Prognostic value of cortical magnetic stimulation in spinal cord injury

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Cortical magnetic stimulation was performed in a consecutive series of 10 patients presenting within 15 days of traumatic spinal cord injury. In those patients with complete paraplegia or quadriplegia, motor evoked potentials at presentation were absent below the level of the lesion. Six months after the injury, potentials had returned in the biceps brachii and abductor pollicis brevis muscles in some quadriplegic cases, but remained absent from the tibialis anterior in all of this group. None of those with a complete lesion made a significant functional recovery. Of the three patients with incomplete quadriplegia, two showed a significant recovery after 6 months. Motor evoked potentials were recordable below the level of the lesion at presentation in these cases, although the latencies were prolonged. In the remaining patient who failed to improve, potentials were unrecordable throughout the study. This small pilot study suggests that cortical magnetic stimulation may be useful in refining the prognosis in patients with an incomplete spinal cord injury.

Keywords: spinal cord injury; cortical magnetic stimulation; motor evoked potentials; prognosis.

Introduction

The prognosis for significant recovery of function following traumatic spinal cord injury (SCI) is poor. At present, the only way of predicting neurological improvement is by clinical examination. Those patients with an incomplete lesion, with some retained motor and/or sensory function below the level of the lesion, have a higher probability of improvement. Thus far, investigative techniques have not been informative in assessing such cases.

In the early 1980s Merton & Morton¹ first described the technique of electrical stimulation of the human motor cortex as a way of measuring central motor conduction time (CMCT). This was superseded by cortical magnetic stimulation (CMS) since this method is painless and more easily performed.^{2,3} This procedure has been used to demonstrate abnormal motor conduction in patients with multiple sclerosis,^{4,5} motor

neuron disease,⁶ hereditary spastic paraparesis,⁷ degenerative ataxic disorders,⁸ and cervical spondylosis.^{9,10} Furthermore, absent motor conduction in the acute phase of stroke has been shown to predict a poor outcome at 2¹¹ and 12¹² months.

The aim of this pilot study was to assess whether cortical magnetic stimulation performed soon after acute spinal cord injury is able to predict the degree of neurological improvement attained by 6 months post injury.

Methods

Patients

A consecutive series of 10 patients (nine male and one female) presenting to the Spinal Injuries Unit at Pinderfields Hospital within 15 days of a traumatic spinal cord injury were recruited for the study. The mean age of the group was 29.9 years (range 16–54). Each patient gave informed consent to take part in the study which was approved by the local ethical committee. Patients with a history of epilepsy, cognitive impairment,

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psychiatric disorder, cardiac pacemaker in situ, intracranial or intraspinal metal artefacts, pregnancy or lactation were excluded from the study.

Each patient underwent a standardised clinical and neurophysiological examination as soon as possible after admission and again 6 months following the injury.

Clinical evaluation

The standardised clinical examination was based on that used in the American National Acute Spinal Cord Injury Study.¹³ Using the MRC 5-point grading scale, power was assessed bilaterally in deltoid, biceps, triceps, flexor carpi radialis, extensor carpi radialis, and abductor pollicis brevis in the upper limbs, and iliopsoas, hip extensors, hamstrings, quadriceps, tibialis anterior, gastrocnemius, and extensor hallucis longus in the lower limbs. Scores from all 26 muscle groups were summated to give an overall motor score (maximum 130).

Pinprick and light touch sensation were tested in the 29 dermatomes from C2 to S5 bilaterally and scored in each as 0 for absent, 1 impaired or 2 normal. The scores were summated to provide overall pain and light touch scores (maximum 116).

Patients were classified as quadriplegic if T1 innervated muscles were weak, with or without weakness in more cephalad myotomes. Paraplegia was defined as weakness caudal to T1 innervated myotomes. Cord lesions were divided into complete and incomplete categories depending on whether motor and sensory function were totally or partially absent below the level of the lesion.

Technique

Transcranial magnetic stimulation was performed using a Novamatrix Magstim 200 machine (Novametric, Bristol, UK). A circular coil centred flat on the scalp over Cz (international 10/20 system) was used when targeting abductor pollicis brevis (APB) and biceps brachii (BB) muscles. A figure-of-8 coil over Fz was used for recording from tibialis anterior (TA). The coil position had to be altered slightly in each case to achieve optimal excitation. Responses were

recorded from surface electrodes using a Dantec Counterpoint machine (Dantec, Wales).

Threshold was established by slowly increasing stimulus strength. Once achieved, the stimulus was then increased by a further 20% and the latency and amplitude of compound muscle action potentials recorded. Five responses were recorded, each with voluntary activation. The shortest latency together with the highest amplitude response (measured peak to peak) were used for analysis.

Peripheral conduction time to BB was measured directly following stimulation at Erb's point. In APB and TA, the 'F' response latencies were utilised and peripheral conduction time was calculated using the formula $((f - 1)/2)$ as described previously.^{5,6} CMCT was calculated by subtracting the peripheral latency from the cortical latency after transcranial magnetic stimulation. Normal values were established using age-matched controls. For CMCT, the mean plus 2 standard deviations was taken as the upper limit of normal (BB = 9.5 ms, APB = 9.2 ms, TA = 16.2 ms). For amplitude measurements, the mean minus 2 standard deviations was taken as the lower limit of normal (BB = 3 mV, APB = 2 mV, TA = 3 mV).

Results

Patients

The characteristics of the patients are detailed in Table I along with the aetiology of the injury and the radiographic findings. Three paraplegic patients had a complete lesion; no cases of incomplete paraplegia were included in the series. In three quadriplegic patients the lesion was incomplete and in four complete.

Assessment intervals

The mean delay in performing the initial clinical assessment of 6.2 days (Table II) was largely attributable to late referral of cases to the spinal injuries unit. The patients with a complete quadriplegia were referred within three days, whereas those with a paraplegia or incomplete quadriplegia were referred between 3 and 15 days post injury.

Table I Patient details and nature of injuries

Patient number	Sex	Age (years)	Cause of injury	Radiological findings	Quadriplegic or paraplegic (Q or P)	Complete or incomplete (C or I)
1	F	31	RTA	Fracture-dislocation C6/7	Q	C
2	M	17	Speedway riding	Crush fracture T12/L1	P	C
3	M	24	RTA	Burst C5	Q	I
4	M	45	Handgliding	Fused C2/3 only	Q	C
5	M	54	RTA	Shattered C5	Q	C
6	M	24	Shallow dive	Wedge fracture C5	Q	I
7	M	33	RTA	Fracture-dislocation T2/3	P	C
8	M	16	RTA	Fracture-dislocation T12/L1	P	C
9	M	25	Gymnastics	Fracture-dislocation C4/5	Q	C
10	M	30	RTA	Fracture arch C2	Q	I

RTA = road traffic accident

Table II Change in clinical scores

Type	Patient number	Assessment time (days from injury)		Motor score			Light touch score			Pinprick score		
		1st	2nd	1st	2nd	2nd-1st	1st	2nd	2nd-1st	1st	2nd	2nd-1st
Paraplegia complete	2	3	203	60	88	+28	76	84	+8	76	84	+8
	7	15	202	60	60	0	36	36	0	36	36	0
	8	13	181	60	60	0	78	78	0	78	78	0
Quadriplegia incomplete	3	5	188	34	38	+4	82	60	-22	82	60	-22
	6	12	206	88	116	+28	64	114	+50	64	113	+49
	10	6	195	53	119	+66	116	116	0	64	74	+10
Quadriplegia complete	1	3	275	16	36	+20	14	24	+10	14	24	+10
	4	2	187	0	74	+74	22	14	-8	22	6	-16
	5	1	195	0	17	+17	16	20	+4	16	12	-4
	9	2	197	2	9	+7	14	14	0	14	14	0

The second 6 month clinical assessment was performed after a mean of 203 days.

The initial neurophysiological assessment was performed a mean of 12.4 days after the injury (Table III). The distribution of assessment times was skewed due to one examination 43 days post injury. This patient required ventilatory support within a day of admission, soon after the clinical examination had been done. The second magnetic stimulation was completed a mean of 190 days post injury. The delay compared with the clinical examination was increased by difficulties in arranging the latter in case 1 following discharge.

Paraplegia (complete)

Clinical improvement occurred only in one patient with such a lesion (patient 2, Table II), but he remained wheelchair bound. Compound muscle action potentials could not be elicited in any of these patients at presentation or at 6 months post injury (Table III). Patient 8 demonstrated abnormal CMCT in APB at both assessments yet power in this muscle was normal throughout.

Quadriplegia (incomplete)

Significant clinical improvement occurred in patients 6 and 10 who were eventually able to return to their former employment with little residual disability (Table II). CMCT was abnormal below the level of the lesion in each case when first examined, but was clearly demonstrable compared with the other patient in this group (Table III). Although CMCT tended to improve over the course of the study, it only returned to normal in TA in patient 6 and APB in patient 10.

The other patient in this group did not make a significant improvement, although the severity of the motor lesion soon after injury was greater in this case. CMCT could not be recorded below the level of the lesion in this case throughout the study.

Quadriplegia (complete)

Patients 1, 5 and 9 suffered a poor outcome from spinal cord injury (Table II). Although patient 4 showed a large increase in motor

score by 6 months, this was not translated into an equivalent functional improvement; he continues to use a wheelchair and has little useful upper limb function.

At the first examination, CMCT was absent in all muscle groups in these patients except for biceps in case 1 in whom it became abnormal by the second assessment (Table III). In patient 5, a potential was recordable in biceps by the second test which was associated with an increase in power from grade 3 to 4. In patient 4, the better clinical outcome was associated with recordable potentials in biceps and APB by the time of the second assessment.

The amplitude of the compound muscle action potential following magnetic stimulation showed considerable variation, but in general was abnormally low when the latency was increased (Table III). However, it proved to be a less reliable indicator of outcome compared with CMCT.

Discussion

Using electrical^{14,15} and magnetic^{16,17} stimulation, it has been shown that motor evoked potentials are abnormal several months to years after traumatic SCI. To our knowledge, the only study to examine the prognostic value of central motor conduction time in the acute phase of SCI was that of Tegenthoff.¹⁸ Although data on all patients are not presented, it is stated that 'the recovery of lost motor evoked potentials in a few patients preceded the favourable clinical outcome'. It is difficult to draw firm conclusions from the present pilot study but valuable pointers can be gained for the direction of future work.

Cortical magnetic stimulation does not appear to have a prognostic value in complete SCI, whether in the paraplegic or quadriplegic patient. Reappearance of motor potentials in the upper limbs of some quadriplegic patients was seen after 6 months, so CMCT seems to parallel improvement but not predict it in these cases. In contrast, motor potentials were elicited in the acute phase in quadriplegic patients with an incomplete lesion who went on to make significant functional improvement, even though the latencies were prolonged. This

Table III Change in central motor conduction time (CMCT–ms) and amplitude (mV) measured during activation of muscle

Type	Patient number	Assessment time (days from injury)		Biceps brachii						Abductor pollicis brevis						Tibialis anterior					
				CMCT			Amplitude			CMCT			Amplitude			CMCT			Amplitude		
		1st	2nd	1st	2nd	2nd–1st	1st	2nd	2nd–1st	1st	2nd	2nd–1st	1st	2nd	2nd–1st	1st	2nd	2nd–1st	1st	2nd	2nd–1st
Paraplegia complete	2	10	185	6.4	6.0	–0.4	3.0	6.6	+3.6	8.5	9.0	+0.5	7.0	7.0	0	NR	NR	—	NR	NR	—
	7	16	194	8.3	7.0	–1.3	3.0	2.5	–0.5	6.8	4.7	–2.1	1.0	1.0	0	NR	NR	—	NR	NR	—
	8	13	181	7.8	7.0	–0.8	1.0	1.0	0	12.7	12.1	–0.6	1.0	1.5	+0.5	NR	NR	—	NR	NR	—
Quadriplegia incomplete	3	8	190	7.0	7.1	+0.1	8.0	6.0	–2.0	NR	NR	—	NR	NR	—	NR	NR	—	NR	NR	—
	6	13	206	4.5	6.2	+1.7	1.8	4.0	+2.2	10.8	10.6	–0.2	0.1	3.0	+2.9	19.0	10.5	–8.5	0.5	0.7	+0.2
	10	8	195	14.2	13.9	–0.3	0.2	0.5	+0.3	11.8	6.6	–5.2	1.0	1.0	0	22.3	20.1	–2.2	1.0	1.0	0
Quadriplegia complete	1	5	180	6.1	10.0	+3.9	0.7	0.5	–0.2	NR	NR	—	NR	NR	—	NR	NR	—	NR	NR	—
	4	5	182	NR	14.2	—	NR	0.4	—	NR	17.2	—	NR	0.3	—	NR	NR	—	NR	NR	—
	5	43	197	NR	9.6	—	NR	1.0	—	NR	NR	—	NR	NR	—	NR	NR	—	NR	NR	—
	9	3	186	NR	NR	—	NR	NR	—	NR	NR	—	NR	NR	—	NR	NR	—	NR	NR	—

NR = not recordable; CMCT upper limits of normal: BB = 9.5 ms, APB = 9.2 ms, TA = 16.2 ms; Amplitude lower limits of normal: BB = 3 mV, APB = 2 mV, TA = 3 mV.

suggests that motor evoked potentials may be able to refine the prognosis in patients with incomplete lesions. It remains to be seen whether the presence of motor evoked potentials is superior to clinical subdivision on the basis of the extent of the motor and sensory sparing.¹⁹

Studying motor potentials in the acute phase of spinal injury provides practical difficulties. Recruitment of patients was a major problem because of late referral from the primary admitting hospital. Also, rapid clinical deterioration in some quadriplegic patients necessitates transfer to the intensive care unit where studies cannot be undertaken. One patient (patient 5) was left in the trial having undergone clinical assessment before a respiratory arrest and hence the neurophysiological follow up assessments were delayed. Further studies of this sort will therefore require rapid transfer of SCI patients to specialist units. This is also to be encouraged to allow early treatment trials and/or steroid therapy.¹³ Further studies will also need to be multicentred to collect sufficient patients for subgroup analysis, particularly those with incomplete lesions subdivided by the 1992 Revised American Spinal Injury Association Classification.¹⁹

Animal studies have suggested that motor evoked potentials may be of some prognostic value. Using direct recordings of electrically elicited MEPs, it has been shown that weight-drop spinal cord injury in rats results in increased latency or loss of MEPs

below the lesion.^{20,21} The recovery of the MEP mirrored clinical improvement in the animals. In similar studies in cats,²² MEPs recovered in some animals 24 hours before ambulation was regained suggesting that the test may have a prognostic role in SCI.

Previous studies have evaluated the prognostic value of the somatosensory evoked potential (SEP) following SCI. Whilst it has been suggested that the early preservation of SEPs correlates with a good neurological outcome,²³ this has not been found by all workers.^{24–26}

In conclusion, further multicentre studies should be developed to examine the prognostic ability of cortical magnetic stimulation in patients with incomplete lesions following spinal cord injury. It may be of more value in future studies to combine motor and sensory evoked potential studies to provide an overview of both motor and sensory function. Empirically this seems more likely to correlate with neurological improvement.

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