletal deformities and soft-tissue contractures⁶. Elbow flexion contracture is a well-recognized complication of brachial plexus birth palsy that can impair upper extremity function.

In a previous study of 319 children with brachial plexus birth palsy, 48% of the patients had an elbow flexion contracture of $\geq 10^\circ$, with more than one-third of these patients having a contracture of $\geq 30^\circ$ ⁷. Despite this high prevalence of elbow flexion contracture in children with brachial plexus birth palsy, the etiology remains unclear. In 1994, Ballinger and Hoffer suggested that elbow contracture may result from elbow flexor

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function returning first and dominating extensor function⁸. Sibinski et al. later proposed that contracture could result from a muscle imbalance between stronger elbow flexors and weaker elbow extensors or a misdirection of regenerating neurons, causing cross-innervation and co-contraction of synergistic and antagonistic muscles⁹. Most recently, Nikolaou et al. studied brachial plexus birth palsy in a mouse model and proposed that elbow flexion contracture is due to impaired growth of denervated muscles¹⁰. Decreased volume and thickness of shoulder musculature also have been reported in magnetic resonance imaging (MRI) studies of children with brachial plexus birth palsy¹¹.

We propose a novel hypothesis based on our understanding of the adverse effects of brachial plexus birth palsy on the shoulder. Muscle weakness about the shoulder is a well-recognized finding in patients with brachial plexus birth palsy. Previous studies have demonstrated evidence of atrophy and fatty degeneration of the supraspinatus, infraspinatus, subscapularis, and deltoid muscles on MRI^{12,13}. Partial paralysis of the muscles about the shoulder results in glenohumeral deformity, including glenoid hypoplasia, flattening of the humeral head, and posterior glenohumeral subluxation¹⁴⁻¹⁷. Previous studies have shown that the long head of the biceps brachii muscle plays a role as a shoulder flexor and humeral head stabilizer and may compensate for glenohumeral instability in athletes¹⁸⁻²¹. It also has been hypothesized that overactivity of unaffected or mildly affected muscle groups may lead to a flexion contracture in patients with poliomyelitis^{22,23}. We propose that the long head of the biceps brachii muscle, which crosses the glenohumeral joint anteriorly, helps to stabilize the shoulder in children with brachial plexus birth palsy-associated weakness of shoulder rotators and abductors. Because contraction of the long head of the biceps brachii muscle also flexes the elbow, overuse of this muscle as a shoulder flexor may contribute to associated elbow flexion contractures.

The purpose of the present study was to compare the mean activity duration of the long and short heads of the biceps brachii muscle in the affected limb with that in the unaffected limb of children with brachial plexus birth palsy-associated elbow flexion contracture as they performed standardized upper extremity tasks. Additionally, we tested the alternate hypothesis that elbow flexion contracture is due to an elbow flexor-extensor muscle imbalance by measuring isometric muscle strength with surface dynamometry. Finally, we studied the impact of elbow flexion contracture on upper extremity function with use of three-dimensional motion analysis and three validated function measures.

Materials and Methods

Participants

Patients older than five years of age who were seen at our institution for brachial plexus birth palsy and who had a documented elbow flexion contracture of $\geq 10^\circ$ were recruited in outpatient clinics or by telephone for participation in the present study. A sample size calculation based on previous research predicted that a minimum of ten patients would be needed to detect a mean difference of 18% in muscle activity duration, assuming a power of 90% (two-tailed, $\alpha = 0.05$)²⁴.

Twenty-one patients with a median age of 14.2 years (range, 6.3 to 18.8 years) participated in the present study. The left limb was affected in 62% of the

patients, and 62% of the patients were female. The degree of elbow flexion contracture ranged from 10° to 60° . Sixteen patients had undergone prior surgery for the treatment of brachial plexus birth palsy: thirteen had had external rotation tendon transfer, one had had nerve exploration and grafting, one had had external rotation osteotomy, and one had had trapezius-to-deltoid transfer. The demographic characteristics of the patient population are shown in the Appendix^{25,26}. All testing was performed at Shriners Hospital for Children, Northern California, and the protocol was approved by our institutional review board.

Electromyography

Dynamic electromyography (EMG) (MA300 EMG System; Motion Lab Systems, Baton Rouge, Louisiana) was used to record biceps brachii muscle activity during four upper extremity tasks: elbow flexion-extension, hand to head, high reach, and overhead ball throw. All twenty-one patients underwent dynamic testing with surface EMG. After the skin was thoroughly cleaned to reduce resistance, a bipolar surface electrode was placed on the biceps brachii muscle belly bilaterally, as described in the *Manual of Surface Electromyography*²⁷. Surface EMG does not distinguish activity of the long head of the biceps brachii muscle from activity of the short head. A bipolar surface electrode also was placed on the triceps brachii muscle belly bilaterally to evaluate for co-contraction of the biceps and triceps muscles.

Twelve patients underwent repeat dynamic testing with fine-wire EMG. Pairs of nylon-coated wires were inserted bilaterally into the long and short heads of the biceps brachii muscle with a 25-gauge needle with use of sterile technique²⁸. The electrodes were secured by ranging the elbow through full passive and resisted motion, and electrode placement was confirmed by palpating the muscle belly during mild electrical stimulation. Data were missing for four fine-wire measurements (for one unaffected long head, one affected short head, and two unaffected short heads) because of wire dislodgement or because the patient opted not to test because of discomfort. Thus, data on the long head of the biceps brachii muscle were included for the affected limb in twelve patients and for the unaffected limb in eleven patients. Data on the short head of the biceps brachii muscle were included for the affected limb in eleven patients and for the unaffected limb in ten patients.

EMG data were sampled at a rate of 2400 Hz, high-pass filtered (150 Hz, twentieth-order Butterworth), full-wave rectified, and normalized to the highest one second of activity during a maximum voluntary contraction. EMG activity for $>5\%$ of maximum voluntary contraction for at least 5% of the duration of the upper extremity task was considered to be related to muscle contraction²⁴. Synchronization of EMG with three-dimensional motion analysis was used to determine the start and stop times of upper extremity tasks. EMG signal quality was reviewed throughout testing to verify proper settings and electrode placement. All post-collection data processing was performed with use of MATLAB 7.8 (The MathWorks, Natick, Massachusetts).

The mean duration of muscle activity (expressed as the percentage of the task cycle) was calculated for the biceps brachii muscle belly (surface EMG), triceps brachii muscle belly (surface EMG), and biceps brachii long and short heads (fine-wire EMG) over three trials of each upper extremity task. The mean duration of muscle activity also was calculated before and after the point of task achievement, defined as the instant the task was achieved, for the long and short heads of the biceps brachii. For the elbow flexion-extension task, the point of task achievement was the point of maximum elbow flexion; for the hand-to-head task, it was the point at which the hand made contact with the head; for the high-reach task, it was the point of maximum elbow extension with the hand overhead; and for the overhead-ball-throw task, it was the point of terminal elbow flexion before ball release. The paired t test was used to compare mean muscle activity duration in the affected limb with that in the contralateral, unaffected (control) limb. A linear regression model was used to evaluate the effect of the degree of elbow flexion contracture on muscle-firing duration.

Kinematics

Eighteen light-reflective markers were placed on osseous landmarks of the upper extremity and trunk with a previously described method²⁹. Upper extremity

TABLE I Duration of Muscle Activity as a Percentage of the Task Cycle*

	Elbow Flexion-Extension		Hand to Head		High Reach		Overhead Ball Throw	
	Affected	Unaffected	Affected	Unaffected	Affected	Unaffected	Affected	Unaffected
Biceps brachii muscle belly	97.4 ± 1.4	90.2 ± 3.8	94.6 ± 1.2	90.3 ± 3.7	92.2 ± 2.5	89.3 ± 3.8	95.5 ± 1.5	91.3 ± 3.2
Biceps brachii long head	82.8 ± 4.9	77.5 ± 6.9	87.3 ± 3.8	68.1 ± 6.8†	78.6 ± 6.3	52.1 ± 9.4†	83.0 ± 5.1	68.9 ± 7.3
Biceps brachii short head	80.4 ± 5.3	77.5 ± 9.4	77.3 ± 6.4	82.0 ± 7.3	70.5 ± 8.4	66.9 ± 12.1	77.2 ± 5.1	83.4 ± 6.1
Triceps brachii muscle belly	94.2 ± 3.7	89.9 ± 5.5	92.9 ± 4.3	88.2 ± 6.0	96.8 ± 1.8	96.2 ± 2.2	97.6 ± 1.2	95.4 ± 2.4

*The values are given as the mean and the standard error and are expressed as the percentage of the task cycle. †Significantly different from value on the affected side ($p < 0.05$).

kinematic data were recorded with an eight-camera, three-dimensional motion-analysis system (Motion Analysis, Santa Rosa, California). Participants performed three trials of each upper extremity task. Marker position data were used to generate segment orientations and joint locations for use in the upper extremity biomechanical model³⁰. Trials were averaged for each participant to obtain mean shoulder and elbow flexion-extension joint curves for each task. The contralateral, unaffected limb served as a control³¹. A paired t test was used to compare the affected and unaffected limbs with regard to range of motion and joint position at the point of task achievement.

Surface Dynamometry

A handheld dynamometer (JTech PowerTrack II Commander; JTECH Medical, Salt Lake City, Utah) was used to quantify the bilateral isometric strength of the elbow flexor and extensor muscles. Before testing, patients were given a brief explanation of the procedure and then were placed in a seated position with the arm held in 90° of elbow flexion. The force of maximum voluntary effort was measured over five seconds of isometric elbow flexion and extension. Mea-

surements were averaged over three trials and were normalized to body weight to account for variability in patient age and size³². A paired t test was used to compare the affected and unaffected limbs with regard to the isometric strength of elbow flexion and extension.

Upper Extremity Function Assessment

Three well-validated outcome instruments were used to evaluate upper extremity function: the Pediatric Outcomes Data Collection Instrument (PODCI), the Liverpool Elbow Score (LES), and the Mayo Elbow Performance Score (MEPS). The PODCI is a questionnaire that is composed of six validated domains to assess function: upper extremity physical function, transfers and basic mobility, sports and physical function, pain and comfort, happiness, and global function. Outcome scores range from 0 to 100 points, with scores above the mid-80s representing normal function^{33,34}. Patient self-reported scores on the PODCI were compared with parent/guardian proxy reports with use of a paired t test, as previously described³⁵. The LES is an elbow-specific assessment tool that consists of a six-item clinical

TABLE II Kinematics of Upper Extremity Tasks*

Task	Shoulder Flexion		Elbow Flexion-Extension	
	Affected	Unaffected	Affected	Unaffected
Elbow flexion-extension				
Range of motion	54 ± 26	36 ± 20†	95 ± 14	129 ± 7‡
Position at point of task achievement	44 ± 24	20 ± 17§	122 ± 14	134 ± 5§
Hand to head				
Range of motion	84 ± 26	77 ± 16	77 ± 14	112 ± 9§
Position at point of task achievement	76 ± 30	61 ± 12‡	104 ± 11	118 ± 8§
High reach				
Range of motion	104 ± 34	153 ± 17§	41 ± 29	44 ± 29
Position at point of task achievement	89 ± 40	123 ± 36†	58 ± 35	27 ± 13§
Overhead ball throw				
Range of motion	105 ± 34	120 ± 16‡	73 ± 19	93 ± 17§
Position at point of task achievement	97 ± 38	110 ± 23	100 ± 19	95 ± 21

*Values are given as the mean and the standard deviation and are expressed in degrees. † $P < 0.01$ in comparison with the affected side. ‡ $P < 0.05$ in comparison with the affected side. § $P < 0.001$ in comparison with the affected side.

Fig. 1-A

Fig. 1-B

Fig. 1-C

Fig. 1-D

Bar graphs showing the duration of muscle activity (expressed as a percentage of the task cycle) for the biceps brachii muscle belly (**Fig. 1-A**), the triceps brachii muscle belly (**Fig. 1-B**), the biceps brachii long head (**Fig. 1-C**), and the biceps brachii short head (**Fig. 1-D**) during four upper extremity tasks. The values are given as the mean and one standard error.

assessment score (flexion, extension, pronation, supination, strength, and ulnar nerve disturbance) and a nine-item, patient-answered questionnaire. All responses are transformed to a scale of 0 (worst) to 10 points (best)³⁶. The MEPS is a four-item (pain, range of motion, stability, and function), elbow-specific score; with this system, elbow function is classified as excellent (90 to 100 points), good (75 to 89 points), fair (60 to 74 points), or poor (<60 points)³⁷.

Radiographic Assessment

Anteroposterior and lateral radiographs of the elbow and anteroposterior and axillary radiographs of the shoulder were used to evaluate osseous structures. For two patients, only radiographs of the elbow were made. Radiographs were interpreted by a musculoskeletal radiologist.

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Results

Electromyography

The mean duration of activity of the long head of the biceps brachii muscle was significantly higher in the affected limb as compared with the contralateral, unaffected limb during the hand-to-head task ($p = 0.02$) and the high-reach task ($p = 0.03$). No significant differences were noted in the mean duration of activity of the short head of the biceps brachii muscle.

Higher durations of biceps brachii and triceps brachii muscle belly activity were observed in the affected limb as compared with the unaffected limb for all upper extremity tasks, but these differences were not significant (Table I, Figs. 1-A through 1-D). The increased duration of biceps brachii muscle and long head activity in the affected limb was not observed in all patients, but the durations were, on the average, higher than those for the unaffected limb for all upper extremity tasks. The degree of elbow flexion contracture had no significant effect on the duration of activity of the long head of the biceps brachii muscle in the affected limb compared with the unaffected limb. Eight of the twelve patients with fine-wire EMG testing had an internal rotation contracture of the shoulder. No significant differences were observed between the affected limb and the unaffected limb with regard to the duration of firing of the long head of the biceps brachii muscle in patients with an internal rotation contracture.

Before the point of task achievement, the duration of activity of the long head of the biceps brachii muscle was significantly higher in the affected limb during high-reach ($p < 0.01$) and overhead-ball-throw ($p < 0.05$) tasks. After the point of task achievement, the duration of activity of the long head of the biceps brachii muscle was significantly higher in the affected limb for the hand-to-head task ($p < 0.05$) (Fig. 2-A). No significant differences were noted in the mean duration of

TABLE III Normalized Force of Elbow Flexion and Extension*

	Affected	Unaffected	P Value
Elbow flexion	1.82 ± 0.5	2.86 ± 1.1	<0.001
Elbow extension	1.66 ± 0.6	2.45 ± 0.8	<0.001
P value	0.11	0.02	

*The values are given as the mean and the standard deviation and are unitless because they measure force (kg) normalized to patient weight (kg) to account for variability in patient age and size.

activity of the short head of the biceps brachii muscle before or after the point of task achievement (Fig. 2-B).

Kinematics

During the elbow flexion-extension and hand-to-head tasks, shoulder motion and shoulder joint position at the point of

task achievement were higher in the affected limb, whereas elbow motion and elbow joint position at the point of task achievement were lower in the affected limb. All differences in mean measurements were significant, with the exception of shoulder motion for the hand-to-head task (Table II, Fig. 3).

During the high-reach and overhead-ball-throw tasks, shoulder and elbow motion were higher in the unaffected limb. Shoulder joint position at the point of task achievement was higher in the unaffected limb, whereas elbow joint position at the point of task achievement was higher in the affected limb. No significant differences were observed for elbow motion during the high-reach task or for shoulder or elbow joint position at the point of task achievement during the overhead-ball-throw task. All other differences were significant (Table II, Fig. 3).

Surface Dynamometry

The isometric strength of muscles for elbow flexion and elbow extension was significantly greater in the unaffected limb than in

Fig. 2-A

Fig. 2-B

Bar graphs showing the duration of muscle activity (expressed as a percentage of the task cycle) for the biceps brachii long head (Fig. 2-A) and the biceps brachii short head (Fig. 2-B) before and after the point of task achievement (PTA) during four upper extremity tasks. The values are given as the mean and one standard error.

TABLE IV Function Assessment Scores *

	Self-Report	Proxy Report	P Value
Pediatric Outcomes Data Collection Instrument			
Upper extremity physical function	76.8 ± 4.2	68.7 ± 5.0	0.02
Transfers/basic mobility	97.7 ± 0.8	97.2 ± 0.8	0.68
Sports/physical function	93.7 ± 1.8	91.1 ± 1.7	0.07
Pain/comfort	85.9 ± 3.9	85.4 ± 4.8	0.66
Happiness	79.1 ± 4.4	82.8 ± 2.9	0.71
Global function	88.5 ± 2.0	85.6 ± 2.1	<0.01
Liverpool Elbow Score	6.4 ± 0.3		
Mayo Elbow Performance Score	82.9 ± 3.2		

*The values are given as the mean and standard error and are expressed in points.

the affected limb ($p < 0.001$). No significant difference was observed between the strength of elbow flexion and the strength of elbow extension in the affected limb ($p = 0.11$) (Table III).

Upper Extremity Function Assessment

On the PODCI, patients reported a below-normal mean upper extremity physical function score of 76.8 points. The parents of the patients underestimated the self-reported scores of upper extremity physical function ($p = 0.02$) and global function ($p < 0.01$). The mean LES was 6.4 points (on a scale of 0 to 10 points), and the MEPS was within the “good” range of function at 82.9 points (Table IV).

Radiographic Assessment

Of the nineteen patients with radiographs of the shoulder, sixteen had skeletal deformities consistent with brachial plexus birth palsy, including scapular winging, hypoplastic changes of the glenoid, flattening of the humeral head, and/or glenohumeral subluxation. One patient had a sessile osteochondroma, and two had normal radiographs.

Of the twenty-one patients with radiographs of the elbow, twelve had normal osseous anatomy, four had exaggerated cubitus valgus, three had hypoplastic changes, one had a radiocapitellar joint effusion, and one had limited concavity of the radial aspect of the distal part of the humerus. No patient had radiographic evidence of a dislocated radial head.

Discussion

The present study showed that overactivity of the long head of the biceps brachii muscle is associated with elbow flexion contracture in children with brachial plexus birth palsy. The absence of significant differences in activity duration of the biceps brachii muscle belly (as measured with surface EMG) or the short head (as measured with fine-wire EMG) demonstrates that the long head may play a distinctive role in children with brachial plexus birth palsy-associated elbow flexion contracture. We propose that, in addition to flexing the elbow, the long head of the biceps brachii muscle assists in stabilizing the glenohumeral joint in children with brachial plexus birth palsy and that this

resulting muscle overactivity may contribute to the development of an elbow flexion contracture.

The difference in firing duration between the long and short heads of the biceps brachii muscle may have resulted from distinct innervation of these muscle groups by the musculocutaneous nerve. However, in a previous cadaveric study, innervation of the two heads of the biceps brachii from two separate branches of the musculocutaneous nerve trunk was observed in only 28% of cases³⁸. In the remaining cases, a common branch innervated both muscle heads. Given the differences in the duration of long and short-head biceps brachii muscle activity, fine-wire EMG may be a more suitable modality than surface EMG for evaluating biceps brachii muscle activity in children with brachial plexus birth palsy-associated elbow flexion contractures.

Three-dimensional motion analysis synchronized with EMG allowed for simultaneous evaluation of kinematics and muscle activity duration. Patients in the present study demonstrated compensatory movements similar to those previously shown for children with brachial plexus birth palsy³⁹. It is possible that increased shoulder motion may have resulted in overactivity of the long head of the biceps brachii muscle because the muscle crosses the glenohumeral joint. However, in the overhead-reach task, increased long head activity was observed despite decreased shoulder motion, suggesting that long-head overactivity cannot be attributed to increased shoulder motion alone.

To evaluate elbow flexor-extensor imbalance in brachial plexus birth palsy-associated elbow flexion contracture, previous studies have used manual muscle testing⁸. Surface dynamometry is a more accurate and less subjective tool. We found no significant difference between elbow flexor and extensor strength in the affected limb, suggesting that children with brachial plexus birth palsy-associated elbow flexion contracture may not have an elbow flexor-extensor muscle imbalance, as previously hypothesized. Our findings support those of a recent study involving a brachial plexus birth palsy mouse model in which excision of the external rotators without brachial plexus injury caused no contractures¹⁰. The absence of significant differences in the activity duration of the triceps brachii muscle belly may argue further against co-contraction in the affected limb, although

given the variability of surface EMG measurements, fine-wire EMG may have tested this hypothesis more reliably.

The present study quantified the functional impairment of children with brachial plexus birth palsy-associated elbow flexion contracture with use of three validated tools. On the average, patients reported below-normal upper extremity physical function scores on the PODCI. Parent proxy reports further underestimated the self-reported scores for this domain. Both the mean self-reported scores and proxy-reported scores for upper extremity physical function were lower than those recently reported for children with congenital below-the-elbow deficiency³⁵. Two elbow-specific tools further demonstrated that children with brachial plexus birth palsy-associated elbow flexion contracture may have substantial functional impairment at the elbow.

In the present study, sixteen of nineteen patients had radiographic evidence of deformity at the glenohumeral joint, which supports our hypothesis that the long head of the biceps brachii muscle helps to stabilize the glenohumeral joint with muscle weakness and osseous deformity. The majority of the patients had a normal-appearing elbow radiograph, suggesting that elbow flexion contracture was not the result of an osseous abnormality, and in these cases there was no radial head dislocation. However, it is possible that overactivity of the long head of the biceps muscle contributes to the supination contractures and anterior radial head dislocations that also may be seen in children with brachial plexus birth palsy. In the present study, internal rotation contracture was not associated with overactivity of the biceps brachii muscle, although a larger sample size would have tested this hypothesis more reliably.

The present study had limitations. First, the variability of EMG, particularly surface EMG, is well recognized. We addressed this issue by utilizing standardized methods of data collection and synchronizing EMG to three-dimensional motion analysis to detect specific start and stop times. Although fine-wire EMG is less prone to variability than surface EMG, because of its invasive nature, the use of this technique is restricted to older children and adolescents. Second, isometric muscle strength was tested with surface dynamometry at only one position (90° of elbow flexion) and would be expected to change throughout elbow motion. Isometric strength also was evaluated at only one time. It is possible that patients had a prior elbow flexor-extensor muscle imbalance if elbow flexor function initially returned before elbow extensor function. Third, the present study did not evaluate all upper limb musculature involved in shoulder and elbow function. Given the nature of the present study population (an otherwise healthy pediatric population who would not directly benefit from the

present study) and the invasiveness of fine-wire EMG, we elected to limit the number of fine wires to two per arm as we considered this number to be sufficient to answer our primary hypothesis. A previous study evaluating muscle pathology with use of MRI showed that the supinator and brachialis muscles may play a role in the development of brachial plexus birth palsy-associated elbow flexion contracture¹³. We did not study the activity duration of these muscles with EMG, although it is likely that the true etiology of brachial plexus birth palsy-associated elbow flexion contracture is a combination of multiple factors, both structural and functional.

The present study demonstrated that, in children with brachial plexus birth palsy, elbow flexion contracture is associated with overactivity of the long head of the biceps brachii and presented initial evidence to indicate that elbow flexion contracture may not be due to elbow flexor-extensor muscle imbalance, as previously hypothesized. Scores on well-validated function assessment tools and three-dimensional motion analysis during functional tasks demonstrated that elbow flexion contracture may substantially impair upper extremity function. Soft-tissue contractures secondary to brachial plexus birth palsy are likely multifactorial with both structural and functional components. Future research should elucidate further the etiology of these contractures and other elbow deformities associated with brachial plexus birth palsy so that new preventive and therapeutic strategies can be developed to improve upper extremity function in children with brachial plexus birth palsy.

Appendix

A table showing the demographic characteristics of the patients is available with the online version of this article as a data supplement at jbjs.org. ■

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