MAGNETIC STIMULATION OF BICEPS AFTER INTERCOSTAL CROSS-INNervation FOR BRACHIAL PLEXUS PALSY

A STUDY OF MOTOR EVOKED POTENTIALS IN 25 PATIENTS

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We studied the motor evoked potentials (MEP) in the biceps of 25 patients with traumatic brachial plexus palsy from root avulsion after cross-innervation by intercostal nerves. We used transcranial, transcervical and transthoracic magnetic stimulation at 8 to 235 months (mean 51) after transfer of intercostal nerves to the musculocutaneous nerve.

Biceps strength recovered to MRC grade 2 in eight patients, grade 3 in three and grade 4 in 14. The mean latency of the MEP in the normal biceps on transcranial stimulation was 12.5 ± 1.3 ms and on transcervical stimulation 6.3 ± 1.1 ms. After intercostal reinnervation the mean latency on transcranial stimulation was 21.7 ± 4.5 ms and on transthoracic stimulation 11.6 ± 3.8 ms.

The latency of the biceps MEP after reinnervation by intercostal nerves on transcranial and transthoracic magnetic stimulation correlated well with the duration of follow-up and the latency of the MEP on transthoracic magnetic stimulation correlated significantly with muscle power.

The use of transcranial pulsed magnetic stimulation to the brain to evoke motor potentials was described by Barker, Jalinos and Freeston (1985), and is non-invasive and well tolerated.

PATIENTS AND METHODS

We treated 25 patients with brachial plexus palsy due to root avulsion by transfer of intercostal nerves to the musculocutaneous nerve. Recovery in the biceps was evaluated by magnetic stimulation using a transcranial stimulus in all, transcervical for the normal side, and transthoracic for the repaired side over a mean period of 51 months (8 to 235), with informed consent from the patients. There were 24 men and one woman; the right side was involved in 15 and the left in ten (Table I). Thirteen patients had upper plexus palsy and 12 had total brachial plexus palsy. All showed root avulsion on myelography, with at least the T1 root preserved in the upper plexus cases.

Intercostal nerves ranging from T2 to T7 were transferred; two intercostal nerves were used in nine patients, three nerves in 12, four nerves in three and six nerves in one. Twenty-one patients also had other nerve repairs including nerve grafts from the cervical nerves, transfer of the spinal accessory nerve and other intercostal transfers. None of these repairs was direct to the musculocutaneous nerve, some were to the upper trunk (Table I). The musculocutaneous nerve was repaired only by intercostal nerve transfer.

We assessed motor power on the MRC scale (MRC 1954). Magnetic stimulation was provided by a stimulator (SMN-1100, Nihon Kohden, Japan) used with a transcranial coil (YM-101B) consisting of a 0.5 Tesla round coil 15 cm in diameter, or a trans-spinal figure-of-eight coil (YM-111B) of 1 Tesla, with double coils each 10 cm in diameter (Ueno, Tashiro and Harada 1988). MEPs were recorded by a Neuropack Four Mini (MEB5304, Nihon Kohden, Japan) using surface electrodes of silver and silver chloride, 1 cm in diameter, placed at 5 cm intervals on both injured and normal sides. Transcranial stimulation was over the midpoint of the parietal motor cortex;

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Fig. 1

Results of transthoracic magnetic stimulation at T4 in case 13, showing an MEP latency of 8.7 ms and a maximum amplitude of 2670 μ V. The normal side showed no response to transthoracic stimulation but this was produced by transcervical stimulation (see Fig. 2).

Fig. 2

Results of transcranial magnetic stimulation in case 13, showing MEPs in both normal and repaired biceps. The normal side showed a latency of 12.6 ms and an amplitude of 8 mV; on the repaired side the latency was 16.6 ms and amplitude 990 μ V.

transcervical stimulation was at C5 and transthoracic stimulation at T4. Responses to magnetic stimulation were obtained four times at each test from relaxed muscles, with the subjects seated in a chair.

We recorded the maximum amplitude and minimum latency of the MEP at each test. Figures 1 and 2 show typical recordings from normal and repaired biceps. We analysed these results in relation to the duration of follow-up, the site of stimulation and the level of recovery of muscle strength.

RESULTS

All 13 patients with upper plexus palsy gained a stable shoulder and all 12 with total plexus palsy had some useful sensory recovery in the median nerve area. Manual

Fig. 3

Duration of follow-up and MEP latency after *transthoracic* stimulation. There is a strong inverse correlation ($r = 0.559$, $n = 25$, $p < 0.004$).

Fig. 4

Duration of follow-up and *transcranial* MEP latency. There is a strong inverse correlation ($r = 0.532$, $n = 22$, $p < 0.02$).

testing of the intercostally innervated biceps showed muscle strength of grade 2 in eight patients, grade 3 in three and grade 4 in 14 (Table I). MEPs were recorded in all 25 patients after transcervical (normal side) and transthoracic (repaired side) magnetic stimulation, but in three cases, all with grade 2 power, transcranial magnetic stimulation failed to evoke MEPs.

Detailed results are shown in Table II. The mean transcervical latency was 6.3 ± 1.1 ms on the normal side, with mean transthoracic latency of 11.6 ± 3.8 ms at the intercostally innervated biceps. The mean transcervical amplitude of the normal biceps was 4153 ± 3585 μ V and the mean transthoracic amplitude on the repaired side was 951.4 ± 1130.4 μ V. The mean transcranial latency was 12.5 ± 1.3 ms for the normal side and 21.7 ± 4.5 ms on the repaired side. The mean transcranial amplitude was 1377.8 ± 1977 μ V on the normal side and 454.9 ± 410 μ V on the repaired side.

The MEP latency by both transcranial and transthoracic magnetic stimulation of the cross-innervated biceps was significantly decreased; this correlated inversely with the duration of follow-up after repair (Figs 3 and 4), but MEP amplitude on both transcranial and transthoracic stimulation did not correlate significantly

Table I. Details of 25 patients treated for traumatic brachial plexus palsy

Case	Sex	Age at surgery (yr)	Side	Type	Avulsed roots (myelogram)	Intercostal nerves transferred	Other nerve repairs*	Follow-up (mth)	MRC grade
1	M	19	Right	Upper	C6, C7, C8	3, 4		18	3
2	M	26	Right	Upper	C6, C7	3, 4, 5	SAN → SSN; C5 → UT (NG)	44	4
3	F	53	Left	Upper	C5	3, 4, 5	SAN → UTPD	90	4
4	M	23	Left	Total	C7, C8, T1	3, 4, 5	ICN 6, 7, 8 → MN; C5 → SSN (NG); C5, C6 → UTPD (NG)	44	4
5	M	48	Left	Upper	C8	3, 4, 5, 6	SAN → SSN; C6 → PC (NG)	52	4
6	M	24	Right	Total	C8, T1	3, 4, 5, 6	C5 → PC (NG)	71	4
7	M	22	Right	Upper	C6, C7, C8	4, 5, 6	C5 → SSN, UTPD (NG)	46	4
8	M	18	Left	Upper	C6, C7, C8	3, 4, 5		17	2
9	M	24	Right	Total	C6, C7, C8, T1	3, 4, 5, 6	SAN → C5	78	4
10	M	22	Right	Total	C6, C7, C8, T1	3, 4	ICN 5, 6, 7, 8 → MN; C5, C6 → PC (NG)	61	4
11	M	26	Left	Total	C8, T1	2, 3, 4, 5, 6, 7	C5, C6 → PC (NG)	51	4
12	M	24	Right	Total	C7, C8, T1	3, 4	ICN 5, 6, 7 → MN; SAN → SSN; C5, C6 → PC (NG)	67	4
13	M	27	Left	Upper	C7, C8	3, 4, 5	C5 → SSN (NG); C5, C6 → UTPD (NG)	50	4
14	M	22	Right	Upper	C5, C6, C7	4, 5, 6	ICN 2, 3 → AXN; SAN → SSN	47	4
15	M	28	Right	Total	C8, T1	4, 5	ICN 6, 7 → MN; C5, C6 → PC (NG)	65	2
16	M	18	Right	Upper	C5, C6, C7, C8	5, 6	ICN 3, 4 → AXN	20	2
17	M	38	Left	Upper	C6, C7, C8	2, 3, 4		235	4
18	M	23	Left	Total	C6, C7, C8, T1	4, 5	SAN → UTPD (NG); SCN → MTAD (NG)	28	2
19	M	25	Right	Upper	C6, C7, C8	3, 4		8	2
20	M	19	Right	Upper	C5, C6	3, 4	SAN → SSN	9	2
21	M	31	Left	Total	C7, C8, T1	5, 6, 7	C5, C6 → PC (NG)	80	2
22	M	22	Right	Upper	C6, C7, C8	3, 4, 5	SAN → SSN (NG)	18	3
23	M	22	Left	Total	C6, C7, C8, T1	2, 3, 4	ICN 5, 6 → MN; C5 → SSN (NG); SAN → TDN (NG)	19	3
24	M	27	Right	Total	C7, C8, T1	2, 3, 4	ICN 5, 6, 7 → MN; C5 → SSN (NG); C6 → PC (NG)	59	4
25	M	17	Right	Total	C6, C7, C8, T1	3, 4	ICN(5) → TDN (NG); ICN(6, 7) → MN	9	2

* SAN, spinal accessory nerve; SSN, suprascapular nerve; UT, upper trunk; NG, with intercalated nerve graft; UTPD, upper trunk posterior division; ICN, intercostal nerve; MN, median nerve; PC, posterior cord; AXN, axillary nerve; MTAD, middle trunk anterior division; TDN, thoracodorsal nerve

with time. Motor recovery of the biceps, from MRC grade 2 to grade 4, after reinnervation by intercostal nerves, correlated significantly with MEP latency on transthoracic stimulation (Fig. 5) but not significantly with that on transcranial stimulation. The mean difference (central motor conduction time) between the latency for transcranial and trans-spinal magnetic stimulation was 6.2 ± 1.6 ms on the normal side and 10.9 ± 3.6 ms on the intercostally innervated side. This increased central motor conduction time on the injured side did not change significantly with time after nerve transfer.

DISCUSSION

Active flexion at the elbow after the use of an ulnar nerve graft to link intercostal nerves to the musculocutaneous

nerve was first reported by Seddon (1963). Since then, satisfactory results have been reported for intercostal nerve transfer in 33% to 66% of patients (Millesi 1977; Alnot, Jolly and Frot 1981; Narakas 1981; Sedel 1982; Kawai et al 1988). The best results were obtained when cross-innervation by intercostal nerves was performed close to the muscle entry of the musculocutaneous nerve and when it was direct, with no intercalated graft. Nagano et al (1989) reported good results in 82% of 110 adult patients under 40 years of age with transfer less than six months after injury.

Pulsed magnetic field stimulation for monitoring and investigation has important advantages and can be used to evaluate inaccessible portions of peripheral as well as central nerve pathways. It is well tolerated and the stimulation coil can be moved easily from one site to

Table II. Latency and amplitude (mean $\pm$ SD) of motor evoked potentials (MEP) before and after repair in 25 patients

MEP	Transcranial		Transcervical (normal) (n = 25)	Transthoracic (repaired) (n = 25)
	Normal (n = 25)	Repaired (n = 22)		
Latency (ms)	12.5 $\pm$ 1.3	21.7 $\pm$ 4.5	6.3 $\pm$ 1.1	11.6 $\pm$ 3.8
Amplitude (μ V)	1377.8 $\pm$ 1977	454.9 $\pm$ 410	4153 $\pm$ 3585	951.4 $\pm$ 1130.4

Fig. 5

Relation between transthoracic MEP latency and strength in the reinnervated biceps. There is a significant difference in latency between grades 2 and 4. The mean latency of grade 2 was 15.2 ± 4.4 ms, of grade 3, 12.2 ± 2.2 ms and of grade 4, 9.5 ± 1.6 ms.

another. No scalp preparation is necessary since no direct electrical contact is needed, and responses can be obtained from relaxed muscles.

Selective magnetic stimulation of normal intercostal muscles from the correct area of the motor cortex of the brain is difficult, but an intercostally innervated biceps is more easily stimulated; the cross-innervated biceps appears to have a low threshold. The results of transthoracic stimulation of the intercostally innervated biceps, however, correlate much more closely with the period of time after cross-innervation. It seems therefore that the peripheral link between the anterior horn cell and muscle is more closely associated with recovery by nerve regeneration than the central link between the motor cortex and the anterior horn cell. The central motor conduction time was consistent irrespective of follow-up time.

It has been reported that muscle power continues to improve for 55 months or more after human peripheral nerve suture (Donoso, Ballantyne and Hansen 1979). Our study tends to confirm this for up to 235 months after cross-innervation by the intercostal nerves: MEP latency was inversely related to postoperative time period. The latency of the MEP resulting from magnetic stimulation helped in the evaluation of the motor recovery conditions but the amplitude evoked by magnetic stimulation did not always correlate with muscle power.

MEP latency can provide a quantitative index of peripheral nerve regeneration, and magnetic stimulation is a convenient method for recording motor recovery after nerve surgery.

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