Electroencephalography and clinical Neurophysiology, 1983, 56: 583–596
Elsevier Scientific Publishers Ireland, Ltd.

CENTRAL SOMATOSENSORY CONDUCTION TIME AND SHORT LATENCY SOMATOSENSORY EVOKED POTENTIALS IN POST-TRAUMATIC COMA

E. RUMPL, M. PRUGGER, F. GERSTENBRAND, J.M. HACKL and A. PALLUA

University Clinic of Neurology and Anaesthesiology, University of Innsbruck, A-6020 Innsbruck (Austria)

(Accepted for publication: June 20, 1983)

The clinical and electroencephalographic evaluation of post-traumatic comatose patients is severely impaired by barbiturates used increasingly in the treatment of brain oedema (Miller 1979). Methods of assessing brain function that are not influenced by sedative drugs were found by the application of multimodality evoked potentials (Greenberg et al. 1977a,b, 1981; Lindsay et al. 1981). Since paths involved in early somatosensory evoked potentials (SEPs) traverse a great extent of the nervous system they seem to be of special clinical utility in comatose states. Measurement of central somatosensory conduction time is especially regarded as useful in predicting the outcome of post-traumatic coma (Hume and Cant 1981). The conduction time within the central somatosensory pathways can be investigated by comparing somatosensory evoked potentials recorded from the scalp and neck following median nerve stimulation. The difference between the peak latency of the major neck potential and the initial negative scalp potential is of the order of 6.0 ± 0.5 msec and varies little in different series of normal young adults (Mathews et al. 1974; Cracco and Cracco 1976; Jones 1977; Hume and Cant 1978; Hume et al. 1979; Symon et al. 1979; Desmedt and Cheron 1980; Eisen and Odusote 1980; Yamada et al. 1980). This study correlates central somatosensory conduction time and components of early SEPs with different stages of post-traumatic coma in order to determine their diagnostic and prognostic value in the evolution of post-traumatic comatose patients.

Case material and Methods

Normal data were obtained from 14 healthy persons (average age 27 years, varying from 18 to 52 years). Fourty-four patients were studied in post-traumatic coma. Thirty-four patients (average age 28 years, varying from 13 to 63 years) were studied in the acute stage (within the first 2 days after the brain injury). Twenty-three patients (average age 23 years, varying from 13 to 54 years) were investigated in a prolonged comatose state (days 3–12 after brain injury). All patients had closed head injuries and demonstrated signs of brain stem dysfunction. The patients underwent the usual neuroradiological examinations (CT scan, cerebral angiography) and appropriate management in the intensive care unit. In most patients barbiturate anaesthesia for treatment of intracranial hypertension was used. Ten patients were examined after recovery from coma within 30 days after trauma. Six patients were studied in brain death. Patients suffering from severe metabolic disturbances were excluded from the study.

The patients were classified neurologically in stages 1–4 of the midbrain syndrome (MBS) according to Gerstenbrand and Lücking (1970) and in stages 1 and 2 of the bulbar brain syndrome (BBS) described previously (Rumpl et al. 1979). These stages usually characterize the well known rostro-caudal deterioration in patients with supratentorial lesions and secondary brain stem involvement (McNealy and Plum 1962; Plum and Posner 1966a). Neurological signs different from

0013-4649/83/$03.00

this expected rostro-caudal deterioration may be found in cases of primary brain stem injuries. The CT scan is diagnostic and eliminates a supratentorial lesion causing secondary brain stem dysfunction (Plum and Posner 1980). In prolonged coma neurological findings are close to those seen in the acute stage and only slight changes can be observed (Avenarius and Gerstenbrand 1977; Rumpl et al. 1982). According to Jennet and Bond (1975) the outcome of patients was classified in 4 categories — death, severe disability, moderate disability and good recovery. The category severe disability includes patients in an apallic (vegetative) state.

Square-wave pulses of 0.2 msec duration were applied at a rate of 5/sec to the median nerve at the wrist with a bipolar surface nerve stimulator. The cathode was placed proximally. Stimulus intensity was increased until a thumb twitch was produced or, in curarized patients, until an evoked potential was recorded from the neck (Hume and Cant 1981). The responses were recorded with tin/lead disc electrodes placed over the seventh cervical vertebra and over the central area of the scalp contralateral to the stimulated wrist (C3 and C4, International 10-20 system). The reference electrode was placed over the midforebrain (Fpz). Two series of 512 responses were averaged and recorded simultaneously from cervical spine Cv7 and the contralateral scalp on each side. Sweep velocity was 5 msec/div, the selected frequency range was between 8 (LF) and 800 Hz (HF). Heart and respiratory rate were carefully noted as well as body movements. Increase of heart rate after the start of stimulation may point to some painful perception of the stimulus; intracranial pressure may increase in this case and therefore stimulation was discontinued if any change of the patient's behavior could be observed.

According to Hume and Cant (1978), Eisen and Odusote (1980) and Hume et al. (1982) the SEPs were termed N10, N12 and N14, when recorded from the neck, and P15, N20, P20, N25, P25, P30, N35 and P45 when recorded from the scalp. The differences in peak latency between N14 and N20, the central conduction times (CCT) and the amplitude ratios (AR) between the peak of N14 and the subsequent positivity and the peak of N20 and subsequent positivity (P20 or P25) were measured and calculated for each side. Measurements of latencies and amplitudes were made on photographs. A clear difference in SEP components (amplitude ratio, wave forms, number of positive/negative waves) between the hemispheres was classified as asymmetry. Further, the absence of SEP responses from one or both hemispheres was noted. For statistical analysis the *t* test for unpaired samples was used.

Results

General observations

A typical trace of a cervical SEP and of a scalp short latency SEP from a healthy young subject is presented in Fig. 1. The components analysed in this study, the CCT and AR are indicated. Latencies of different cervical SEPs and scalp SEPs in

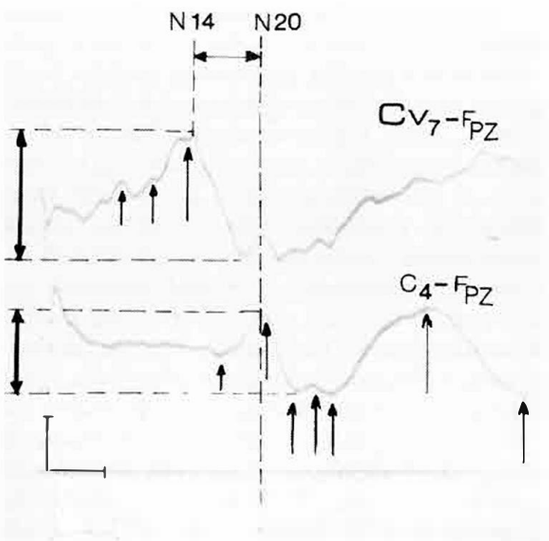

Fig. 1. Trace of cervical SEP (upper channel) and scalp short latency SEP (lower channel) over the right hemisphere from a 22-year-old normal female. The most frequently found positive or negative (upward deflection) components N10, N12, N14 on cervical spine Cv7 and P15, N20, P22, N25, P25, N35 and P45 on scalp are marked by arrows. Further CCT — latency between N14 and N20 — and the amplitudes used for calculation of AR are indicated; 2.5 μV; 5 msec/div.

TABLE I

Latencies of cervical SEP (Cv7) and short latency scalp SEP (C3 or C4) in normal persons, in patients in acute and prolonged coma and in patients during recovery. P45 was usually not found within 50 msec post stimulus under pathological conditions. Mean latencies are expressed in msec ± S.D. No difference of significance in comparison to normals were found in latencies of the different components. Absent SEPs are excluded from calculation.

	N10	N12	N14	P15	N20	P20	P25	N25	P30	N35	P45
Normals (average age 27 ±7 years) (N = 14)											
Right	9.9	12.5	14.1	16.4	19.8	22.4	25.0	26.1	30.3	33.6	42.5
S.D.	0.8	0.9	0.9	1.4	1.3	1.1	1.6	2.8	0.9	1.7	2.4
Left	9.9	12.3	14.2	16.5	19.9	22.5	25.9	27.0	30.9	34.1	40.2
S.D.	0.6	0.6	0.9	1.1	0.8	1.5	1.6	1.8	1.0	2.2	3.7
Acute coma (average age 28 ± 15 years) (N = 34)											
Right	9.6	12.0	13.9	15.8	20.5	22.2	25.1	25.2	29.8	36.8	
S.D.	1.0	1.3	1.4	1.2	1.6	0.8	1.7	1.8	2.5	3.5	
Left	9.7	12.0	13.9	16.8	20.6	22.4	25.3	26.1	30.3	35.1	
S.D.	1.1	1.3	1.4	1.6	1.7	1.0	1.7	2.0	2.9	2.5	
Prolonged coma (average age 23 ± 9 years) (N = 23)											
Right	9.8	12.2	14.1	16.9	21.1	22.2	24.9	26.0	29.9	34.8	
S.D.	1.0	1.0	1.1	1.5	1.9	0.6	1.2	2.1	3.1	3.5	
Left	9.7	12.1	14.0	17.0	20.9	21.8	24.9	26.1	30.5	37.9	
S.D.	1.1	0.9	1.2	1.2	1.4	1.5	1.5	2.1	2.5	5.3	
Recovery (average age 20 ± 3 years) (N = 10)											
Right	9.6	11.8	13.8	16.2	20.1	22.3	24.7	25.5	30.1	36.6	
S.D.	0.5	0.7	1.1	1.3	1.2	1.0	1.0	1.6	5.7	4.5	
Left	9.8	11.9	13.7	17.0	20.1	22.1	25.5	29.7	29.7	36.5	
S.D.	0.4	0.9	0.8	1.8	1.6	0.9	1.6	2.6	2.6	4.5	

normal persons, in patients in acute and prolonged coma and in patients at the recovery stage are presented in Table I. Only the first 6 components listed in Table I are really of relevance in this study, because the significance of the later components is limited by the use of a single pair of scalp electrodes. However it might be useful to show that both the latencies of N20 and P20 and the latencies of the later scalp components did not differ significantly in records made from normals, from patients in acute and prolonged coma or during recovery. Components behind N20 and P20 were found in all patients in prolonged coma and during recovery and were only absent in 6 patients in the acute stage of coma.

There was a significant increase ($P < 0.001$) of CCT in acute coma followed by a more pronounced increase of CCT in prolonged coma in comparison to normal persons (Table II). During recovery a decrease of CCT was noted. AR decreased in acute as well as in prolonged coma and increased again during recovery. Patients with primary brain stem injuries showed CCTs some-what closer to normals in acute coma but a highly significant increase ($P < 0.001$) of CCT in pro-longed coma. ARs were usually lower in cases suffering from primary brain stem injuries both in acute and prolonged coma if compared with the AR of all comatose patients.

Special observations in acute coma (within 2 days after injury)

Prognostic value

All patients who made good recovery had CCTs close to those seen in normals. The CCT increased with the worsening of outcome (Table III). The most prolonged CCTs were seen in patients who

TABLE II

Central conduction time (CCT) and amplitude ratio (AR) in normals, in patients in acute and prolonged coma, during recovery, and in patients suffering from primary brain stem injuries in acute as well as in prolonged coma. Increase of CCT in acute and prolonged coma, slight decrease of CCT during recovery. Reduction of AR in acute and prolonged coma, return to normal during recovery. Markedly low AR in cases of primary brain stem impairment. CCT is expressed in msec (S.D). ARs are derived from a simple division amplitude N20/ amplitude N14. Important significant differences in comparison to normals are indicated by 3 symbols (* $P < 0.001$; ** $P < 0.005$, *** $P < 0.05$)

	N	CCT (msec)		AR	
		Right	Left	Right	Left
Normals	14	5.8	5.7	1.0	1.0
S.D.		0.4	0.8	0.6	0.4
Acute coma	34	6.8 *	6.6 *	0.6 ***	0.5 *
S.D.		1.1	1.1	0.6	0.4
Prolonged coma	23	7.1 *	6.9 *	0.5 *	0.5 *
S.D.		1.5	0.9	0.3	0.4
Recovery	10	6.5 *	6.5 *	0.6 ***	0.9
S.D.		0.5	1.0	0.6	0.8
Primary brain stem injury, acute coma	13	6.5 *	6.1 ***	0.4 **	0.3 *
S.D.		0.7	0.8	0.3	0.2
Primary brain stem injury, prolonged coma	10	7.2 *	6.9 *	0.3 ***	0.5 *
S.D.		1.9	1.0	0.2	0.4

died from brain death within 14 days after injury. Patients who remained severely disabled had remarkably asymmetrical CCTs. The CCT to one

TABLE III

CCT and AR of the different outcome categories in acute coma. CCT increases, but AR decreases with worsening of outcome. Note the asymmetry in CCT in the severe outcome group. Important significant differences in comparison to patients with good outcome are indicated by 3 symbols (* $P < 0.001$; ** $P < 0.005$; *** $P < 0.05$).

Acute coma	N	CCT (msec)		AR	
		Right	Left	Right	Left
Good outcome	14	6.1	6.3	1.0	0.7
S.D.		0.5	0.7	0.7	0.6
Moderate disability	7	7.0 **	6.6	0.3 ***	0.4
S.D.		1.1	0.6	0.2	0.2
Severe disability	5	7.5 *	5.9	0.2	0.2
S.D.		0.2	0.8	0.1	0.1
Death	8	7.6 *	8.0 *	0.2 ***	0.3
S.D.		1.4	1.5	0.1	0.1

TABLE IV

CCT and AR of the different outcome categories in acute coma confined to patients suffering from primary brain stem injuries. CCT increases with the worsening of outcome. Note asymmetry of CCT in the severe outcome category and the highly significant difference in comparison to the good outcome category marked by an asterisk (* $P < 0.001$). AR is generally low.

Primary brain stem injury, acute coma	N	CCT (msec)		AR	
		Right	Left	Right	Left
Good outcome	6	6.2	6.2	0.4	0.3
S.D.		0.4	0.9	0.3	0.2
Moderate disability	3	6.6	6.5	0.2	0.3
S.D.		0.8	0.6	0.1	0.2
Severe disability	4	7.5 *	5.9	0.2	0.2
S.D.		0.2	0.7	0.1	0.2
Death	0				

hemisphere was strongly increased in these cases. The ARs of all patients were usually low to the normal mean, but showed close relations to normal values in cases with good outcome. The AR decreased with the worsening of outcome and was low in cases with severe disability outcome and with brain death. Table IV demonstrates that patients in coma mainly due to primary brain stem impact showed a similar increase of CCT with worsening of outcome. The CCT of patients with good outcome did not differ significantly from the CCT of normals. In contrast the AR was clearly reduced in all outcome categories ($P < 0.001$, except $P < 0.02$ on the right hemisphere of the good outcome category).

TABLE V

Asymmetry and absence of scalp SEP in the different outcome categories in acute coma. Patients suffering from primary brain stem impact are listed in parentheses. Most patients who recovered well suffered from primary brain stem involvement. Otherwise the number of asymmetric and absent SEPs increases with worsening of outcome.

	Scalp SEP in acute coma				
	Asymmetric		Absent		
	Right	Left	Right	Left	Both
Good outcome	2 (1)	2 (2)			1 (1)
Moderate disability	3 (2)		2 (1)		
Severe disability	2 (1)				3
Death	2				6

Asymmetries of scalp SEPs were observed in 11 patients in acute coma (Table V). The SEP could be normal on one hemisphere, but in most cases (6 traces) it was distorted over both sides (Fig. 2a,b). Four patients with good recovery had asymmetric SEPs. They all suffered from primary brain stem dysfunction. Scalp SEPs were absent in 7 patients (Table V, Fig. 3a). One patient in coma due to primary brain stem injury with absent SEP from both hemispheres recovered well; he showed early recovery of SEPs in prolonged coma (Fig. 4a, b, c, d). All other patients with totally absent SEPs died or developed severe disability. Two patients with unilaterally absent SEPs were moderately disabled (Fig. 3a, b).

Asymmetries of CCT were seen in 11 patients. Only differences of more than 0.5 msec were noted. Four patients recovered well. Three of them were judged to have primary brain stem injuries. Two patients developed moderate disability, 3 patients remained severely disabled and 2 patients died.

Neurological findings

Twelve out of 14 patients of the good outcome category were classified to early stages of the midbrain syndrome (MBS 1 and 2). Five of them

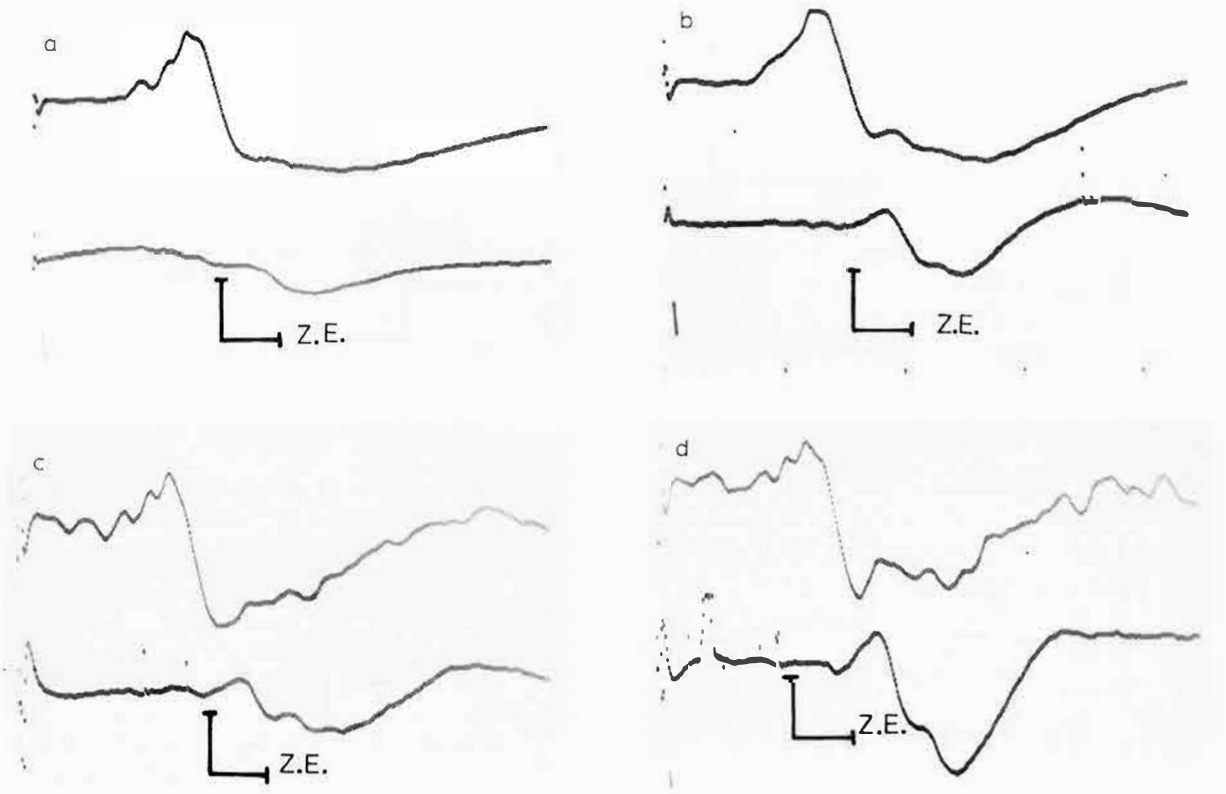

Fig. 2. a: cervical (upper channel) and scalp SEPs (lower channel) over the right hemisphere from a 24-year-old female patient in midbrain syndrome stage 3; acute coma; primary brain stem injury; normal CT scan; severely distorted SEP with small N20 and low AR; 2.5 μV; 5 msec/div. b: cervical and scalp SEPs over the left hemisphere from the same patient as in a; acute coma; better performed SEP and clear difference in AR indicate asymmetry in SEP; CCT delayed on the left (6.3, 6.5 msec); outcome: moderate disability; 2.5 μV; 5 msec/div. c: cervical and scalp SEPs over the right hemisphere from the same patient as in a; prolonged coma; recovery of SEP, but still low AR; 1.25 μV; 5 msec/div. d: cervical and scalp SEPs over the left hemisphere from the same patient as in a; prolonged coma; normal looking scalp response, increase of AR and reduction of CCT on the left (5.7, 5.8 msec); asymmetry in SEP still present; 1.25 μV; 5 msec/div.

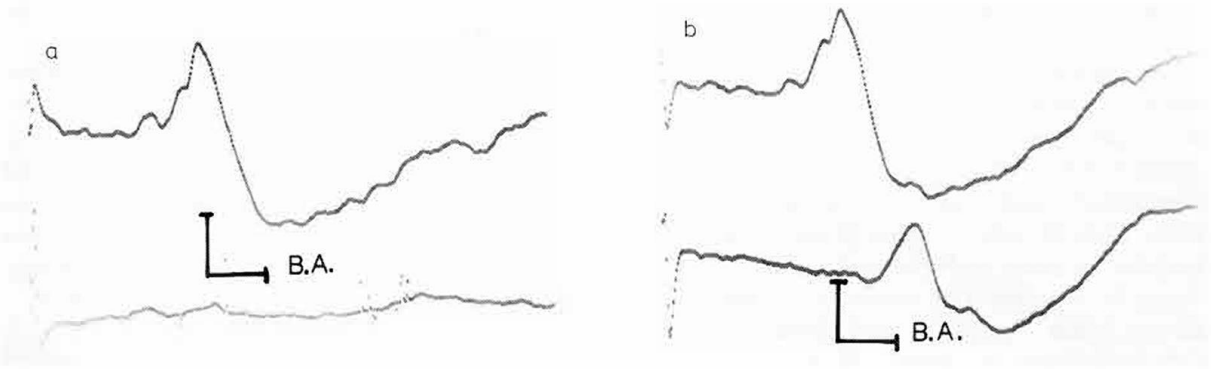

Fig. 3. a: cervical (upper channel) and scalp SEPs (lower channel) over the right hemisphere from a 21-year-old male patient; acute coma; midbrain syndrome stage 2 with signs of uncal herniation; CT scan: large intracerebral haematoma at right basal ganglia level; absent scalp SEP; 1.25 μV; 5 msec/div. b: cervical and scalp SEPs over the left hemisphere from the same patient as in a; good response but low AR; outcome: moderate disability; 1.25 μV; 5 msec/div.

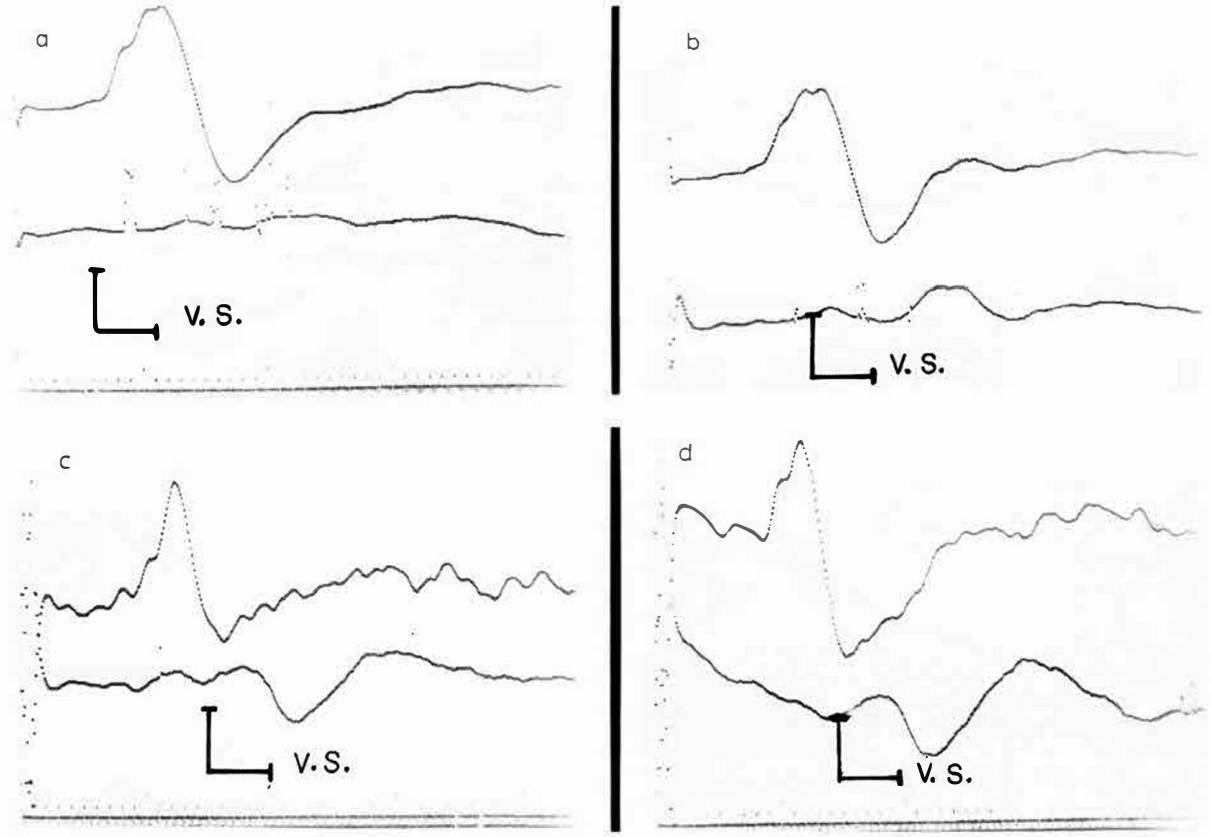

Fig. 4. a: cervical (upper channel) and scalp SEPs (lower channel) over the right hemisphere from a 13-year-old male patient; prolonged coma (day 5 after injury); midbrain syndrome stage 4 — decerebrate posture; primary brain stem injury; CT scan: small area of right frontal contusion; otherwise normal findings; absent scalp SEP in acute coma; now severely distorted SEP, low AR; CCT markedly increased (8.2, 8.7 msec); 1.25 μV; 5 msec/div. b: cervical and scalp SEPs on left hemisphere from the same patient as in a. A more detailed scalp response and higher AR than on the right; CCT more prolonged than on the right hemisphere (9.2, 9.7 msec); outcome: good recovery; 1.25 μV; 5 msec/div. c: cervical and scalp SEPs over the right hemisphere from the same patient as in a; prolonged coma (day 9 after injury); midbrain syndrome stage 2 — decerebrate posture confined to the legs, undirected warding off movements in upper extremities; recovery of scalp response; CCT decreased (6.0, 6.5 msec), AR increased; 1.25 μV; 5 msec/div. d: cervical and scalp SEPs over the left hemisphere from the same patient as in a; prolonged coma (day 9 after injury); recovery of SEP as seen on the right; CCT decreased (5.0, 5.5 msec), AR increased; 1.25 μV; 5 msec/div.

were judged to have primary brain stem injuries (decerebrate posturing confined to the legs). Two patients belonged to MBS 4 (decerebrate posturing), both with primary brain stem injury. In 7 patients with moderate disability outcome 3 patients belonged to MBS 2 (1 primary brain stem injury), 2 to MBS 3 (1 mainly due to direct violence to the brain stem) and 2 belonged to MBS 4 (decerebrate posture due to primary brain stem lesion). The severe disability outcome group included 1 patient in MBS 3 (primary brain stem impact), 3 patients in MBS 4 (2 primary brain stem injuries) and 1 patient in BBS 1. Seven out of 8 patients who died from brain death were in BBS 1; one was in MBS 4.

CT scan findings

The CT scan revealed slight brain oedema in 8 out of 14 patients with good recovery. The CT scan was normal in 2 cases. Small local areas of contusion were found in 6 CT scans. A large area of fronto-basal contusion was found in 1 case. A small frontal intracerebral haematoma was seen in another. One CT scan demonstrated moderate brain oedema and blood in both lateral ventricles. Despite normal or slightly abnormal CT scan findings absent or asymmetric SEPs were found in 5 cases. Four of them were primary brain stem injuries.

In the moderate disability outcome category (7 patients) the CT scan demonstrated normal findings in 2, slight brain oedema in 1 and moderate brain oedema in 2 patients. A large intracerebral haematoma at basal ganglia level combined with marked brain oedema was present in 1 patient. In 1 case severe brain oedema with signs of tentorial herniation was seen. The SEP was absent from one hemisphere in the case of intracerebral haematoma (see Fig. 3a, b) but also in a case suffering from primary brain stem injury with a normal CT scan. Asymmetric SEPs were seen in the case with signs of tentorial herniation, but also in 2 patients suffering from primary brain stem impact with a normal or slightly abnormal CT scan.

The CT scan findings of the severe disability outcome category (5 patients) included severe brain oedema with tentorial herniation in 2 cases, slight brain oedema in 1 case. Two patients had normal CT scans. Absent or asymmetric SEPs were found in 3 patients, one of them thought to have a primary brain stem injury. Both patients with normal CT scans had symmetric but severely altered SEPs; both were judged to have primary brain stem injuries.

In the death outcome category (8 patients) the CT scan revealed severe brain oedema with signs of tentorial herniation in 7 cases. Large areas of cerebral contusion were seen in 2 cases. Large intracerebral haematomas at basal ganglia level on one or both sides were present in 3 cases. A small intracerebral frontal haematoma was found in 1 case. Two cases demonstrated an extensive epidural or subdural haematoma, respectively. SEPs were absent on one or both sides in 5 cases.

Special observations in prolonged coma (days 3–12 after injury)

Prognostic value

The CCT of the severely disabled patients was markedly increased ($P < 0.001$) and the AR was low ($P < 0.001$) in prolonged coma in comparison to normals (Table VI). The CCT was also significantly prolonged on the left hemisphere ($P <$

TABLE VI

CCT and AR of the different outcome categories in prolonged coma. Asymmetry of CCT and AR in the good outcome group can be explained by the fact that 4 of these patients suffered from primary brain stem injuries. Otherwise similar increase of CCT and decrease of AR as seen in acute coma with worsening of outcome. Three out of 5 patients who died had totally absent SEPs. The two other patients who died had absent SEPs on right (a). One important significant difference in comparison to the good outcome category is marked by an asterisk (* $P < 0.001$).

Prolonged coma	N	CCT (msec)		AR	
		Right	Left	Right	Left
Good outcome	6	6.3	7.5	0.6	0.2
S.D.		1.2	1.2	0.5	0.1
Moderate disability	6	6.7	6.7	0.4	0.6
S.D.		0.7	0.6	0.3	0.4
Severe disability	6	8.5 *	7.2	0.4	0.3
S.D.		1.8	0.5	0.3	0.2
Death	5	a	6.6	a	0.9
S.D.			0.6		0.7

0.002) in the good outcome group accompanied by a low AR on the same side. Interestingly, 4 out of 6 patients with good recovery suffered from primary brain stem involvement. One patient of special interest had no SEPs in acute coma but showed continuous recovery of SEPs in prolonged coma (Fig. 4a, b, c, d). In the second trace the CCT was 8.2, 8.7 msec on the right and 9.2, 9.7 msec on the left; in the third trace CCT decreased to 6.0, 6.5 on the right and 5.0, 5.5 msec on the left. The AR steadily increased. The patient recovered well. Two patients who died had no SEPs on the right but showed CCT and AR close to normal on the left. Three patients of the death outcome category had totally absent SEPs.

Patients in prolonged coma mainly due to primary brain stem impact showed the asymmetry of CCT and AR already discussed above in the good outcome category (Table VII). In comparison to normals the CCT was significantly increased ($P < 0.005$) and the AR significantly reduced ($P < 0.005$) over the left hemisphere. The AR of the moderately disabled patients was low if compared with all patients of this outcome group. The severely disabled patients showed prolonged CCTs at least to one hemisphere. One patient died, demonstrating absent SEP on the right but normal findings on the left.

TABLE VII

CCT and AR of the different outcome categories in patients in prolonged coma suffering from primary brain stem injury. Extremely prolonged CCT at least to one hemisphere in cases with severe disability outcome. The asterisk indicates a highly significant difference ($P < 0.001$) in comparison to the good outcome category. The patients who died had absent SEPs on the right (a), but a normal result over the left hemisphere. Note asymmetry of CCT and AR over the left hemisphere in the good outcome category, demonstrating significant differences from normals ($P < 0.005$).

Primary brain stem injury, prolonged coma	N	CCT (msec)		AR	
		Right	Left	Right	Left
Good outcome	4	6.2	7.0	0.6	0.2
S.D.		1.3	1.5	0.5	0.2
Moderate disability	2	6.7	6.5	0.1	0.3
S.D.		1.2	0.6	0.1	0.2
Severe disability	3	9.9 *	7.1	0.4	0.3
S.D.		1.4	0.5	0.5	0.3
Death	1	a	6.1	a	1.4
			6.4		1.2

TABLE VIII

Asymmetry and absence of scalp SEP of the different outcome categories in prolonged coma. Patients suffering from primary brain stem injury are listed in parentheses. Good outcome only in 2 patients suffering from primary brain stem injury. Asymmetries of SEP strongly related to moderate or severe disability outcome, absent SEP closely related to severe disability or death.

	Scalp SEP in prolonged coma				
	Asymmetric		Absent		
	Right	Left	Right	Left	Both
Good outcome	1 (1)			1 (1)	
Moderate disability	5 (2)		1		
Severe disability	2 (2)	1	1 (1)	1	1
Death			2 (1)		3

Asymmetry of SEP indicated moderate or severe disability outcome in most cases (Table VIII). One patient (see Fig. 4a, b) made a good recovery; SEPs were absent over one or both hemispheres in 10 patients. One patient suffering from primary brain stem injury recovered well. He failed to show a SEP on the left in prolonged coma (first trace done at this stage, Fig. 5a, b) but also after recovery from coma (Fig. 5c, d). At the time neurological examination revealed only slight signs of hemiparesis, hemiataxia and hemihypaesthesia of the right extremities. Five patients with absent SEPs on one or both sides died.

Differences in CCT of more than 0.5 msec were found in 11 patients. Four patients, all suffering from primary brain stem dysfunction, had good outcomes. Moderate disability persisted in 3 patients. Four patients (2 with primary brain stem lesions) remained severely disabled.

Neurological findings

Six patients had good outcomes: Four belonged to MBS 2 and two to MBS 4. Four patients, including both in MBS 4, were judged to have primary brain stem injuries. Three patients in MBS 2, two in MBS 3 and one in MBS 4 belonged to the moderate disability outcome category. One patient each of MBS 2 and MBS 3 were thought to be in coma due to primary brain stem impact.

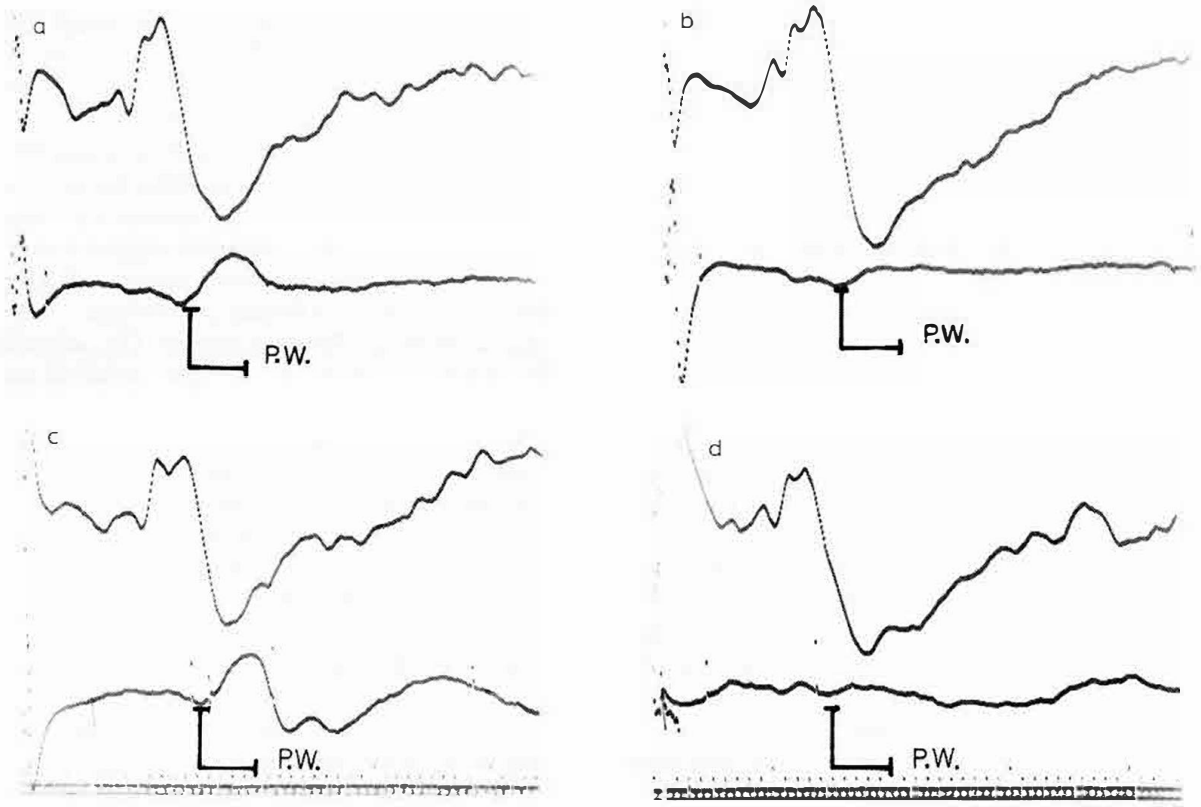

Fig. 5. a: cervical (upper channel) and scalp SEPs (lower channel) over the right hemisphere from a 19-year-old female patient; prolonged coma; midbrain syndrome stage 2; primary brain stem injury; CT scan: slight brain oedema; first trace done in prolonged coma; low amplitude N20, no subsequent components; 1.25 μV; 5 msec/div. b: cervical and scalp SEPs over the left hemisphere from the same patient as in a; prolonged coma; P15 present, no subsequent components; outcome: good recovery; 1.25 μV; 5 msec/div. c: cervical and scalp SEPs over the right hemisphere from the same patient as in a; recovery from coma; slight hemiparesis, hemiataxia and hemihypaesthesia of right extremities; CT scan: normal SEP response. d: cervical and scalp SEPs over the left hemisphere from the same patient as in a; recovery from coma; P15 present, but cortical components still absent; 1.25 μV; 5 msec/div.

Four patients in MBS 4 (2 primary brain stem injuries) and 1 patient each in MBS 3 (primary brain stem injury) and BBS 1 remained severely disabled. One patient in MBS 4 (primary brain stem injured) and 4 patients in BBS 1 died.

CT scan findings

CT scan examination was done in only 1 case of the death outcome category in prolonged coma; this CT scan was normal but the SEPs were absent from the right hemisphere. Two CT scan examinations were made in the severe outcome group; both were normal but absent or asymmetric SEPs were found. All 6 patients of the moderate disability outcome group had CT scan examinations. In 1 patient the evacuated haematoma was demonstrated but there were still signs of mass displacement. One patient showed moderate brain oedema. Small subdural haematomas without signs of brain oedema were found in 2 patients and 2 patients had normal CT scan findings. Six CT scan controls were also done in the 6 patients of the good outcome category. Four CT scans were normal; in 2 otherwise normal CT scans small subdural haematomas could be detected.

Brain death

In 6 patients studied in brain death confirmed

by isoelectric EEGs scalp SEPs were totally absent.

Subsequent recording and measurement of CCT and AR in acute and prolonged coma could be done in 13 patients. In 8 cases the CCT did not change more than 0.5 msec (increase or decrease). A decrease of CCT on both hemispheres was seen in 3 patients. One of these recovered well, two remained moderately disabled. One patient with good recovery showed an increase of CCT to one hemisphere, but decrease of CCT to the other. In one severely disabled patient an increase of both CCTs was observed.

The AR did not change in 2 patients in acute and prolonged coma. The AR increased on both hemispheres in 5 patients. Three of them recovered well; 1 patient was moderately, another severely, disabled. An increase of AR on one hemisphere was seen in 2 patients accompanied by good outcome in one, moderate disability outcome in the other. An increase on one side with a decrease of AR on the other was seen in 2 patients with good or moderate disability outcome. The AR decreases over both hemispheres in 2 patients who later were moderately or severely disabled.

Discussion

The monitoring of the progress of brain-injured patients and the prediction of outcome by clinical (Jennet et al. 1976) or EEG examinations (Stockard et al. 1975; Bricolo et al. 1978; Rumpl et al. 1979) may be limited by sedation and neuromuscular paralysis frequently used in the therapy of post-traumatic comatose patients. CT scan examinations can only reflect the anatomical conditions but fail to give information about the functional condition of the central nervous system. Therefore any method which permits monitoring of the central nervous system in sedated and paralysed patients is of clear value. Because of their resistance to alterations by medication, including high doses of barbiturates, short latency SEPs are especially useful for this monitoring (Chiappa and Ropper 1982).

The short somatosensory evoked responses obtained from median nerve stimulation provide information about the peripheral nerve, spinal cord, the brain stem, diencephalon and cortex. Significant correlations between SEP and outcome were noted (Greenberg et al. 1977b, 1981; De la Torre et al. 1978). In these studies early and late SEPs were recorded and a close relation between the number of SEP peaks and the outcome was found. However it is not clear from these reports whether asymmetries in responses were noted and which response was used for further calculations. A more detailed study of SEPs was done by Lindsay et al. (1981) who found the highest correlation of outcome with the number of waves in the response from the poorer hemisphere. In our study late potentials (50 msec and beyond) were not analysed. The number of positive-negative waves was only used for determination of asymmetry between the hemispheres. We found similar wave latencies of early SEPs in normals and in patients in acute and prolonged coma, but also during recovery. This finding confirms previous observations (Greenberg et al. 1977a) of latencies similar to normal through the first 40 msec post stimulation in most brain-injured comatose patients.

SEP components recorded from the scalp may be affected by traumatic lesions not only of the brain stem, thalamus and cortex but also of the peripheral nerves and spinal cord. Using scalp electrodes alone the identification of the site of the lesion may be difficult. Simultaneous recording of SEPs from the scalp and neck overcomes this problem and provides a measure of conduction time in the central pathways only, which is independent of conduction time in the peripheral nerves and spinal cord tracts (Hume and Cant 1978; Desmedt and Cheron 1980; Eisen and Odusote 1980). Also, the problem of how to ensure adequate stimulation of the median nerve, when patients are curarized, is solved by the simultaneous registration of the SEP from the neck.

The study of Hume and Cant (1981) showed that in patients in post-traumatic coma, the CCT and the presence or absence of SEPs over both hemispheres predicted the outcome. Thus, three-fourths of their patients showing normal conduction time within 3.5 days of injury made good recovery, while consistent asymmetries of amplitude and CCT or long-term absence from one

hemisphere predicted moderate or severe disability outcome. The absence of the SEP from both hemispheres was only noted in patients who died (Hume and Cant 1981).

Our general observations confirm this previous finding of CCT and AR close to normal in patients with good outcome within the first 2 days after trauma (acute coma). CCT increased and AR decreased with the worsening of outcome. The most prolonged CCTs were found in patients who died. However, except in cases with brain death, abnormalities of CCT and AR over each hemisphere rarely exceeded 3 S.D. above the mean for normal subjects. The CCT also increased and the AR decreased between days 3 and 12 (prolonged coma) with worsening of outcome. There was a clear relationship between prolonged CCT and low AR in all outcome categories. For all patients CCT decreased and AR increased during recovery.

The scalp SEP may become so distorted in brain-injured patients that identification of the individual waves may be difficult. Therefore, and because of the probable wide spread of brain damage in head injury, any suggestion for localizing the origin of early SEP components (Hume and Cant 1978; Allison et al. 1980) must be rather speculative. However, the presence of P15 in a patient with a large haematoma at basal ganglia level may support the view that P15 is a subcortical potential generated in the cerebral lemniscal pathway (Greenberg et al. 1977a; Allison et al. 1980). The medullary component N14 is best recorded from the neck and derives partly from the dorsal column nuclei and partly from the dorsal horn (Jones 1977; Desmedt and Cheron 1980). This accounts for its persistence in brain-dead patients (Goldie et al. 1981); it was present in all our patients including the patients in brain death.

In cases with supratentorial lesions confirmed by CT scan examination the SEP findings and CCT showed close correlation with the site of the hemispheric lesions. There was a steady increase of CT scan abnormalities with the worsening of outcome, which were also strongly related to the severity of the neurological findings. Patients with good outcome had normal CCTs and only slightly altered ARs. CCT increased and AR decreased with worsening of outcome in both acute and prolonged coma. Asymmetries of SEPs predicted moderate or severe disability outcome in most patients. These findings not only confirm the results of Hume and Cant (1981) but also those of Lindsay et al. (1981) who found asymmetries (= poorer hemisphere) closely related to poor outcome. The patients with absent SEPs over one or both hemispheres due to supratentorial lesions died within 14 days after injury or, as seen in 1 case, survived in an apallic (vegetative) state without any signs of recovery over an observation period of 8 months. Thus, in cases with supratentorial lesions our findings strongly agree with the results of previous work in this field (Greenberg et al. 1977a,b; Hume et al. 1979; Hume and Cant 1981; Lindsay et al. 1981).

In contrast to these previous reports we also found prolonged CCTs and asymmetric or absent SEPs in cases with good recovery. All these patients were judged to have primary brain stem injuries and therefore special interest was taken in them. Head injury often damages both brain stem and supratentorial functions simultaneously. Although primary brain stem injury rarely exists in pure form (Mitchell and Adams 1973) a primary brain stem lesion may be the principal cause of coma. The appearance of neurological signs different from the expected rostral caudal pattern (McNealy and Plum 1962; Plum and Posner 1966a; Gerstenbrand and Lücking 1970) may point to direct brain stem injury. The CT scan is diagnostic and eliminates a supratentorial lesion causing secondary brain stem dysfunction (Plum and Posner 1980). Also the final outcome may be helpful for better distinction between primary and secondary brain stem lesions. Because of the slight cortical impairment of these patients the prognosis is generally good if the brain stem lesions are reversible. Early appearance or early recovery of initially distorted SEPs and decrease of CCT in prolonged coma or during recovery was a favourable prognostic sign in patients suffering from primary brain stem injuries who demonstrated asymmetric or absent SEP and prolonged CCT in acute or prolonged coma. In these cases the suppression or abolition of the SEP seemed to be more likely to be due to a functional disturbance of neurons than a structural lesion within the lemniscal system. On

the other hand persistent asymmetry and absence of the SEP may point to irreversible damage to the lemniscal system. Because of the good recovery of the cognitive functions these patients resemble a state described as traumatically induced locked-in syndrome (Britt et al. 1977). However, absent SEPs should be interpreted carefully, as demonstrated by one primary brain stem-injured patient with good recovery, who showed persistently absent SEP on one hemisphere even after recovery from coma. Unfortunately, the question of SEP pattern in primary brain stem injuries was not discussed in previous papers (Greenberg et al. 1977a,b; Hume and Cant 1981; Lindsay et al. 1981). Greenberg et al. (1977b) recorded 2 patients with verified brain stem lesions and absent SEPs on both or on one hemisphere, respectively. However both brain stem lesions seemed to be mainly due to supratentorial mass displacement (right uncal herniation in one, left temporal lobectomy in the other case) and therefore should be regarded as secondary brain stem lesions.

Our suggestion that absent or asymmetric and delayed SEPs may be due to a functional disturbance or structural lesion of the lemniscal system within the brain stem should be confirmed by Noël and Desmedt (1975) who demonstrated that vascular lesions of the brain stem in the form of the locked-in syndrome (Plum and Posner 1966b) present markedly delayed, size-reduced and distorted SEPs. The suggestion of a functional disturbance within the brain stem was further supported by the striking similarity to our previous findings concerning the late responses of the blink reflex. These late responses, passing the lateral reticular formation in the lower brain stem, were frequently absent in patients with primary brain stem injury in acute coma. The early recovery of late reflexes in prolonged coma was a favourable prognostic sign (Rumpl et al. 1982). It may be also relevant to our suggestion that histopathological examinations found the medical lemnisci commonly damaged (Adams et al. 1977).

The particular value of CCT studies may be that observations can be made in sedated and paralysed patients, even in patients under administration of phenobarbital. Abnormal conduction times should be interpreted cautiously if serum phenobarbital levels exceed 300 μmol/l, but phenobarbital may contribute to only 4% of variance in the CCT (Hume and Cant 1981). Serum phenobarbital levels were not measured in our study, but there seemed to be no remarkable influence on CCT and SEP at all.

The method used in this study has been shown to provide useful diagnostic information (Hume et al. 1979; Symon et al. 1979; Eisen and Odusote 1980; Hume and Cant 1981). We agree with Hume and Cant (1981), that the method is simple and robust and most suitable for clinical use in intensive care units, using portable equipment. After training in placement of the electrodes CCT studies can be carried out within 15 min. Considering the high prognostic and diagnostic information in post-traumatic comatose patients, who have to be treated with sedative drugs and therefore can hardly be examined and monitored by any other method, CCT studies should be done more frequently in these patients.

Summary

Short latency evoked potentials (SEPs) were elicited by stimulation of the median nerve at the wrist and recorded simultaneously from the neck and the contralateral scalp in 44 comatose patients with signs of brain stem impairment due to head injury. Thirty-four patients were studied in acute coma on day 1 or 2 after brain injury. Twenty-three patients were studied in prolonged coma during days 3–12 after trauma. Six patients were examined in brain death. Brain stem involvement was divided clinically and by CT scan into secondary lesions due to supratentorial mass displacement and primary lesions due to direct violence to the brain stem. The central somatosensory conduction time (CCT) was measured by subtracting the peak latency of the major response from the neck (N14) from that of the primary scalp response (N20). The amplitude ratios (ARs) N20/N14 were calculated for each trace. Further asymmetries and absence of SEP over one or both hemispheres were noted. In cases in coma due to supratentorial lesions CCT and AR were close to normal in patients with good outcome. CCT in-

creased and AR decreased with the worsening of outcome both in acute and prolonged coma. Asymmetries of SEPs indicated moderate or severe final disability. Patients with absent SEPs over one or both hemispheres due to supratentorial lesions died or survived severely disabled (1 case). In patients suffering from primary brain stem dysfunction, confirmed by a normal or slightly abnormal CT scan, prolonged CCT, asymmetric but also absent SEPs were also found in patients with good outcome both in acute and prolonged coma. AR was generally low in these cases. Early appearance of SEPs or early recovery of initially distorted SEPs and decrease of CCT in prolonged coma or during recovery was a favourable prognostic sign. Therefore even absent or severely distorted SEPs should be interpreted cautiously in patients who may suffer from primary brain stem involvement. Scalp SEPs were totally absent in patients with brain death.

Résumé

Temps de conduction somatosensorielle centrale et potentiels évoqués somatosensoriels à courte latence, dans les comas post-traumatiques

On a suscité par stimulation du nerf médian du poignet, des potentiels évoqués à courte latence (PES) recueillis simultanément sur la nuque et sur le scalp contralatéral, chez 44 patients comateux avec signes d'atteinte du tronc cérébral, à la suite d'un traumatisme crânien. Trente-quatre patients furent étudiés en coma aigu, au 1er ou 2ème jour après le traumatisme. Vingt-trois le furent en coma prolongé, 3–12 jours après le traumatisme, et 6 patients en mort cérébrale.

Dans l'implication du tronc, on a distingué, à partir de la clinique et du scan, d'une part des lésions secondaires liées au déplacement de la masse supratentorielle, et des lésions primaires, par atteinte directe du tronc. Le temps de conduction somatosensorielle centrale (TCC) était évalué en soustrayant la latence du pic principal à la nuque (N14) de celle de la réponse primaire du scalp (N20). Les rapports d'amplitude (RA) N20/N14 ont été évalués dans chaque enregistrement. On a également recherché des asymétries, et des absences de PES sur l'un ou les deux hémisphères. Dans les comas par lésions supratentorielles, TCC et RA étaient quasi-normaux chez des patients avec issue favorable. Les TCC ont augmenté et les RA ont diminué d'autant plus que l'issue était plus mauvaise, que le coma soit aigu ou chronique. Les asymétries des PES laissaient prévoir un déficit final modéré ou sévère. Les patients sans PES sur l'un ou les deux hémisphères, à la suite de lésions supratentorielles, ont succombé ou, dans un cas, survécu avec de sévères déficits. Chez les sujets souffrant de dysfonctionnements primaires du tronc (confirmés par scan normal ou subnormal), des TCC allongés, des PES asymétriques ou absents, ont été également trouvés chez des patients avec issue favorable, que le coma ait été aigu ou prolongé. Les RA étaient généralement basses dans ces cas. L'apparition précoce de PES ou la restauration précoce du PES initialement anormal, et la décroissance du TCC en coma prolongé, ou pendant la récupération, étaient un signe pronostic favorable. En somme, il convient d'interpréter avec prudence l'absence ou la distorsion des PES, chez des patients susceptibles de souffrir d'implications primaires du tronc. Les PES du scalp ont fait totalement défaut chez des patients en mort cérébrale.

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