Involuntary movements and abnormal spontaneous EMG activity in syringomyelia and syringobulbia

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Article abstract—*Objective:* To describe different types of involuntary movements and abnormal spontaneous electromyographic (EMG) activity in patients with syringomyelia. *Background:* A comprehensive study on involuntary movements in patients with syringomyelia has not yet been undertaken, to these authors' knowledge. *Methods:* One hundred adult patients with syringomyelia were examined over the last 15 years. Involuntary movements were videotaped and evaluated by two independent observers. Electromyographic recordings were made using bipolar surface electrodes. The H-reflex recovery curve was obtained after stimulation of the median nerve at the elbow and recording from the flexor carpi radialis. *Results:* Involuntary movements or abnormal postures were observed in 22 patients. Three patients showed segmental spinal myoclonus, nine minipolymyoclonus, and four propriospinal myoclonus. Five patients had unilateral or bilateral hand postural tremor (8–10 Hz). Focal or segmental dystonia was observed in three patients. Electromyography showed spontaneous bursts of grouped action potentials synchronous in muscles innervated by the same spinal segment, synchronous firing of neurogenic motor unit potentials, or continuous motor unit activity. Increased H-reflex responses to conditioning stimuli were found in patients with spinal myoclonus. Long latency responses were obtained during peripheral nerve stimulation in four patients. Four patients had rigidity and abnormal upper limb posture. Respiratory synkinesis was observed in three patients. One patient developed inverse masticatory muscle activity. *Conclusions:* Patients with syringomyelia showed a wide spectrum of involuntary movements. An increased excitability of spinal motor neurons was probably the basic underlying mechanism.

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Damage to the central gray matter of the spinal cord may lead to excitability of spinal motor neurons, continuous motor unit activity (CMUA), myoclonus, and rigidity.[1-3] This has been shown experimentally in encephalomyelitis produced in cats by infection with Newcastle virus.[4,5] The myoclonic discharges spread through propriospinal pathways, not by viral dissemination. As early as 1913, Babinski[6] described a patient with syringomyelia who had increased tone in the left upper limb in the absence of corticospinal signs, and postulated that the contracture was caused by irritation of spinal motor neurons by the syrinx. Tarlov[7] described a patient with extensive cervicothoracic posttraumatic syrinx who developed flexor spasms and rigidity in the lower limbs and increased perspiration; the postulated mechanism was hyperactivity of motor and sympathetic neurons.

Syringomyelia sometimes causes involuntary movements, but there are only a few descriptions in the literature; a few cases of torticollis,[8] foot dystonia,[9] inverse masticatory activity,[10] and spinal myoclonus[11-14] have been reported. In our experience, a variety of movement disorders occur in syringomyelia and may shed light on the pathophysiology of the spectrum of abnormal movements caused by damage to the central region of the spinal cord. Accordingly, we here review the types of involuntary movements in 100 patients with syringomyelia studied over the last 15 years.

Methods. *Patients.* One hundred patients newly diagnosed with syringomyelia were examined over 15 years. There were 43 men and 57 women, ranging in age from 16 to 69 years (mean ± SD, 40.8 ± 12.2). The diagnosis was based on the classic syringomyelia syndrome as revealed by neurologic examination. In all cases the diagnosis was confirmed by brain and spinal MRI. The patients included had 1) no history of any other neurologic disease; 2) normal results on laboratory tests including copper, ceruloplasmin, thyroid hormones, and peripheral blood smears; 3) no focal lesion on brain MRI scan; and 4) no past or present intake of drugs that might have induced abnormal involuntary movements. Sixty-one patients had communicating syringomyelia, 10 had idiopathic, 11 had syringomyelia caused by arachnoiditis, 10 had syringomyelia associated with spinal cord tumor, 5 posttraumatic, and 3 familial. Four patients died during the follow-up period, two suddenly and two from pulmonary infection.

Clinical evaluation. Neurologic disability was assessed by the quantitative neurologic examination proposed by Kurtzke[15] for MS. In each patient it was possible to obtain

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scores for different functions (brainstem, pyramidal, and sensory function) as well as for overall disability, as follows:

0 = normal neurologic examination result
1 = no disability, minimal signs
2 = minimal disability
3 = moderate disability
4 = relatively severe disability not preventing work or everyday activities, excluding sexual function
5 = disability severe enough to inhibit work, with maximal motor function walking unaided for several blocks
6 = assistance such as canes, crutches, or braces required for walking
7 = restricted to wheelchair
8 = restricted to bed but with effective use of arms
9 = totally helpless and bedridden

Involuntary movements were assessed with a standard protocol on admission and with the help of videotapes by two independent observers blinded to the category of syringomyelia.

Neurophysiologic studies. Electromyography. To study synchronous discharges recorded from nearby muscles, EMG recordings were made using bipolar silver/silver chloride surface electrodes placed 2 cm apart longitudinally over the muscle. Concentric needle electrodes were used when needed to eliminate the possibility of volume conduction. For the study of stimulus sensitivity and flexor responses, the median or tibial nerve was stimulated at the wrist or ankle, respectively, with single supramaximal stimuli, and muscles more regularly involved and with well-defined bursts of EMG activity in each jerk were selected for recording. The order of recruitment of muscles was calculated from single rectified or unrectified traces rather than from averaged data.

H-reflex recovery curve. Motor neuron excitability in five patients with spinal myoclonus was studied with the H-reflex recovery curve. The median nerve was stimulated at the elbow by bipolar surface electrodes (cathode proximal) with the subject supine and the elbow slightly flexed. A rectangular pulse lasting 0.5 msec was delivered with increasing voltage strength. The stimulation value was chosen to give a small M-response and a maximal H-reflex. The active recording surface electrode was placed over the belly of the flexor carpi radialis at about one third of the distance between the medial epicondyle and the radial styloid. The reference was placed over the brachioradialis, away from other median-innervated muscles in the forearm. Amplitudes were measured from the baseline to the negative peak, and latencies from the beginning of the stimulus artifact to the start of the reflex response.

Once the maximal activated H-reflex had been obtained, stimulation was kept constant, and the patient was requested to remain relaxed. An H-reflex program was especially used to obtain the recovery curve,[16] which automatically gave 13 double pulses, one every third second. Interstimulus intervals (ISI) varied randomly from 75 to 900 msec, and four times during each complete series a 100-msec interval was delivered to allow a method check throughout the investigation. After each double stimulation, the ratio (H_2/H_1) between the negative amplitude of the H-reflex after the second (H_2) and the first (H_1) stimuli was calculated. The values obtained from three reproducible curves were averaged. Results were compared with a control group of 12 healthy volunteers (eight men, four women) whose ages ranged from 19 to 58 years (mean ± SD, 38.4 ± 12.1).

Results. Twenty-two patients had one or more involuntary movements or abnormal postures during neurologic or EMG examination. Their clinical and MRI data are summarized in table 1. In the text and tables, patients are identified by number according to increasing degree of disability: Patient 1 is the least affected and Patient 22 the most disabled. The Disability Status Scale (DSS) score ranged from 1 to 6 (mean 3.2 ± 1.4). Involuntary movements of a given type were observed in patients with a wide range of disability, although tremor was observed mainly in less disabled patients and head tilt and rigidity in patients with advanced disease. Three patients had segmental spinal myoclonus and nine had minipolymyoclonus, with or without associated hand tremor, whereas in four patients the myoclonic jerks were induced by electrical nerve stimulation. Five patients had unilateral or bilateral hand tremor, which in three was associated with minipolymyoclonus. Respiratory synkinesis was observed in three patients, and inverse masticatory muscle activity in one. Three patients had head tilt and abnormal arm and shoulder girdle postures.

Segmental spinal myoclonus. Clinical observations. Segmental spinal myoclonus was observed in three patients (table 1). In two of them, myoclonus was localized to proximal muscles, whereas in the other, Patient 12, it affected more distal muscles, leading to unilateral jerky flexion of hand and fingers. The movements were rhythmic or semirhythmic and occurred at a variable frequency, between 2 and 50 times per minute, but in general they were sporadic.

Minipolymyoclonus, characterized by intermittent and irregular movements with amplitudes just sufficient to produce visible and palpable movements of the joints of the fingers or toes, was observed in eight patients with cervical syringomyelia and in a single patient with lumbar syrinx (Patient 16, table 1). Finger movements were more obvious with the hands supine and during relaxation. These movements included 1) flexion and adduction of the thumb, 2) simultaneous flexion of the fourth and middle fingers at the metacarpophalangeal joints, and 3) adduction and abduction of the fifth finger. Movements were observed in both hands and occurred independently or simultaneously on either side. Stretching of the affected muscles led to a reduction in frequency of the flexor movements. Some patients stretched their fingers from a claw posture to reduce the jerks.

Neurophysiology. *EMG.* Different types of spontaneous EMG discharges were observed:

1. Spontaneous, semirhythmic bursts of grouped action potentials (between 8 and 20), firing at a mean rate of 10 Hz, followed by a period of silence and subsequent repetition of a grouped discharge of identical potentials, with bursts occurring either independently in different muscles or synchronously in one or more muscles, the intervals between bursts being somewhat variable (figure 1); bursts were usually observed sporadically, but they could become rhythmic for seconds or minutes in some patients; myclonic discharges were either subclinical, associated with jerking of a proximal muscle with-

Table 1 *Involuntary movements or postures in 22 patients with syringomyelia or syringobulbia*

	Patient no.	Age, y	Sex	Disease duration	DSS	Description of movement	Physiologic findings	MRI findings: Syrinx	MRI findings: Other
Minipolymyoclonus and segmental spinal myoclonus	2	17	M	2 y	1	L hand finger flexion	CMUA	T1–T3	Chiari I
	4	16	M	1 mo	2	Bilateral finger flexion	CMUA	Medulla–T4	Chiari I
	5	23	F	1 y	2	Bilateral finger flexion	CMUA, SMUPs	C1–T1	Chiari I
	6	19	F	7 y	2	Bilateral finger flexion	CMUA, SMUPs	C1–Conus	Chiari I
	7	33	F	3 y	3	Bilateral finger flexion	CMUA	C3–Conus	None
	9	25	M	10 y	3	R hand finger flexion; R arm rhythmic myoclonus	SSM R deltoid	C3–T5	Chiari I
	10	35	M	5 y	3	Bilateral finger flexion; myoclonus R hand	SSM R hand	Medulla–T8	Chiari I
	12	33	M	10 y	3	Bilateral finger flexion; L leg flexion; myoclonus L leg	CMUA, SMUPs, SSM L leg	Medulla–Conus	Chiari I
	13	61	M	32 y	3	Bilateral finger flexion	CMUA	Medulla–T4	Cervical spondylosis
	16	69	F	15 y	4	Bilateral toe plantar flexion	CMUA, SMUPs	T10–Conus	None
	19	57	F	10 y	5	Bilateral finger flexion	CMUA	C1–T8	Chiari I
Tremor	1	42	M	23 y	1	L hand action tremor	Rhythmic SMUPs burst (10–13 Hz) in finger flexors and extensors	C6–T7	None
	2	17	M	2 y	1	L hand action tremor		T1–T3	Chiari I
	5	23	F	1 y	2	Bilateral action tremor		C1–T1	Chiari I
	6	19	F	7 y	2	L hand action tremor		C1–Conus	Chiari I
	15	20	M	5 y	3	L hand action tremor		C3–T4	None
Propriospinal myoclonus	8	68	M	3 y	3	L leg extension (ES)	EMG silence, LLRs	C7–T1	None
	9	25	M	10 y	3	Arms flexion (ES)	R deltoid myoclonic bursts LLRs	C3–T5	Chiari I
	10	35	M	5 y	3	Generalized flexor responses (spontaneous and with ES)	Spontaneous propriospinal myoclonus, LLRs	Medulla–T8	Chiari I
	19	57	F	10 y	5	L finger flexion (ES)	CMUA, LLRs	C1–T8	Chiari I
Abnormal postures	18	45	F	9 y	4	R arm rigidity	—	C1–T1	Chiari I, BI
	20	38	F	7 y	5	Arms rigidity & head tilt	—	Medulla–T11	None
	21	68	M	38 y	6	Arms rigidity & head tilt	—	C1–C7	None
	22	38	M	13 y	6	Arms rigidity & head tilt	—	Medulla–Conus	Arachnoiditis
Dystonia	1	42	M	23 y	1	Torticollis (R)	Spontaneous MUPs in SCL	C6–T7	None
	3	60	F	2 y	2	Torticollis (L); R hand athetosis		C3–T3	Posterior fossa meningioma
	4	16	M	1 mo	2	Blepharospasm; torticollis (R)	Tonic and clonic HFD in OO muscles	Medulla–T4	Chiari I
Respiratory synkinesis	11	68	F	6 y	3	Dimpling middle portion R biceps	Bursts of MUPs during inspiration, EMG silence during expiration	C3–C5	Intramedullary metastasis
	13	61	M	32 y	3	Twitching L biceps, brachioradialis, and finger flexors		Medulla–T4	Cervical spondylosis
	17	45	F	25 y	4	Twitching R triceps		C3–T3	Chiari I
Myokymia	5	23	F	1 y	2	Wave-like movements spreading across surface of forearm and intrinsic hand muscles	HFD (30–50 Hz), spontaneous semirhythmic MUP burst	C1–T1	Chiari I
	10	35	M	5 y	3			Medulla–T4	Chiari I
Inverse masticatory muscle activity	14	25	F	10 y	3	Impaired mouth opening; jaw deviation to right	Masseters: inverse EMG activity	Syringobulbia; syrinx: C1–T1	Chiari I, atlas occipitalization

DSS = Disability Status Scale; SSM = segmental spinal myoclonus; CMUA = continuous motor unit activity; R = right; L = left; MUPs = motor unit potentials; SMUPs = synchronous MUPs in antagonistic muscles of a limb; ES = electrical stimulation; BI = basilar impression; SCM = sternocleidomastoid; HFD = high-frequency discharges; OO = orbicularis oculi muscles; LLRs = long latency responses.

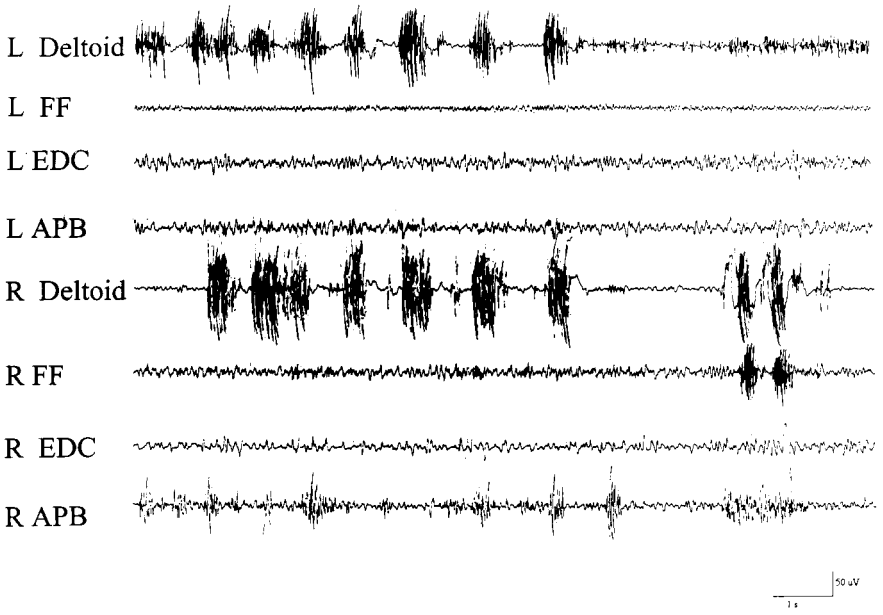

Figure 1. Segmental spinal myoclonus in a patient with occasional jerks of proximal upper limb muscles. Synchronous myoclonic bursts were recorded either on both deltoids or on the right deltoid and finger flexor muscles. There are also myoclonic bursts in the right thenar muscles, asynchronous with the bursts (surface EMG). FF = finger flexors; EDC = extensor digitorum communis; APB = abductor pollicis brevis.

out displacement of the joint, or leading to a brief myoclonic flexion of the hand and fingers.

2. Synchronous firing of single or multiple neurogenic motor unit potentials (MUPs) in two or more muscles innervated by the same spinal segment (figure 2) associated to minor involuntary movements of the toes bilaterally (Patient 16).
3. CMUA in two or more muscles innervated by the same spinal segment (minipolymyoclonus) (figure 3).

None of these discharges were modified by loud noises or voluntary movements. Brief myoclonic discharges were associated to the pattern of CMUA in one patient with segmental spinal myoclonus (flexion of left hand and fingers) and minipolymyoclonus (bilateral finger flexion) (Patient 12, figure 4).

In one patient (Patient 5), EMG was recorded during sleep; minipolymyoclonus involving bilateral distal upper limb muscles and CMUA in intrinsic hand muscles markedly decreased during REM sleep.

H-reflex recovery curve. The H-reflex was obtained from both sides in five patients with minipolymyoclonus and wasting and weakness of upper limb muscles (Patients 2, 5, 6, 12, and 13). The integrated H-reflex recovery curve of control subjects showed a depression at test intervals <200 msec, followed by a progressive and slow recovery with ISI >200 msec. The mean H_2/H_1 ratio at 200 msec ISI in control subjects was 0.54 ± 0.19. There was shortening of the recovery profile in syrinx patients, followed by a period of facilitation with ISI between 150 and 300 msec (figure 5).

Tremor. Clinical observations. Unilateral or bilateral hand tremor was observed in five cases. Tremor was worse on the side more affected. Four of these patients had a mild disease, with DSS ranging between one and two, while one had a moderate disability (Patient 15). Tremor was present mainly during activity and maintenance of outstretched hands, but not at rest, and it disappeared during sleep in the patient studied overnight (Patient 5). In three patients (Patients 2, 5, and 6), tremor and minipolymyoclonus coexisted, whereas in one (Patient 2), tremor was associated with torticollis.

Neurophysiology. Tremor at a frequency of 10 to 13 Hz

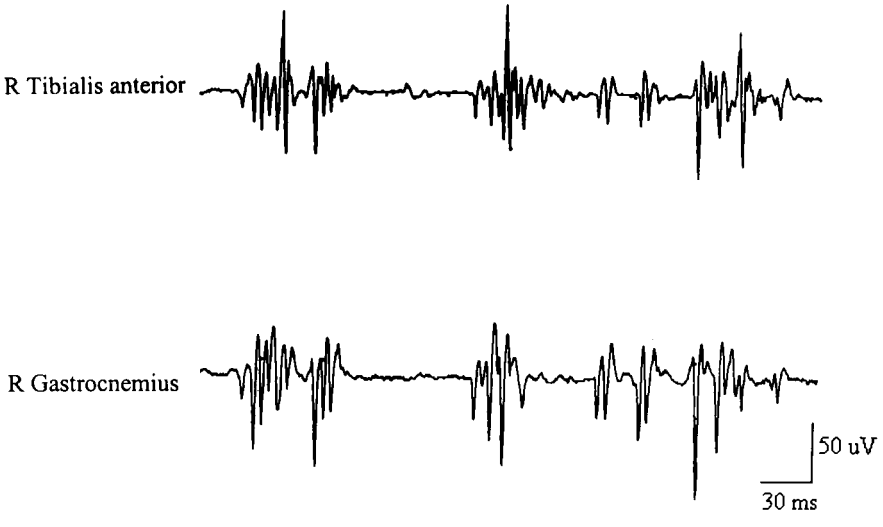

Figure 2. Spontaneous synchronous discharges of multiple motor unit potentials in two antagonistic muscles from the same limb. (Concentric needle EMG).

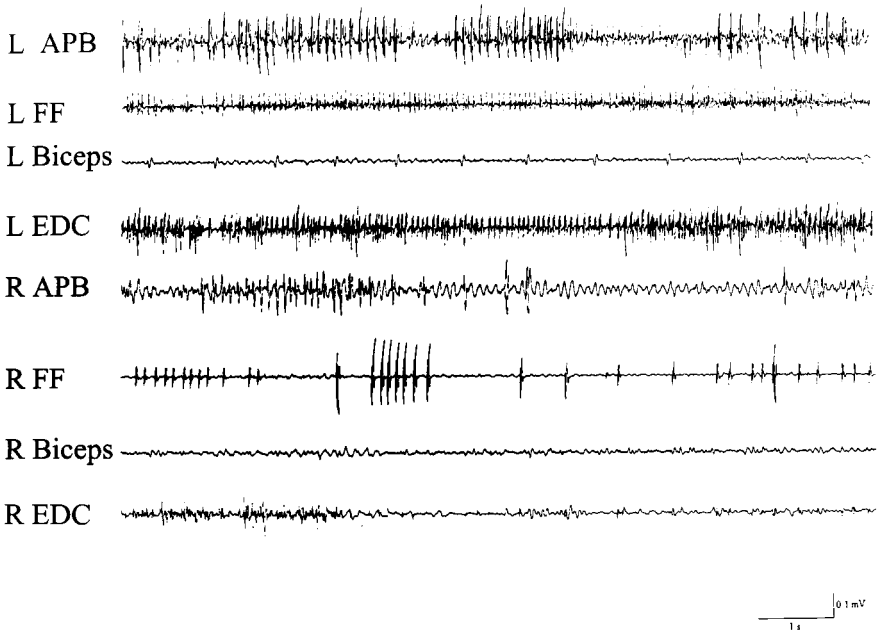

Figure 3. EMG recording from upper limb muscles at rest in a syrinx patient with involuntary, intermittent, irregular finger flexion movements, with visible displacement of the interphalangeal and metacarpophalangeal joints (minipolymyoclonus) and myokymia. There is spontaneous firing of motor unit potentials (continuous motor unit activity) in hand and forearm muscles bilaterally (surface EMG). APB = abductor pollicis brevis; FF = finger flexors; EDC = extensor digitorum communis.

was recorded from flexor and extensor finger muscles. Three patients with tremor (Patients 2, 5, and 6) also had CMUA, interfering with EMG recording of the tremor.

Propriospinal myoclonus. Clinical observations. A fortuitous observation during conventional nerve conduction studies in a man with cervico-thoracic syringomyelia (Patient 10) was that during electrical stimulation of the tibial nerve on both sides, the patient had a synchronous jerking of both arms and legs (flexion at the elbows, hips, and knees on both sides). The response was more obvious if the patient was relaxed and in the supine position (figure 6). The same patient also showed occasional spontaneous nonrhythmic myoclonic jerks involving the left upper and lower limbs, but they were of smaller amplitude than those observed after electrical stimulation (figure 7). The same flexor response was induced by electrical stimulation of a peripheral nerve in two other patients (Patients 9 and 19). Similarly, Patient 8, a 68-year-old man with a history of poliomyelitis, while being investigated with nerve conduction studies for suspected postpolio syndrome, was found to have jerks (extension of the left leg at the knee) elicited by electrical median nerve stimulation of the opposite side. This finding led to further investigation with an MRI scan and to the demostration of a small cervical syrinx at the C7 to T1 segment.

Neurophysiology. During the more violent jerks induced by supramaximal stimulation of the tibial nerve, EMG activity was recorded in the following flexor and

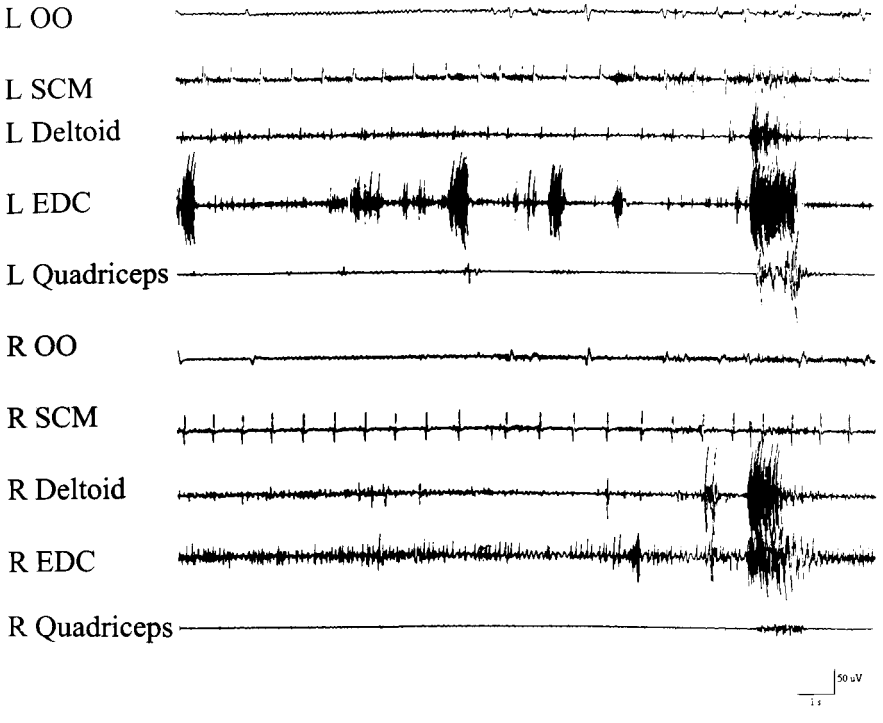

Figure 4. EMG during relaxation. There are nonrhythmic myoclonic jerks in the left EDC and continuous motor unit activity in the right EDC. At the end of the recording, more widespread bursts were recorded in deltoid, EDC, and quadriceps muscles bilaterally (surface EMG). OO = orbicularis oculi; SCM = sternocleidomastoid; EDC = extensor digitorum communis.

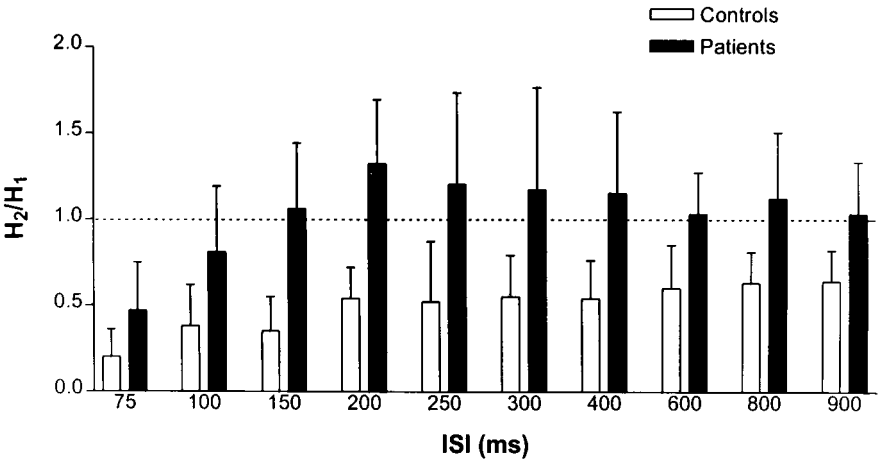

Figure 5. H-reflex recovery curve values (mean ± SD) in normal subjects and in five patients with minipolymyoclonus. Major differences are noted with interstimulus intervals (ISI) ranging from 150 to 200 msec.

extensor muscles: finger flexors and extensors, cervical and lumbar paraspinals, quadriceps, hamstrings, calf, and abductor hallucis bilaterally (see figure 6). The duration and amplitude of EMG bursts evoked by supramaximal stimulation were greater than those recorded for spontaneous jerks. Table 2 shows the shortest latencies obtained after a series of single stimuli applied to a peripheral nerve. The pattern of recruitment was characteristic. Repetitive stimulation resulted in a much smaller or absent response, and stimuli separated by intervals <5 seconds were not accompanied by a reflex response.

The duration of EMG activity bursts in the various muscles during spontaneous jerks ranged from 100 to 1,000 msec (see figure 7). Spontaneous jerks in Patient 10 were more frequently observed within the 20 seconds following supramaximal stimulation and were recorded consistently in the same sequence in upper and lower limb muscles. The intervals between spontaneous jerks varied from 3 to 65 seconds, and on occasion, two or three subsequent bursts were recorded in a row with a rhythmic pattern, separated by intervals <1 second.

Abnormal head, shoulder girdle, and arm postures. Clinical observations. Four patients (Patients 18, 20, 21, and 22) with severe disability developed rigidity of the upper limbs. The arms were extended and adducted, with the forearms pronated. This was a fixed posture. The shoulders were turned down forward, and the head was tilted. The head was tilted toward the more affected side. The finger and wrist movements progressively deteriorated as a result of muscle rigidity, fixing the wrist in extension and the fingers in flexion. The abnormal arm posture persisted unchanged until death in all four patients.

All of these patients died of respiratory complications,[17]

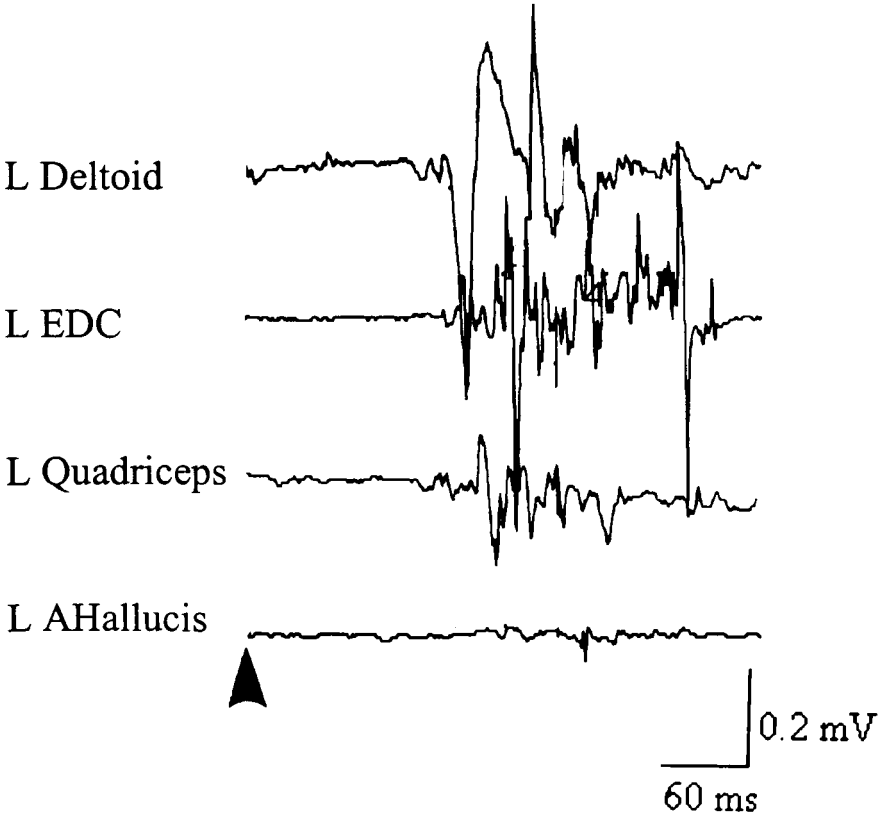

Figure 6. EMG responses obtained after supramaximal electrical nerve stimulation (arrow) of the right tibial nerve at the ankle. There is progressive recruitment of upper and lower limb muscles in a descending order. AHallucis = abductor hallucis; EDC = extensor digitorum communis.

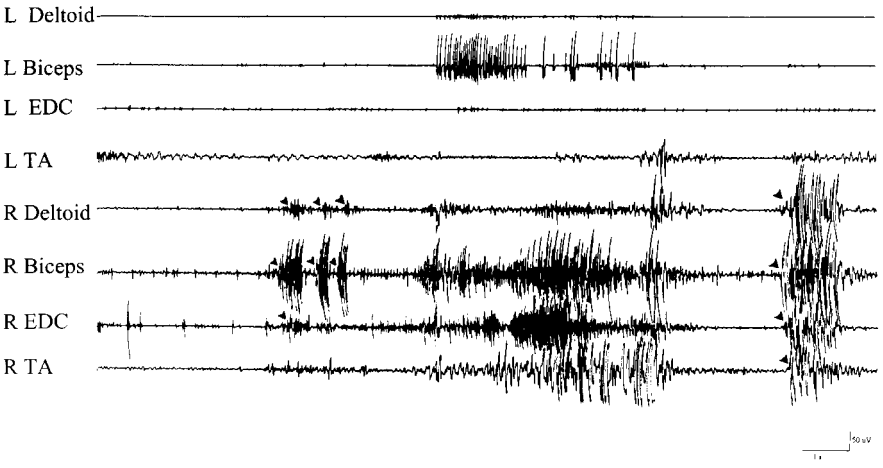

Figure 7. Myoclonic bursts almost synchronous in right upper and lower limb muscles during complete relaxation. Arrows indicate the beginning of the myoclonic bursts in each muscle. The spinal generator is supposed to be at C5, because activity is recorded first in the right biceps muscle, followed by the right deltoid, EDC, and TA muscles. At the end of the recording, a larger and longer burst is observed in all four muscles. There is also a spontaneous high-frequency discharge in the left deltoid and biceps muscles (surface EMG). EDC = extensor digitorum communis; TA = tibialis anterior.

and thus were not available at the time of neurophysiologic investigation.

Dystonia. Clinical observations. Torticollis (laterocollis and retrocollis) was observed in Patient 1; very mild disease was manifested only by pain and dissociated sensory loss in the right upper limb and trunk, and a small cervical syrinx.

Conversely, Patient 4, a 16-year-old boy, had craniocervical dystonia and vertigo of acute onset. He acutely developed oscillopsia, blepharospasm, torticollis, and gait unsteadiness. Examination showed retrocollis and laterocollis toward the left side, horizontal nystagmus, blepharospasm, and loss of pain and temperature sensation on the left side of the body. Blepharospasm was very striking. Two months after posterior fossa decompression, the blepharospasm had almost disappeared.

Patient 3, with mild disability caused by syringomyelia secondary to a posterior fossa meningioma, had torticollis and athetoid dystonic movements of the right hand in the absence of posterior column sensory loss.

Neurophysiology. In two patients with torticollis (Patients 1 and 3), EMG showed spontaneous firing of MUPs in the sternocleidomastoid muscles. In the patient with blepharospasm (Patient 4), EMG showed tonic and clonic high-frequency spontaneous discharges in both orbicularis oculi muscles at rest (figure 8).

Respiratory synkinesis. Clinical observations. Three patients (Patients 11, 13, and 17) with moderate disability showed visible contraction of the upper limb muscles during inspiration. In one patient (Patient 11), the contractions affected the right biceps brachii; in another (Patient 13), they affected the left biceps brachii, brachioradialis, and finger flexors during deep inspiration; and in the remaining patient (Patient 17), the visible contractions were restricted to the right triceps muscle during spontaneous breathing. They were under voluntary control, and if pa-

Table 2 *Neurophysiologic findings in patients with abnormal motor responses induced by electrical nerve stimulation*

Patient	Nerve stimulated	Movement induced	Recording site	Latency* (msec)	F-wave latency (msec)
8	Left median	Hip flexion	R rectus femoris	120.0	Absent
9	Right tibial	Bilateral flexion of arms	L biceps	88.6	
			L EDC	90.2	44.5 ± 3.5
			L rectus femoris	106.0	
			L gastrocnemius	113.0	
10	Right tibial	Bilateral flexion of arms	L biceps	90.3	
			L EDC	110.0	49.6 ± 1.0
			L rectus femoris	120.0	28.9 ± 3.3
			L gastrocnemius	130.2	
	Left median	Bilateral flexion of arms	L EDC	60.8	Absent
			R EDC	64.0	
19	Left tibial	Left finger flexion	L biceps	59.1	
			L EDC	65.2	Absent
			L quadriceps	75.6	
	Right median	Left finger flexion	L finger flexors	61.2	28.1 ± 1.0
			L EDC	62.3	

* Shortest recorded latency.

EDC = extensor digitorum communis.

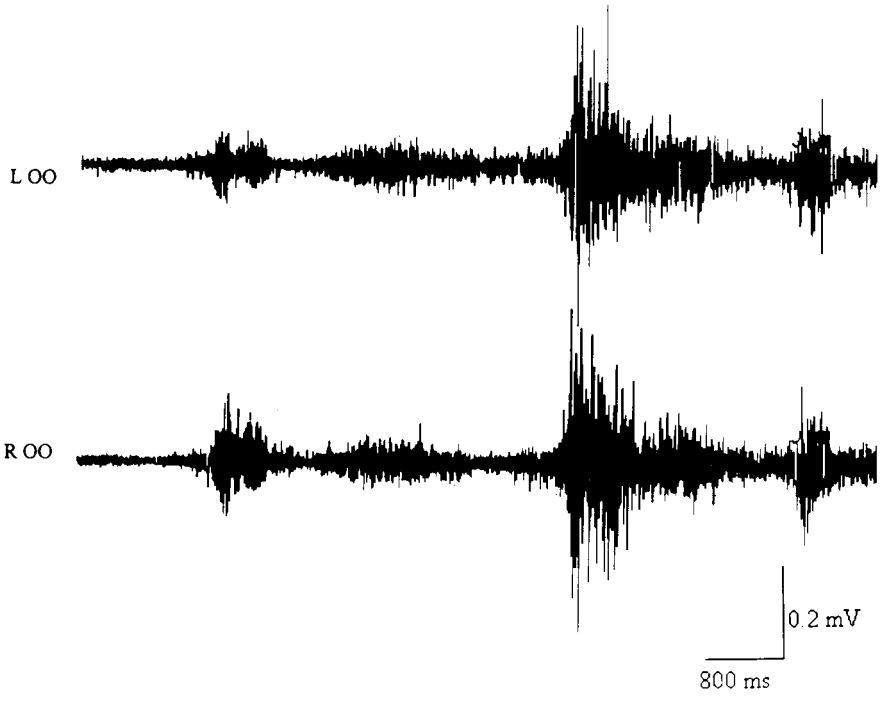

Figure 8. EMG from orbicularis oculi (OO) muscles in a patient with blepharospasm. There is tonic and clonic EMG activity.

tients voluntarily held their breath in expiration, the discharges stopped. All three patients were unaware of such movements.

Neurophysiology. Surface EMG showed bursts of 10 to 15 MUPs during inspiration. In EMG recordings, respiratory synkinesis resembled myokymic discharges: spontaneously occurring grouped action potentials, each group followed by a period of silence, with subsequent repetition of a group discharge of identical potentials in a semirhythmic pattern (figure 9).

Bursts occurred synchronously in all three affected muscles in Patient 13. Simultaneous recording from the external intercostal muscles by use of surface electrodes, and from the abdomen by use of a belt with a transducer, confirmed synchronicity between bursts and inspiration. Bursts disappeared during breath-holding. Synkinetic MUPs were polyphasic and different from the ones obtained during voluntary activation at the same needle recording site.

Myokymia. Clinical observations. Two patients had undulating, vermicular rippling, and wavelike movements spreading across the surface of the forearm and intrinsic hand muscles. In one of them (Patient 5), these movements were accompanied by rhythmic or semirhythmic movement of one or more fingers (minipolymyoclonus), either adduction and flexion of the thumb, or simultaneous flexion of the fourth and middle finger. Patient 10 also showed propriospinal myoclonus. The limb myokymia persisted during sleep.

Neurophysiology. Two types of spontaneously generated bursts of identical individual MUPs were demonstrated by EMG, with each burst recurring rhythmically or semirhythmically, usually several times per second: 1) slow and prolonged muscle contraction with multiple MUPs firing at a frequency of 30 to 50 Hz, and 2) bursts of MUPs unassociated with slow contractions.

Inverse masticatory muscle activity. Clinical observations. Patient 14 (who has been previously reported[10]) had experienced progressive difficulty in opening her mouth and had recently been forced to feed herself through a straw. She was unable to open her mouth and, on attempting to do so, could achieve only lateral movements of the jaw directed toward the right. Passive mouth opening was quite impossible, and she could protrude her tongue

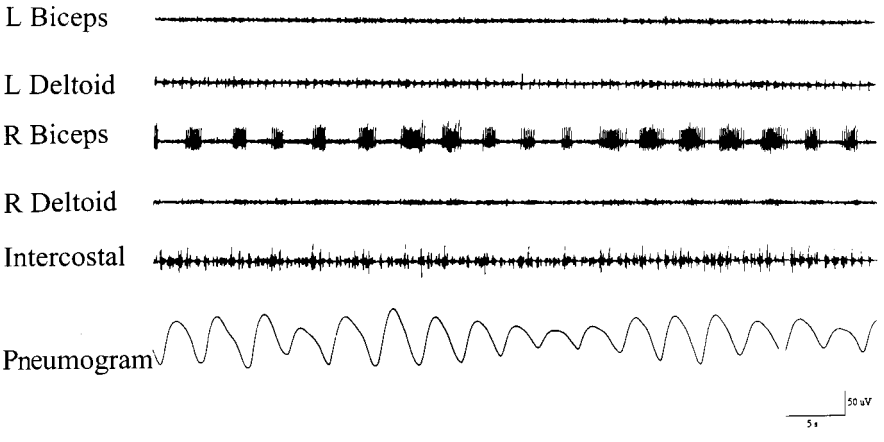

Figure 9. "Breathing arm," or respiratory synkinesis (Patient 11). Synchronous bursts of motor unit potentials resembling myokymic discharges in the right biceps muscle, synchronous with inspiration. There is also some muscle activity in the right deltoid muscle (surface EMG).

only with great difficulty. There was mild atrophy of the tongue with fasciculations and wasting of both hypothenar muscles, as well as decreased pain and temperature sensation from the C3 to the T5 dermatone. The left plantar response was equivocal.

Neurophysiology. Simultaneous recording from both masseters showed a paradoxical contraction of the right masseter during mouth opening with complete lack of activity of the left masseter. The opposite was found during mouth closure.

MRI findings. The characteristics of the syrinx and the presence of an associated craniovertebral anomaly varied in patients with similar involuntary movements. A Chiari Type I anomaly was found in 11 of the 22 patients with involuntary movements. In all patients with segmental spinal myoclonus and in those with minipolymyoclonus in the upper limbs, the syrinx was found to be extensive at cervical levels, whereas in a single patient with involuntary toe movements, the syrinx was localized between T10 to the conus medullaris levels. Propriospinal myoclonus was associated with long cervicothoracic cavities in three of four patients (figure 10). Head tilt and arm rigidity were found in patients with end-stage disease who had marked cord atrophy and collapsed cavities. Syringobulbia and syringopontia were found in the patient with inverse masticatory muscle activity. A small syrinx in the dorsolateral medulla was found in the patient with acute blepharospasm; in a follow-up MRI scan 2 months after foramen magnum decompression, the bulbar lesion was not visible, and this was associated with complete recovery from blepharospasm.

All three patients with respiratory synkinesis had syringes involving the C4 to C7 spinal segments. In one of them (Patient 11), the syrinx was secondary to a spinal cord tumor, whereas in another (Patient 17), there was an associated Chiari I anomaly.

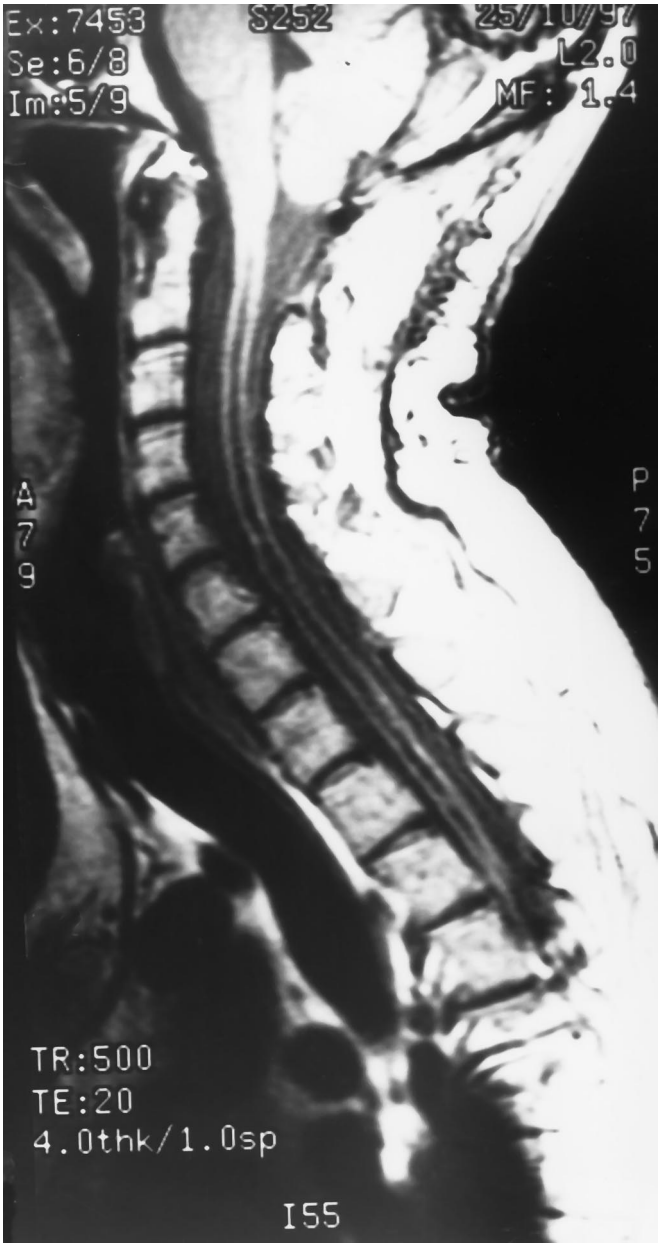

Figure 10. MRI from a patient with propriospinal myoclonus and myokymia. There is a decompressed Chiari Type I anomaly, an extensive cervicothoracic syrinx, and cord atrophy.

Discussion. This work was prompted by the observation during the neurologic examination of spontaneous finger flexion movements in a few syringomyelia patients. A search of the literature strongly suggested that a central spinal cord lesion such as a syrinx may predispose to spinal motor neuron hyperexcitability, CMUA, involuntary movements, and rigidity. This contrasted considerably with the scanty number of previous reports on this subject in syringomyelia, leading us to search for abnormal movements or EMG discharges in patients with this condition.

The main finding of this study was that the patients with syringomyelia displayed a wide variety of involuntary movements, which were of small amplitude and nondisabling. Inverse masticatory muscle activity was the only disabling movement; it interfered considerably with feeding and prompted the neurologic consultation and further diagnosis of syringomyelia.[10] Otherwise, patients were either unaware of involuntary movements or described them as a minor problem in comparison with the much more severe neurologic disability secondary to muscle weakness, spasticity, or sensory loss. This may well be because most patients had wasting, weakness, and chronic active denervation of affected muscles, so that motor neurons were most likely damaged to a degree that interfered with the clinical expression of an abnormal state of disinhibition and excitability.

From the wide spectrum of movements observed, propriospinal myoclonus, tremor, respiratory synkinesis, and blepharospasm have not previously been associated with syringomyelia, as far as we know. The stimulus-induced jerks described were of long latency and had a constant sequential order of recruitment. Latencies were similar to the second component found by Shahani and Young[18] by supramaximal electrical stimulation of the medial

sole of the foot. According to those authors, smaller and shorter flexor responses can also be present in normal subjects after facilitation. On the contrary, they were easily elicited in many muscles and without facilitation in the syringomyelia patients described above. The differences in latencies to onset of EMG activity between upper and lower limb muscles, the marked jitter of the responses, and the long duration of bursts suggest that the stimulus is conducted along propriospinal pathways.[19,20]

The observed tremor resembled benign essential and physiologic tremor, given its frequency and clinical characteristics. A variety of mechanisms have been proposed to explain tremor oscillations in the 8- to 12-Hz range, which appear to be generated by CNS activity. One theory is that this 8- to 12-Hz peak is caused by the inherent properties of motor neuron firing.[21] Taylor[22] demonstrated that if several motor neurons fire quite independently, but at the same frequency, grouping of motor unit action potential occurs by chance, so that the probability that the units will fire within a given time interval is related to their frequency of discharge. Accordingly, units firing at ~8 Hz at any level of contraction will tend to exhibit chance synchronization, thus augmenting tremor at that frequency.

Respiratory synkinesis was a curious phenomenon found by chance during careful visual inspection or EMG of the upper limb muscles. A lesion of the motor neuron at the C4 to C5 level may lead to abnormal regeneration and misdirection of respiratory fibers into the brachial plexus.[23] An alternative explanation would be the spread of discharges from rhythmic generators within the CNS to anterior horn cells, because a feature of some excitable cells is the ability to generate a spontaneously rhythmic burst of potentials.[24]

The case of blepharospasm was exceptional, because the brain stem lesion was limited to the medulla, with preservation of the pons, and blepharospasm disappeared on MRI scan after foramen magnum decompression and collapse of the syrinx. Previous reports have described blepharospasm caused by rostral brain stem or lower pontine lesions[25-27] but not in medullary lesions. Jankovic and Patel[25] reported six patients with rostral brain stem lesions and bilateral blepharospasm, but in none of their cases was the medulla involved, as it was in our patient. Similarly, Gibb et al.[26] and Aramideh et al.[27] described blepharospasm in patients with structural lower pontine lesions. The syrinx in the medulla might have damaged inhibitory interneurons of the reflex arc, leading to blepharospasm.

Head tilt may be explained by damage to central vestibular nuclei or connections.[28] In fact, vestibular symptoms are the most common manifestations of syringobulbia[29,30] and were presenting symptoms in the patient with blepharospasm. This is readily understood in view of the extensive vestibular connections localized in the subependymal area of the medulla. Progressive rigidity of one or both upper limbs leading to a decerebrate-like posture was observed in the three patients with end-stage syringes. Although these patients were unavailable for EMG examination at the time of this study, it is most likely that a mechanism similar to the one proposed by Rushworth et al.[31] and Tarlov[7] to explain rigidity in patients with intramedullary tumors may account for the postures observed in the terminal stages of syringomyelia.

Athetoid dystonic postures like the one described in one patient from this series have previously been described, even in the absence of any sensory deficit.[32] Hyperexcitability of motor neurons and interneurons, resulting from loss of inhibition from sensory inputs, has also been postulated to explain spinal athetosis.[33]

Torticollis has been described in children with syringomyelia secondary to tumors, and it may be the presenting sign of a cervical syrinx.[8] In these patients, EMG recordings from sternocleidomastoid muscles showed spontaneous firing of MUPs. It is possible that damage and isolation of motor neurons when associated to muscle weakness may lead to torticollis.

Although facial myokymia has been described in syringobulbia,[34] to our knowledge there are no published reports of limb myokymia in patients with syringomyelia. Myokymia may be caused by abnormal excitability of the anterior horn cell or root. The central localization of the syrinx may induce spontaneous discharges from anterior horn cells; alternatively, it may disrupt inhibitory interneuronal mechanisms.[35]

A disturbance in the central programming of mastication has been proposed as a possible explanation of inverse masticatory muscle activity.[10] A lack of Renshaw inhibition of motor neurons involved in mastication may play a contributory role.[36]

From the electrophysiologic standpoint, the variety of abnormal EMG discharges was unexpected: CMUA, synchronous firing of complex motor units in antagonistic muscles, myokymic discharges, myoclonus, and long latency reflexes. H-reflex recovery curve findings in patients with spinal myoclonus, and a previous report on the finding of large amplitude F-waves and H-reflexes from intrinsic hand muscles,[37] suggest that such patterns are the expression of abnormal motor neuron discharges attributable to 1) damage to alpha motor neurons by the syrinx itself, inflammation around the syrinx, or a spinal cord tumor responsible for fasciculations, myokymia, complex repetitive discharges, and chronic active denervation; 2) a lesion of spinal interneurons leading to segmental and propriospinal myoclonus, respiratory synkinesis, tremor, rigidity, and their corresponding EMG discharges, including CMUA; or 3) damage to descending motor pathways caused by the syrinx itself or by the associated Chiari anomaly, which could facilitate the expression of many of these abnormalities. The presence of all three pathogenetic factors in several patients also

explains the appearance of two or more different types of movement in the same subject, such as segmental spinal myoclonus, minipolymyoclonus, and tremor, or limb myokymia and propriospinal myoclonus, and the recording of two or more different EMG discharges in the same patient.

CMUA was a striking and frequent EMG abnormality in patients who clinically exhibited either tremor, segmental spinal myoclonus, or minipolymyoclonus. This term has been used to describe intermittent, irregular movements, with amplitudes sufficient to produce visible and palpable movements of the joints, easily noticeable in the distal joints of patients with chronic and more benign forms of spinal muscular atrophy.[38] It has been suggested that CMUA results from isolation of the spinal alpha motor neurons from inhibitory interneuronal circuits by the syrinx, because it has been found in individual cases of intramedullary tumor or cyst.[3,7,13,31] Isolation of spinal alpha motor neurons could account not only for the continuous activity recorded in EMG but also for the spontaneous discharges observed in agonist and antagonist muscles recorded in some patients, as has been described in adults with motor neuron disease[11] and in children with myelomeningocele.[39]

The previously mentioned different types of abnormal spontaneous EMG activity, although relatively frequent in this series of patients, may be easily overlooked in routine EMG studies if not especially looked for. CMUA can be interpreted as voluntary activity caused by the patient's inability to relax during an EMG. Myoclonic discharges, either rhythmic or nonrhythmic, are rare and sporadic events in syringomyelia, in contrast to what has been reported in patients with spinal cord tumors;[13] therefore, long EMG recordings from several muscles are required to detect them. Similarly, in order to record abnormal flexor responses and long latency reflexes during conventional nerve conduction studies, it may be necessary to use multichannel EMG and a very slow sweep speed.

Involuntary movements were found more frequently than had previously been recognized in 22% of patients in the present series, thus providing an additional clinical sign that may be useful in the diagnosis of syringomyelia and syringobulbia. Further studies may be helpful to understand the intrinsic mechanism of respiratory synkinesis and to determine the long-term effect of these electrophysiologic abnormalities on the survival of the spinal motor neuron, to define whether early surgical treatment of the syrinx may prevent development of spinal motor neuron hyperexcitability, and whether any pharmacologic treatment directed to reduce the state of hyperexcitability of spinal motor neurons may help to prevent the relentlessly progressive muscle weakness frequently observed in this disease.

Acknowledgment

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Blink reflex recovery in facial weakness

An electrophysiologic study of adaptive changes

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Article abstract—*Objective:* To study the electrophysiologic effects of unilateral facial weakness on the excitability of the neuronal circuitry underlying blink reflex, and to localize the site of changes in blink reflex excitability that occur after facial weakness. *Background:* Eyelid kinematic studies suggest that adaptive modification of the blink reflex occurs after facial weakness. Such adaptations generally optimize eye closure. A report of blepharospasm following Bell's palsy suggests that dysfunctional adaptive changes can also occur. *Methods:* Blink reflex recovery was evaluated with paired stimulation of the supraorbital nerve at different interstimulus intervals. Comparisons were made between normal control subjects and patients with Bell's palsy who either recovered facial strength or who had persistent weakness. *Results:* Blink reflex recovery was enhanced in patients with residual weakness but not in patients who recovered facial strength. Facial muscles on weak and unaffected sides showed enhancement. In patients with residual weakness, earlier blink reflex recovery occurred when stimulating the supraorbital nerve on the weak side. Sensory thresholds were symmetric. *Conclusion:* Enhancement of blink reflex recovery is dependent on ongoing facial weakness. Faster recovery when stimulating the supraorbital nerve on the paretic side suggests that sensitization may be lateralized, and suggests a role for abnormal afferent input in maintaining sensitization. Interneurons in the blink reflex pathway are the best candidates for the locus of this plasticity.

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After nervous system injury, changes may occur in the motor system that appear to optimize functional outcome. An example of such an adaptive change can be found in the human blink reflex after facial weakness. Eyelid kinematic studies show that unilateral facial weakness alters the relationship between blink peak velocity and blink amplitude in a manner that assists with eye closure on the paretic side. However, the enhanced motor output is bilateral, even though the adaptive response on the nonparetic side is unnecessary.[1] Adaptations may compensate for disturbances of normal responses, but they can also be maladaptive and dysfunctional. In one such case of an apparent maladaptive response, a patient developed bilateral blepharospasm after an episode of Bell's palsy. A gold weight implanted into the paretic eyelid to aid eye closure eliminated the blepharospasm, presumably by removing the drive for enhanced motor output.[2]

Although facial weakness can play a role in developing blepharospasm, most patients with facial weakness do not develop blepharospasm and most

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patients with blepharospasm do not have facial weakness. The link between facial weakness and subsequent development of blepharospasm may be mediated by abnormal sensory inputs that result from incomplete lid closure. Excessive sensory input could lead to disproportionate changes in the gain of the blink circuits. A number of observations point to abnormal sensory processing in benign essential blepharospasm. Patients with blepharospasm are known to demonstrate enhanced sensitivity to stimuli such as bright lights. Sensory tricks such as pressure on the eyebrow or temple may be effective in relieving the blepharospasm.[3] Additionally, local ocular pathology that may cause abnormal sensory input is frequently implicated early in the course of benign essential blepharospasm.[4]

A spontaneous blink causes rubbing of the eyelids over the cornea, which produces a sensory stimulus for another blink, thus potentially setting up a series of blinks causing blepharospasm. This is normally prevented by a period of inhibition after each blink. The inhibition is maximal immediately following a blink and lasts for approximately 1.5 seconds. By evoking the blink reflex using a pair of electrical stimuli at progressively increasing interstimulus intervals, it is possible to construct a blink reflex recovery curve. Blink reflex recovery has been found to be abnormal in a number of diseases[5,6] with abnormal neuronal excitability, including blepharospasm.

In the current study we evaluated the blink reflex recovery in patients with unilateral facial weakness to identify electrophysiologic correlates for adaptive changes suggested by kinematic studies. We investigated the effect of persistent and resolved unilateral facial weakness on the excitability of the brainstem neuronal circuitry underlying the ipsilateral and the contralateral blink reflex.

Methods. Seven healthy volunteers (age range, 35 to 60 years) and 12 patients with a history of Bell's palsy (age range, 33 to 67 years) gave written informed consent, in accordance with the Declaration of Helsinki, for the study protocol, which was approved by the institutional review board. The degree of facial weakness was graded as 0, 1, 2, 3, 4, or 5, according to the House–Brackmann grading system.[7] At the time of the study all patients were divided into two groups: 1) patients demonstrating complete or almost complete recovery of facial weakness on clinical examination (House–Brackmann grade 0 or 1); and 2) patients demonstrating persistent facial weakness on clinical examination (House–Brackmann grade 2 or higher).

None of the patients demonstrated grade 4 or 5 weakness. All patients were diagnosed with Bell's palsy by a neurologist who evaluated for possible alternative underlying conditions.

Patients were seated comfortably in a quiet room during the study and were asked to look at given reading materials during the test to maintain a relatively uniform level of alertness. A Counterpoint electromyograph (Dantec Medical, Inc., Allendale, NJ) was used for all studies. Direct orbicularis oculi compound muscle action potentials were obtained by stimulation of the facial nerve anterior to the mastoid process. Blink reflexes were evoked by electrical stimulation of the supraorbital nerve using a bar electrode. The cathode was placed over the supraorbital notch, and the anode was placed 3 cm superiorly and laterally with adjustment as necessary to minimize stimulus artifact, and was then taped securely. The R2 threshold stimulus intensity and the sensory perceptual threshold stimulus intensity were measured. The R2 threshold intensity was defined as the stimulus intensity necessary to evoke a consistent bilateral 50-μV R2 response. The sensory threshold for the supraorbital nerve was defined as the minimum stimulus intensity detected by the patient on at least three of six trials. The blink reflex was evoked with a 0.2-msec square-wave pulse at three times the R2 threshold intensity.[6]

Blink responses were obtained using paired pulses delivered at the following interstimulus intervals: 160, 300, 500, 700, and 1,000 msec. These intervals were pseudorandomized in blocks of five, with a minimum of eight blocks recorded on each side. To prevent habituation, consecutive paired pulses were delivered at an interval of 20 to 25 seconds. The blink reflexes were recorded from orbicularis oculi muscles bilaterally using tin-plated electrodes with shielded cables. The high-frequency filter setting was 1,000 Hz and the low-frequency filter setting was 30 Hz. The active recording electrode was placed on the lower orbicularis oculi muscle directly below the pupil, and the reference recording electrode was placed laterally on the temple.[8] The evoked responses were sampled at a frequency of 10 kHz using a Macintosh computer with LabView software (version 4.0) and boards (National Instruments Corporation, Austin, TX). Peak area and amplitude of the R2 response was measured within a window from 32 to 90 msec[6,9] from an average of eight rectified traces.

The R2 amplitude and area were expressed as a ratio of the second R2 ($R2_b$) to the first R2 ($R2_a$). This $R2_b$-to-$R2_a$ ratio was plotted against the interstimulus intervals to construct a blink reflex recovery curve. The blink reflex recovery curves were compared between patients and control subjects, and within patients between those that had recovered strength (House–Brackmann grade 0 or 1) and the group with persistent weakness (House–Brackmann grade 2 or 3).

Statistical analysis consisted of analysis of variance to determine the effects of groups (patients versus control subjects, residual weakness versus recovered strength), side of stimulation (stimulation of the supraorbital nerve on the paretic side versus the nonparetic side), and side of recording (electromyographic [EMG] activity from the paretic versus the nonparetic side). A log transformation of the $R2_b$-to-$R2_a$ ratio was performed to normalize the distribution.[9,10] Paired comparisons using f-tests with Bonferroni corrections were used for post hoc comparisons of individual intervals.

Results. Of the 12 patients with a history of Bell's palsy, six had recovered from their weakness (mean age, 54.3 years) and six were left with residual weakness (mean age, 57.2 years). All patients were tested at least 3 months after Bell's palsy. None of the patients showed clinical signs of blepharospasm or hemifacial spasm. There was no significant side-to-side difference in the threshold stimulus intensity to evoke an R2 response in control subjects or

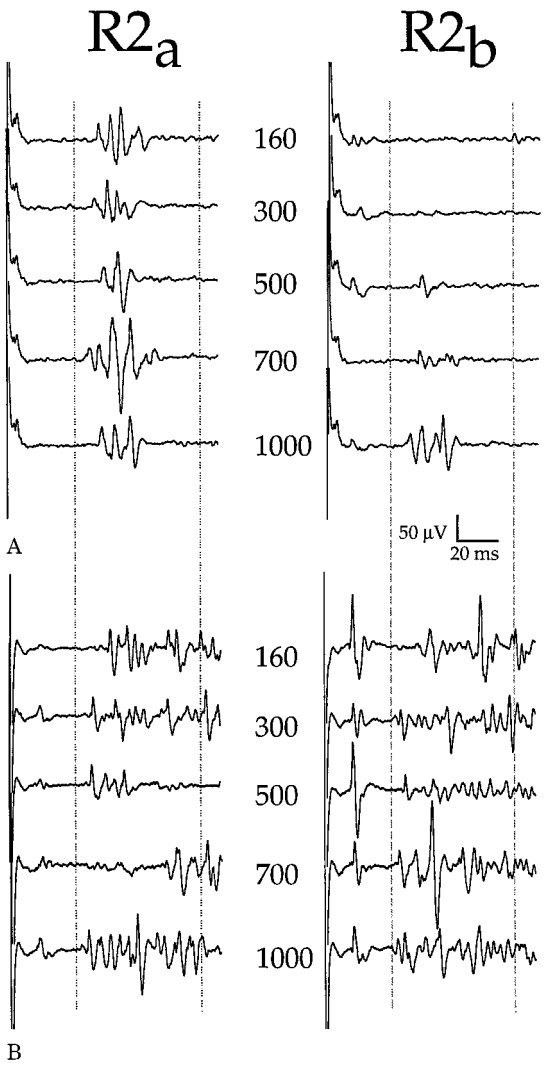

Figure 1. Blink reflex recordings using paired electrical stimulation of the supraorbital nerve at selected interstimulus intervals from a normal control subject (A) and a Bell's palsy patient with residual weakness (B). Dotted lines show the portion of the trace that was used to calculate the R2 area.

Bell's palsy patients. There was no side-to-side difference in the threshold stimulus intensity for sensory perception in control subjects or Bell's palsy patients.

In patients as well as control subjects, paired pulse stimulation produced suppression of the R2 component of the second blink reflex ($R2_b$). Suppression was maximal at the shortest interstimulus interval tested and recovered gradually. Patients with residual facial weakness had less suppression of the $R2_b$ compared with normal control subjects. This is illustrated for a normal control subject and a patient with persistent facial weakness (figure 1). In contrast, patients who recovered strength were not different from control subjects. Recovery curves (figure 2) for the three groups were obtained by pooling all recordings at each interval for each person and plotting the means of subject means. Recovery curves from patients with persistent facial weakness (House–Brackmann grade 2 or 3) were significantly different from control subjects ($p < 0.001$). On post hoc analysis this difference was found to

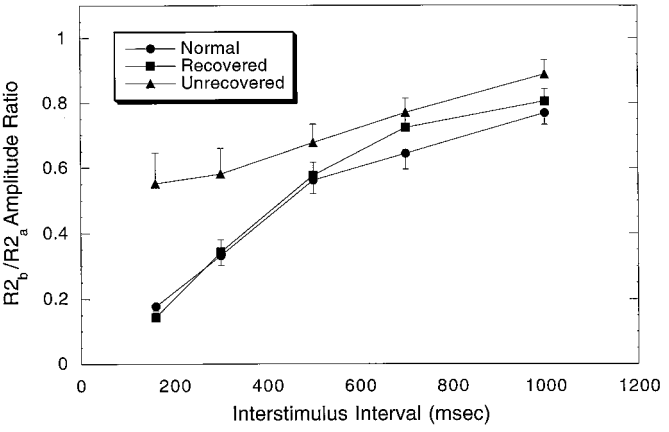

Figure 2. Blink reflex recovery curves (mean and SEM) for normal control subjects (●) and Bell's palsy patients with (■) or without (▲) recovery of facial strength.

consist of enhanced recovery of the $R2_b$ at the shorter interstimulus intervals. The mean $R2_b$-to-$R2_a$ ratio at an interstimulus interval of 160 msec was 0.55 for patients with residual weakness versus 0.18 for control subjects, and at 300 msec was 0.58 for patients with residual weakness versus 0.33 for control subjects. At interstimulus intervals longer than 300 msec, the patient's $R2_b$-to-$R2_a$ ratio was not different from the control subjects. Recovery curves of patients who recovered facial strength (House–Brackmann grade 0 or 1) were not significantly different from control subjects.

In patients with persistent weakness, the enhanced R2 recovery occurred in facial muscles of the paretic as well as the nonparetic side, but was greater on the paretic side ($p = 0.04$).

The side of stimulation also affected the blink reflex recovery curves of patients with persistent facial weakness. The recovery curves obtained by stimulation of the trigeminal nerve on the paretic side were significantly different from those obtained by stimulation of the trigeminal nerve on the nonparetic side ($p = 0.03$; figure 3). The mean $R2_b/R2_a$ value for each interstimulus interval was higher when stimulating the paretic side. Although the more stringent criteria for post hoc analysis did not allow

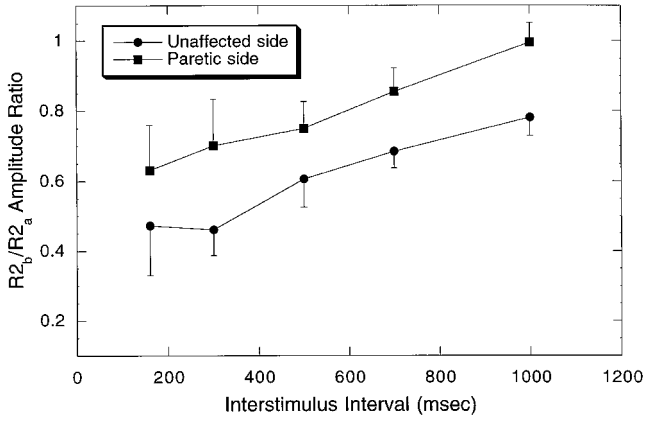

Figure 3. Comparison of blink reflex recovery curves (mean and SEM) for patients with residual weakness after Bell's palsy with stimulation of the supraorbital nerve on the weak side (■) and the unaffected side (●).

us to pinpoint individual intervals with enhanced recovery, the curves appear most different at the shortest intervals. For example, the difference between the mean $R2_b$-to-$R2_a$ ratio at an interstimulus interval of 160 msec was 0.35 versus 0.26 when stimulating the paretic versus the nonparetic side ($p = 0.034$), and at 300 msec the mean $R2_b$-to-$R2_a$ ratio was 0.42 versus 0.26 ($p = 0.031$). Stimulation of either side produced a significantly higher $R2_b$-to-$R2_a$ ratio at an interstimulus interval of 160 msec compared with control subjects ($p = 0.0001$); but within the group of patients with residual weakness, the magnitude of the enhanced recovery exhibited a dependence on the side of stimulation.

Discussion. We found enhanced recovery of the blink reflex in patients with unilateral facial weakness. Earlier blink reflex recovery was recorded in the orbicularis oculi muscles bilaterally and was more prominent when evoked by stimulating the supraorbital nerve on the paretic side compared with stimulating the supraorbital nerve on the normal side. This trend toward lateralization of the enhanced excitability is most easily explained on the basis of alterations in the sensory pathways and premotor circuits mediating the R2 component of the blink reflex. Studies[11,12] of patients with brainstem lesions indicate that the R2 component of the blink reflex is produced through polysynaptic pathways in the lower brainstem. The afferent loop of the R2 component of the blink reflex is mediated via the supraorbital branch of the trigeminal nerve, with inputs relayed to the spinal trigeminal nucleus ipsilateral to the side of stimulation and subsequently to bulbopontine R2 interneurons. These project bilaterally to the facial motor nucleus in the pons. Thus several anatomic loci are candidate sites for plastic changes. The enhanced sensitivity of the blink reflex pathway is probably not mediated at the level of the trigeminal afferents because we did not find a significant difference in either the magnitude of the R2 threshold or the sensory threshold between the supraorbital nerve on the paretic and the normal side. Although there was somewhat greater enhancement of R2 recovery in paretic facial muscles, the enhancement occurred bilaterally in facial muscles. Because the enhanced blink reflex recovery occurs to a greater extent when stimulating the affected side, we conclude that the site of sensitization of the blink reflex is most likely to occur within the trigeminal complex or the R2 interneurons rather than both facial nuclei.

This finding of enhanced blink reflex excitability is consistent with previous electrophysiologic studies. Valls–Solé[13] found a larger R2 response on the paretic side of patients recovering from facial palsy, suggesting hyperexcitability of either facial motoneurons or their inputs. Contralateral R1 responses have also been found in patients with Bell's palsy and may reflect unmasking of preexisting trigeminofacial reflex pathways.[14,15]

Adaptive gain modification occurs when the relationship between the magnitude of a stimulus and the amplitude of a reflex response is changed to compensate for a disturbance of the amplitude of the reflex response. Previous kinematic studies also indicated that unilateral facial weakness causes adaptive enhancement of the blink reflex. Studies of blink main sequence slope (relationship of blink peak velocity versus blink amplitude) and eyelid peak velocities during blink in patients recovering from facial weakness suggest that the adaptive gain mechanisms are bilateral.[1,16] Studies of the eyelid peak velocity versus amplitude in monkeys following unilateral weakness induced by botulinum toxin also found bilateral enhancement of the main sequence slope. Additional studies to assess the etiology of this enhancement in rabbits used isotonic weights to impede eyelid closure. Weights produced an increase in the force and EMG activity generated by the orbicularis oculi. Impeding eyelid closure to different degrees showed that the final position of the eyelid at the end of a blink was the driving factor for enhanced orbicularis oculi force, rather than a specific amplitude of blink.[17]

In the current study, enhanced blink excitability was limited to patients with residual weakness and did not occur in the group of patients who recovered from their facial palsy. This suggests that the enhanced excitability of the blink reflex recovery is dependent on ongoing weakness. The feedback mechanism is not clear. The supraorbital nerve has been shown to have a critical role in maintaining the adaptive gain modification of the blink in animal models. Rabbits exhibiting normal adaptation when their blinks were impeded lost the ability for adaptive gain modification after sectioning of the supraorbital nerve.[17] The lack of eyelid closure caused by weakness itself may provide abnormal afferent signals that maintain abnormal gain of the blink reflex. Alternatively, sensory input from dry or inflamed eyes may cause enhancement of the blink reflex in certain situations leading to abnormal eye closure.

Inputs from the cerebral cortex and basal ganglia are known to modulate the blink reflex. Cortical input has been implicated by the findings of depressed unilateral and bilateral R2 components following focal hemispheric lesions.[18] Diseases of the basal ganglia affect the excitability of the blink reflex. Huntington's disease is associated with increased habituation of the blink reflex, whereas in PD the blink reflex is hyperactive. Enhanced sensitivity of the cortex or basal ganglia is an unlikely cause for the enhancement of the blink reflex noted in the current study because supranuclear sensitization would not be expected to result in a lateralized sensitivity of the blink reflex. Additionally, the adaptive gain modification in decerebrate rats was similar to healthy alert rats.[17]

Blepharospasm has been proposed to be caused by an abnormal excitatory drive from the basal ganglia to the facial and other motor brainstem nuclei. This hypothesis is supported by the presence of enhanced

R2 recovery in patients with blepharospasm.[6,9,19,20] Although some cases of blepharospasm may be secondary to lesions in the brainstem or basal ganglia, the majority of cases of blepharospasm are idiopathic. The etiology of the increased excitatory output of the facial motor neurons in these patients is not clear. It is clear that the vast majority of patients with blepharospasm do not have a clinically obvious facial palsy to account for their dystonia, but subtle abnormalities and maladaptive responses involving the afferent and efferent pathways may be important in the etiology of some dystonias.

Recent work on rats[21] proposed a two-step process underlying the pathophysiology of blepharospasm. In the first step, mild striatal dopamine depletion reduced the inhibition of the blink reflex. An additional lesion, slight weakening of the facial nerve, caused blepharospasm. Either of the two lesions alone caused increased excitability of the blink reflex, but spontaneous blepharospasm was induced only with the combination of the two lesions. The development of blepharospasm in only a small fraction of patients with facial weakness[2,22] might be explained on the basis of a relative dopaminergic deficiency, perhaps caused by an underlying acquired insult or a genetic susceptibility. There may be similar mechanisms operative in at least some of the cases of essential blepharospasm in humans. The contribution of a dopaminergic deficit in producing blepharospasm can also be inferred from the normalization of the blink reflex recovery curve in patients with essential blepharospasm after the infusion of apomorphine.[23]

In four patients with blepharospasm[22] there was a disparity in the main sequence relationship between the two eyelids, suggesting divergent influence on the blink reflex as a result of conflicting adaptive needs in a patient with both blepharospasm and Bell's palsy. Although kinematic studies cannot distinguish whether adaptation occurs on the sensory or motor side of the reflex, it is interesting that patients with blepharospasm are noted frequently to display enhanced sensitivity to sensory stimuli such as light. Light is a frequent trigger for blepharospasm. Abnormal ophthalmologic symptoms were present in 57% of 272 patients with blepharospasm. Inflammation of the lid margin and the Meibomian gland margin is diagnosed frequently in early blepharospasm. Some blepharospasm patients with local ocular pathology experience resolution of their eyelid spasms after treatment of their local ocular pathology.

Given the alternative possibilities that the increased excitability of the blink reflex in Bell's palsy could be caused by enhanced supranuclear drive or by abnormal sensory inputs, we would favor the latter explanation in view of the relative lateralization to the afferents on the paretic side. Abnormal sensory input could be caused by eyelid weakness causing incomplete eye closure or the dry, inflamed eyes that result from corneal exposure.

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