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Brainstem Auditory Evoked Potentials in Patients with Subarachnoid Haemorrhage

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***Abstract**: Objective. The aim of the present study is to typify BAEPs configurations of patients with different location of lesions caused by subarachnoid haemorrhage (SAH) and the ensuing complications, in view of assessing the auditory-brainstem system disturbance.*
Methods. The typization was performed by comparing BAEPs with standard patterns from two sets of types of BAEPs by ipsilateral and binaural stimulation and by cross-stimulation.
Results. 94 BAEPs were used for collection of normal referential values: for the absolute latencies and the absolute amplitudes of waves I, II, III, IV and V; for inter-peak latencies I-III, II-III, III-V, I-V and II-V; for amplitude ratios I/V and III/V. 146 BAEPs of patients with mild SAH and 55 from patients with severe SAH, were typified. In 5 types of BAEPs out of a total of 11, the percentage of the potentials in patients with mild SAH and severe SAH differed significantly (p < 0.01).
Conclusions. The use of sets of types of BAEPs by ipsilateral, binaural and cross-stimulation correctly classifies the potentials in patients with mild and severe SAH.

***Keywords:** Brainstem auditory evoked potentials (BAEPs), Subarachnoid haemorrhage, Typification of BAEPs.*

Introduction

Recording and analysis of brainstem auditory evoked potentials (BAEPs) is an objective electrophysiological method, which allows assessment of the functional state of brain stem following primary or secondary damage. Unlike the cortical auditory brain potentials in patients with severe cerebral lesions, BAEPs have much greater information value, owing to their waveform stability and to the fact that they are less influenced by various exogenous and endogenous factors [2, 11, 13, 15, 17, 20, 21, 23].

Few studies [15, 16, 22] have attempted to systematize BAEPs in the case of subarachnoid hemorrhage (SAH). This is due to the difficulties in conducting the study, in particular its duration. For some severely ill SAH patients, BAEPs studies have to be performed in an intensive care unit. Filling of the 4th ventricle leads to additional microcirculatory disorders in the tegmentum of the brainstem, which affects the reticular formation and the ascending auditory routes localized there. Consequently, systematization is needed for tracing the transition from norm to pathology and for identifying abnormalities of BAEPs in SAH and their secondary complications. This motivated us to apply our system for classification of BAEPs, which we introduced for patients with cerebrovascular pathology [6, 7], to investigate

BAEPs in patients with different location of lesions caused by SAH and their complications.

Methods

Clinical Sample

The study was performed on 58 individuals, divided as follows:
First (control) group: 19 healthy subjects (10 women and 9 men), mean age 38.1±16.1, used for collection of normal referential BAEP values.
Second group: 37 patients (26 women and 11 men), mean age 42.7±12.0. Depending on the severity of SAH, this group was divided into two subgroups using the Hunt and Hess scale [12].

The subgroup of "mild SAH" has a total of 29 patients, 21 of them with 1st degree by the Hunt and Hess scale and 8 with 2nd degree. Two of them were with clinical evidence for SAH and unilateral lesion of the oculomotor nerve. One had evidence about combined otoneurological syndrome. One was with proved peripheral unilateral otoneurological syndrome and SAH in the vertebro-basilar system, due to a rupture of collateral vessel, developed with the subclavia style syndrome. One had unilateral pre-morbid deafness. Two patients of the group died of rapidly developing brain edema with tonsillar herniation.

The "severe SAH" subgroup consists of 12 patients, with 3rd to 5th degrees by the Hunt and Hess scale, of which 11 died and one was in coma vigil. Four patients had control study with BAEPs after deterioration of their neurological status and changed from "mild SAH" to "severe SAH". Two other patients from the group have been studied twice after changes in their neurological status. Three patients had an aneurysm in the vertebral-basilar system. Five had evidence of combined otoneurological syndrome, and one was with peripheral unilateral otoneurological syndrome.

The total number of valid patterns of the first group was 94 BAEPs, used for collection of normal referential BAEP values. A total of 201 validated BAEP patterns were recorded from 43 studies of patients from the second group, from one to three BAEPs were obtained with the same stimulation type. Of all 43 studies of BAEPs, 39 were conducted with ipsilateral bilateral stimulation, 36 with cross-lateral bilateral stimulation, and 26 with binaural bilateral stimulation. The potentials from some of the studies were removed from the study due to suspected presence of artifacts. Table 1 presents the distribution of the patterns according to group and type of stimulation.

Instrumentation

BAEPs were studied in a specialised functional laboratory of an intensive care unit equipped with acoustic and electrical isolation, oxygen sources (above 5 atm.) and vacuum-aspiration system.

A hardware and software instrumentation complex was developed for real time and off-line investigation of BAEPs, as well as for their storage in a database. The complex comprises of a generator of click-stimuli of 100 ms duration and alternating polarity, with a frequency of the 12 s^{-1}, intensity of the 90 dB above the level of the individual click-threshold, and with 50 dB white noise given to the opposite ear. The cerebral electrical activity was initiated by needle electrodes allowing repeated chemical sterilization. In accordance with the American Electroencephalographic Society Guidelines [1], the position of the electrodes was mentioned as the positive electrode was always placed on the vertex (C_z position of the 10-20 system), the reference electrodes were placed on both mastoid points (M_1 and M_2 position of the 10-20 system) and the ground electrode was placed frontally on the median line, at 3 cm in front of F_Z (position of the 10-20 system). The resistance of all electrodes was kept below 3 kOm. The evoked cerebral activity was amplified approximately 100000 times and displayed on computer screen with 10 msec sweep. The full amplitude/division scale of the screen contains 10 divisions with voltage range from 0.1 to 1.0 μV/div. Analogue and subsequent digital filtering was used to select the frequency band of 156 to 2031 Hz. At least two separate averages of 2000 clicks were superimposed. Cz-M1 or Cz-M2 was consequently recorded with ipsilateral, cross-lateral, and binaural stimulation. With ipsilateral stimulation, electrical activity is conducted to a reference electrode on the ipsi-mastoid and an active electrode on the vertex. With cross-lateral stimulation, electrical activity is conducted from a reference electrode on the mastoid and an active electrode on the vertex. With binaural stimulation, the active electrode remains on the vertex, and the reference electrode is in mastoid position at the side of the preceding ipsilateral stimulation. The two sides are studied consequently, placing the reference electrode on the left and right mastoid, respectively.

Table 1. BAEP patterns for patient groups and stimulation types

Group	Side of Stimulation			Number of Patterns
	Ipsilateral	Binaural	Crossed	
Normal	37	28	29	94
SAH (total)	77	51	73	201
Mild SAH	56	35	55	146
Severe SAH	21	16	18	55

Examination methods

The groups of subjects were investigated using: otoneurological study with suprathreshold test for perception of click-stimuli; Doppler sonography; EEG; computer tomography; cerebral panangiography; basic blood parameters; liquor and urine study; clinical-pathoanatomical verification.

Different examination methods were used for patients in coma. They were subjected to various treatment procedures for acute cerebral circulation disorders, as well as all reanimation measures for patients with disturbed vital functions. Continuous pulmonary ventilation was applied during the BAEP study. Respiratory equipment was used, operating on the volume principle and set in motion by the inhaled gases.

Patients having qualitative consciousness disorders, such as delirium, were not suitable for studies during the excitation state. In these patients, benzodiazepine sedation failed to guarantee the state of rest needed for the study. In the patients with quantitative consciousness disorders it was possible to study BAEPs using benzodiazepine sedation, when necessary. Non-depolarizing myorelaxants were used for the patients in stupor or coma on artificial pulmonary ventilation. These myorelaxants have a sufficiently prolonged action to eliminate muscle artifacts and the unconscious movements of the patients during the actual study [16].

Typification of BAEPs

The absolute latencies (L) and the absolute peak amplitudes (A) of the main waves I, II, III, IV and V were measured. The inter-peak latencies (IPL) I-III, III-V and I-V, as well as the amplitude ratios (AR) I/V, I/III and III/V were measured in ipsilateral and binaural stimulation. In contralateral stimulation (cross-stimulation), IPL II-III, III-V and II-V, as well as III/V AR were measured.

Table 2. Reference upper limits (UL) of ipsilateral, binaural and crossed stimulation indices; for latencies: UL = mean + 2.5xSD, for amplitudes and amplitude ratios: UL = mean + 3.0xSD.

Stimulation		Indices													
		Latencies (msec)									Amplitude (μV)			Amplitude ratio	
		Absolute				Inter-peak									
		I	II	III	V	I-III	II-III	III-V	I-V	II-V	I	III	V	I/V	III/V
Ipsilateral (90 dB)	mean	1.35	2.44	3.44	5.27	2.08	-	1.83	3.92	-	0.51	0.42	1.11	0.48	0,4
	SD	0.14	0.17	0.19	0.19	0.17	-	0.13	0.17	-	0.23	0.24	0.36	0.23	0,2
	UL	**1.70**	**2.87**	**3.92**	**5.75**	**2.51**	**-**	**2.16**	**4.35**	**-**	**1.20**	**1.14**	**2.19**	**1.17**	**1.00**
Binaural (90 dB)	mean	1.36	2.53	3.39	5.29	2.03	-	1.9	3.92	-	0.65	0.55	1.33	0.48	0.42
	SD	0.15	0.16	0.14	0.17	0.15	-	0.10	0.18	-	0.33	0.3	0.39	0.2	0.2
	UL	**1.74**	**2.93**	**3.74**	**5.72**	**2.41**	**-**	**2.15**	**4.37**	**-**	**1.64**	**1.45**	**2.50**	**1.08**	**1.02**
Crossed (90 dB)	mean	-	2.52	3.38	5.31	-	0.86	1.93	-	2.8	-	0.47	1.0	-	0.47
	SD	-	0.16	0.25	0.20	-	0.26	0.22	-	0.18	-	0.31	0.33	-	0.25
	UL	**-**	**2.92**	**4.01**	**5.75**	**-**	**1.51**	**2.48**	**-**	**3.25**	**-**	**1.40**	**1.93**	**-**	**1.19**

An earlier study of ours [5] proved by discriminant analysis that the following are of highly informative value: L of I, II, III and V waves; IPL I-III, III-V, I-V; AR I/V, III/V, in cases of ipsilateral and binaural stimulation. In contralateral stimulation the informative indices are: L of II, III, V waves; IPL II-III, III-V, II-V; AR III/V.

According to the American Electroencephalographic Society Guidelines [1], the reference upper limits (UL) of three types of stimulation for the latencies were determined using mean + 2.5 SD, and for amplitudes and for AR using mean + 3.0 SD (Table 2).

Fig. 1 presents a set of ***types of ipsilateral and binaural stimulation BAEPs***, which comprises all possible variants: normal and abnormal BAEP patterns, including patterns with no evoked activity (in the case of cerebral death or total deafness).

In the case of the **1st type** of BAEP, the parameters L, IPL and AR are statistically not different from those in the group of individuals with normal hearing.

When the latencies of wave I and wave V are above normal and IPL and AR are normal, the BAEP are typified as **1st "peripheral" (1$^{st\ "p"}$) type**.

In the 2nd **type**, IPL I-III and I-V are abnormal, whereas IPL III-V and AR I/V and III/V are normal.

In the 3rd **type** there is abnormal prolongation of the III-V IPL, which abnormally prolongs IPL I-V. AR are also normal in this type, i.e. the balance in amplitudes of the main waves is preserved, the abnormality appearing only in the latencies. In some patients with delayed latency of the first wave and extended I-V IPL, the existence of a combined type of "cochlear" and "retrocochlear" auditory disorder was assumed.

Consequently the **2nd** and **3rd types** reflect only the changes in IPL, without abnormal changes in the main wave's amplitudes or amplitude ratios.

In **subtype 4th-A** the main criterion is the disordered I/V AR, due to abnormally dominating amplitude of wave I over wave V. This means that its absolute value exceeds the accepted maximum normal value (I/V > N). In this type not only all IPL are normal, but AR between wave III and wave V is also normal (III/V < N).

In **subtype 4th-B**, in addition to the abnormal I/V AR, also IPL I-III and/or III-V and I-V are prolonged. Only the III/V AR is normal for this subtype.

In the **5th type** the main criterion is abnormal III/V AR, which exceeds the maximum value accepted for this parameter (III/V > N), because the amplitude of the wave III dominates the amplitude of wave V.

In **subtype 5th-A** the III/V AR is abnormal, I/V AR being normal; IPL I-III, III-V and I-V are also normal with ipsilateral and binaural stimulation.

In **subtype 5th-B** the III/V AR, as well as the IPL I-III or/and III-V, and I-V are abnormal, I-V AR being normal in ipsilateral and binaural stimulation.

The principal criterion for creating the next, **6th type**, is a combination of the **abnormal I/V and III/V AR** (I-V > N and III/V > N). This type has three subtypes, depending on the combination of the abnormal ratios: 6th-A, 6th-B and 6th-C.

In **subtype 6th-A,** I-V and III/V AR are abnormal, with normal IPL I-III, III-V and I-V.

In **subtype 6th-B,** there is a combination of abnormal I/III and III/V AR with abnormal IPL I-III, III-V and I-V.

Subtype 6th-B reflects abnormal BAEP for which "incoherent activity" is recorded, i.e., averaged unprovoked brainstem activity, demonstrating the presence of waves with uncharacteristic waveform. When two or more such patterns are superimposed, the amplitudes of the existing waves show phase displacement. They have higher amplitude than the "noise" activity of the equipment and do not reflect the presence of additional activity, such as muscle artifacts, etc.

The last, **7th type** characterizes BAEP for which missing evoked activity is recorded, or only wave I is present (sometimes wave II as well), as in the case of brain death.

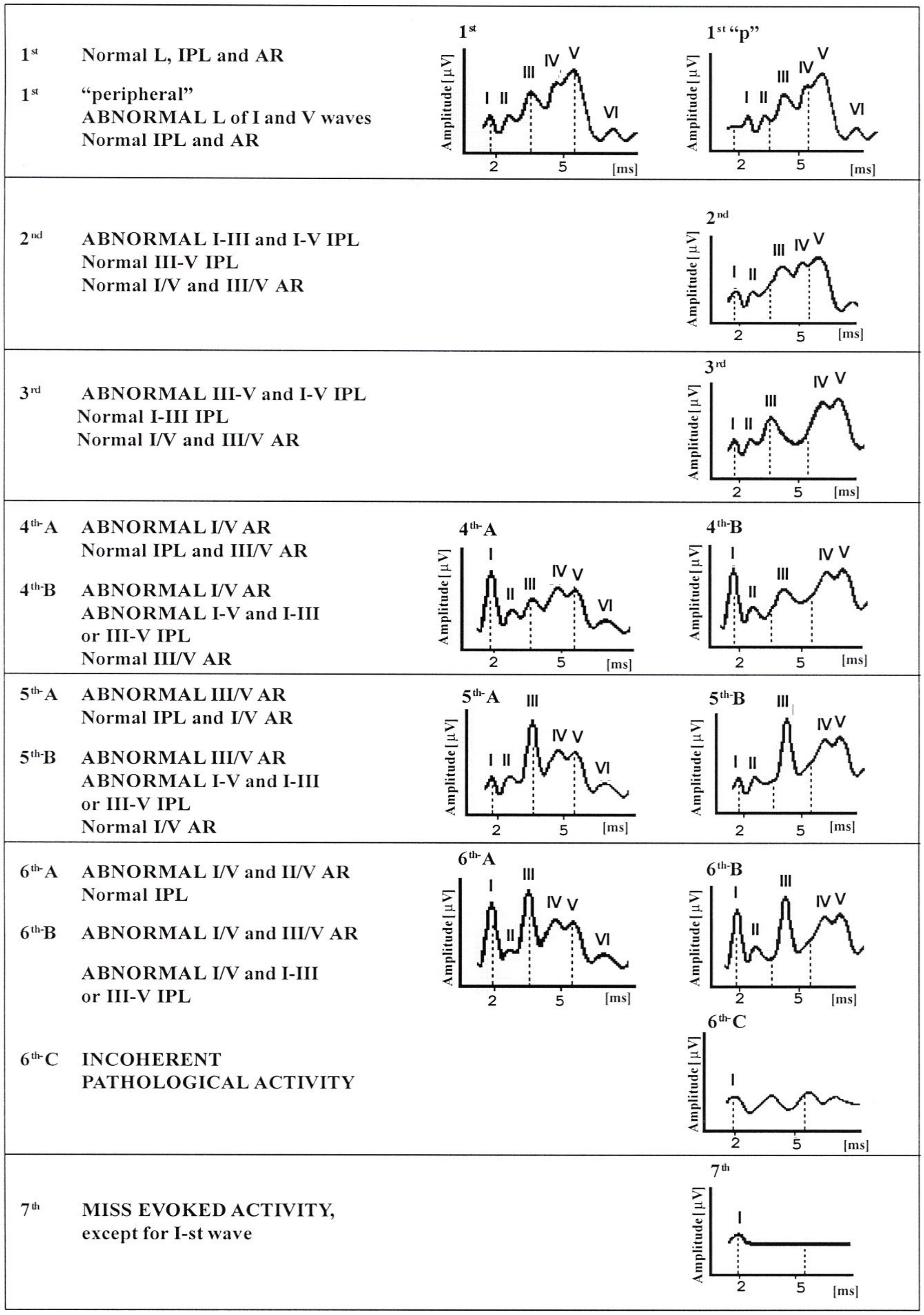

Fig. 1 Set of patterns for classifying BAEPs in ipsilateral and binaural stimulation

When in ipsilateral and binaural stimulation prolonged absolute L wave I with prolonged I-V IPL is registered, in combination with/without abnormal I/V and/or III/V AR or "incoherent activity" or "missing evoked activity", this type of pattern is associated with the so-called "combined type" of abnormal BAEP – peripheral and brainstem, as in combined otoneurological syndrom.

Unlike the set for classifying BAEPs in ipsilateral and binaural stimulation, **the set of BAEP types due to cross-stimulation** uses wave II instead of wave I. The criteria are IPL II-III, III-V and II-V, as well as the AR III/V. This set of patterns is convenient for reflecting changes in the waveform, especially in BAEP obtained by cross-stimulation. Wave I is not recorded as a positive peak in the contralateral mastoid. Fig. 2 presents a set of patterns for categorizing BAEPs in cross-stimulation. In the case of prolonged L of wave II and normal remaining parameters, there is a "peripheral type" of BAEPs with cross-stimulation. In the case of prolonged absolute L of wave II and prolonged II-V IPL in combination with or without abnormal III/V AR, the pattern is considered as "combined type" of abnormal BAEP.

Results

Of all 29 studies conducted with the three types of stimulation on "mild SAH" patients, 16 had bilaterally normal BAEP (classified as 1^{st} type). Six studies registered unilaterally normal potentials, while in 7 there were bilaterally abnormal potentials.

With "severe SAH" patients, 2 of the 14 studies exhibited bilaterally normal potentials; the rest had bilaterally abnormal potentials with some type of stimulation.

The distribution of the types of BAEPs in the patients with mild SAH is presented in Table 3.

Table 3. BAEP types in patients with mild SAH (1 and 2 degrees by the Hunt & Hess scale)

Types >	1st	2nd	3rd	4^{th}-A	4^{th}-B	5^{th}-A	5^{th}-B	6^{th}-A	6^{th}-B	6^{th}-C	7^{th}	Total
IPSILATERAL	46	1	1	3	0	1	0	0	0	1	0	53
"peripheral"	2	0	0	0	1	0	0	0	0	0	0	3
BINAURAL	27	2	4	1	0	0	0	1	0	0	0	35
CROSSED	46	1	4			2	0			1	0	54
"peripheral"	1	0	0			0	0			0	0	1
Total	122	4	9	4	1	3	0	1	0	2	0	146
%	83.6	2.7	6.16	2.7	0.7	2.1	0	0.7	0	1.4	0	

With ispilateral stimulation, 46 normal potentials were registered. Normal potentials were found in patients with clinical signs of SAH and one-side oculomotor nerve damage. Two potentials were of peripheral type (1^{st}"p"), registered in the patients with evidence of unilateral peripheral otoneurological syndrome. They had prolonged L of waves I and V on the side of the peripheral damage. One of these 1^{st} "p" types was found unilaterally in the patient with subclavia style syndrome and SAH in the vertebro-basilar system. Another potential was recorded in a patient with SAH and vertigo.

The eight abnormal potentials were registered in the patients with clinical evidence of mild manifestation of brainstem dysfunction. Two of them were only with abnormal IPL, i.e., they are of 2^{nd} and 3^{rd} type. Four BAEPs were with abnormal AR, but with normal IPL. In three of them, only I/V AR was abnormal (4^{th}-A type). Abnormal BAEPs classified as 4^{th}-A type was found only after ipsilateral stimulation on left ear in the patients with mild SAH and clinical evidence of unilateral lesion of the left oculomotor nerve. It suggested a mild disturbance of either nuclear or intrabrainstem part of oculomotor nerve. One unilateral abnormal 4^{th}-A type potential was found in the one patient with SAH and vestibular syndrome. Another abnormal potential of 4th-A type was recorded on the side of development of hemispheric secondary focal ischemic dysfunction. A patient with 2 degree by Hunt and Hess had a potential with abnormally prolonged I-st wave L and I-V wave IPL, as well as abnormal I/V AR, classified as 4th-B“p”. One potential with abnormal III/V (5th-A type) was found in one patient with mild SAH and complaint about dizziness.

One BAEP was with severe configurational changes, but it was registered in a patient with pre-morbid reduction of hearing in one ear: 6th-B type. In one patient, with proved combined otoneurological syndrome, a “combined type” potential was registered, whereby L of wave I is prolonged: prolonged IPL I-V and abnormal III/V AR, i.e., “type 5th-B”.

In the case of cross-stimulation, the normal potentials were 46 and one was of “peripheral type”. The latter was registered in a patient with peripheral otoneurological syndrome. BAEP was with prolonged L of wave II in the case of normal IPL and AR - type 1$^{st\ “p”}$.
The eight abnormal potentials with this stimulation were in the same patients who also had the abnormal potentials with the ipsilateral one. However, not all of them had potential patterns as with ipsilateral stimulation. Five of them had abnormal II-V IPL in combination with abnormal II-III or III-V IPL: 2nd and 3rd types. Two potentials were abnormal only according to AR III/V: type 5th-A. One was with configurational changes due to stimulated ear with pre-morbid strong reduction of hearing: 6th-C type.

With binaural stimulation, 27 BAEPs were normal and 8 were abnormal. Six of the abnormal potentials had abnormal I-V and II-V IPL, with normal AR (2nd and 3rd types). Of the remaining two, one was with abnormal I/V AR - type 4th-A. The other one was with abnormal I/V and III/V AR with normal IPL - type 6th-A. This was the result of summing of the abnormal I/V AR (4th-A type) with ipsilateral stimulation with abnormal III/V AR (5th-A type) with cross-stimulation.

The patterns of the BAEPs with binaural stimulation often are the same types as one of unilateral stimulation and differ from the other one. In two patients with SAH, one with oculomotor nerve damage and another with vestibular syndrome, the potentials were 1st type, the same as for cross-stimulation. In one patient with SAH without brainstem dysfunction the potentials were 3rd types for binaural stimulation, the same as for cross-stimulation.

In some patients the patterns of the BAEPs with binaural stimulation differ from the potentials recorded for ipsilateral and cross- stimulation. In one patient with mild SAH the potentials were 6th-A types for binaural stimulation, but for ipsilateral and cross-stimulation the potentials were 5th-A types. In another patient with mild SAH without brainstem dysfunction the potentials for binaural stimulation were 3rd type, but potentials for ipsi- and cross-stimulation were normal on right hemisphere side. On the other hemispherical side in same patient the potentials were: 1$^{st“p”}$ type for ipsilateral stimulation; 2nd type for cross-stimulation and normal (1st type) for binaural stimulation.

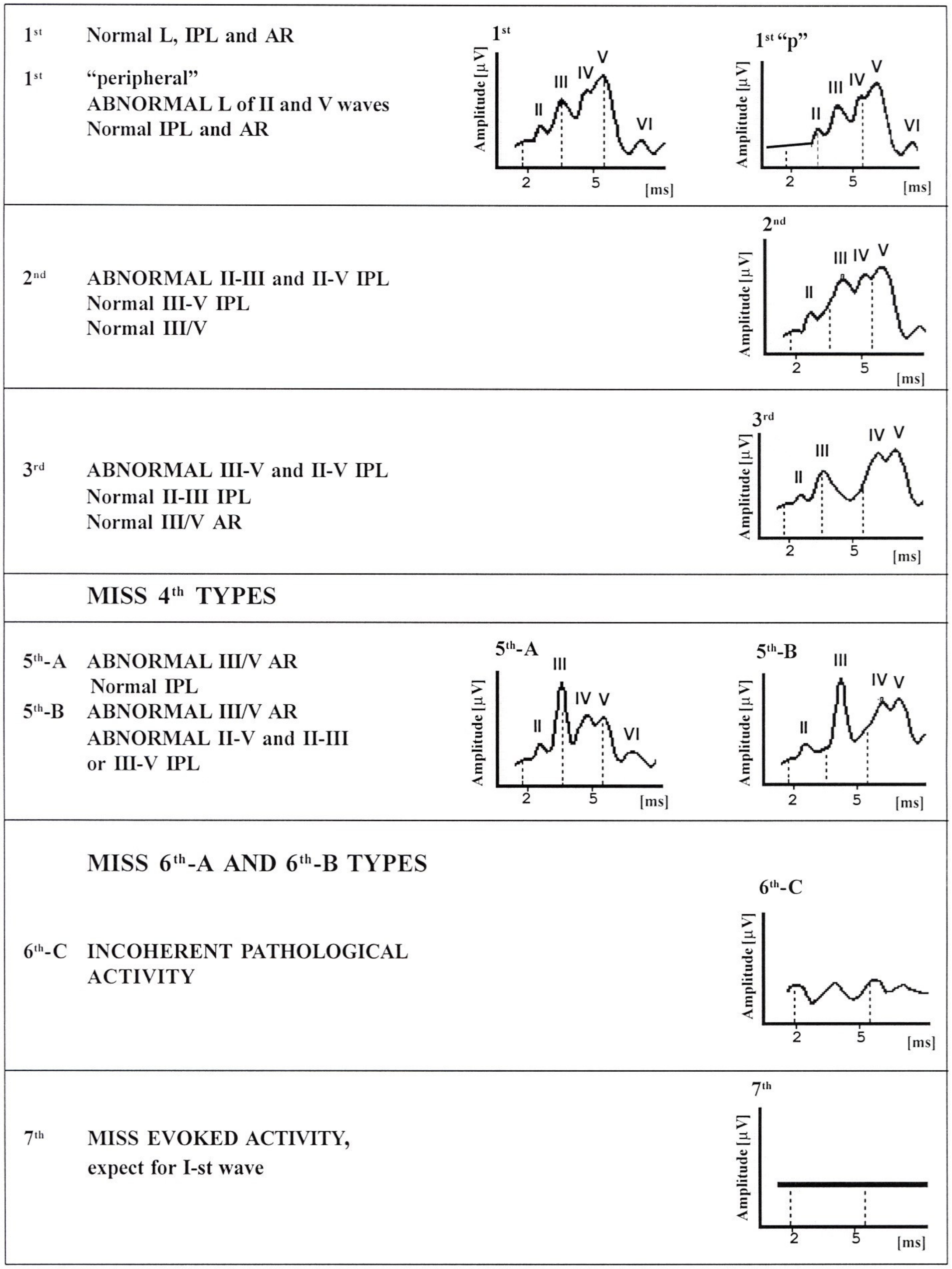

Fig. 2 Set of patterns for classifying BAEPs in cross-stimulation

The distribution of the BAEPs types in the patients from the severe SAH group is presented in Table 4. Only ten BAEPs were normal, three BAEPs were of peripheral type, and the remaining 42 BAEPs were abnormal.

Table 4. BAEP types in patients with severe SAH (3^{rd} to 5^{th} degrees by the Hunt & Hess scale)

Types >	1st	2nd	3rd	4^{th}-A	4^{th}-B	5^{th}-A	5^{th}-B	6^{th}-A	6^{th}-B	6^{th}-C	7^{th}	Total
IPSILATERAL	**3**	**1**	0	0	**1**	0	**2**	0	**2**	**2**	**5**	**16**
„peripheral”	**1**	0	0	0	0	0	0	0	0	**2**	**2**	**5**
BINAURAL	**3**	0	0	0	**1**	0	0	**1**	**4**	**3**	**4**	**16**
CROSSED	**4**	0	**1**			0	**2**			**6**	**2**	**15**
„peripheral”	**2**	0	0			**1**	0			0	0	3
Total	**13**	**1**	**1**	0	**2**	**1**	**4**	**1**	**6**	**13**	**13**	**55**
%	23.6	1.8	1.8	0	3.6	1.8	7.3	1.8	10.9	23.6	23.6	

After ipsilateral stimulation, one peripheral type potential and four combined ones were registered. The latter had abnormal L of wave I and desynchronized or isoelectric activities after it, i.e. types 6^{th}-C and types 7^{th}. Thirteen abnormal potentials were also registered. One potential was with abnormal III-V and I-V IPL (7^{th} type); one was with abnormal I-V IPL in combination with abnormal I/V AR (4^{th}-B type); two potentials were with abnormal I-V IPL in combination with abnormal III/V AR (5^{th}-B type); two potentials - with abnormal I-V IPL and abnormal I/V and III/V AR (type 6^{th}-B); two with desynchronized activity (6^{th}-C type); 5 – with isoelectric activity (type 7^{th}).

Using cross-stimulation, four normal potentials, two of peripheral type and 12 abnormal ones were registered. Of the latter, one BAEP was of combined type – cochlear and brainstem dysfunction. That potential had abnormal L of wave II and abnormal III/V AR – type 5^{th}-A. Among the remaining potentials, one had abnormal III-V and II-V IPL – type 3^{rd}. Two other potentials had abnormal II-V IPL and II/V AR – type 5^{th}-B. Six were with desynchronized activity – type 6^{th}-C. Two were with missing evoked activity, registered in the case of brain death – type 7^{th}.

Using binaural stimulation in this group, 3 normal and 13 abnormal potentials were registered. Of the latter, one was with abnormal I-V IPL and I/V AR – 4^{th}-B type. One was with abnormal I/V and III/V AR – type 6^{th}-A. Four were with abnormal I-V IPL and abnormal I/V and III/V AR – potential 6^{th}-B. Three were with desynchronized activity – type 6^{th}-C, and four – with missing evoked activity – type 7^{th}.

The patterns of the BAEPs with binaural stimulation often differ from those with ipsilateral or cross-stimulation. This effect was found in a patient with severe SAH, for whom I/V AR with ipsilateral stimulation and III/V AR with cross-stimulation were combined and the pattern with binaural stimulation reflects the two abnormalities.

The distribution of the types of BAEPs in the two groups of patients in percentages, with indication of the statistically significant differences, is presented on Fig. 3.

The normal BAEPs in the patients with mild SAH had a higher percentage (83.6%). Normal potentials were only 23.6% in the patients with severe SAH. The difference between these percentages is statistically significant (p < 0.001). In the patients with mild SAH, we registered more frequently potentials only with abnormal I-V IPL in combination with prolonged I-III or III-V IPL, although the difference was not statistically significant from cases with severe SAH. The highest percentage among abnormal potentials in the group with mild SAH was of those with prolonged I-V or II-V IPL – 2^{nd} and 3^{rd} types.

In our study the potentials with abnormal AR I/V or III/V, combined with abnormal I-V PL (4th-A, 4th-B, 5th-A, 5th-B, 6th-A, 6th-A and 6th-B) for "mild SAH" subgroup are total of 21.8% and for "severe SAH" there are 25.4%.

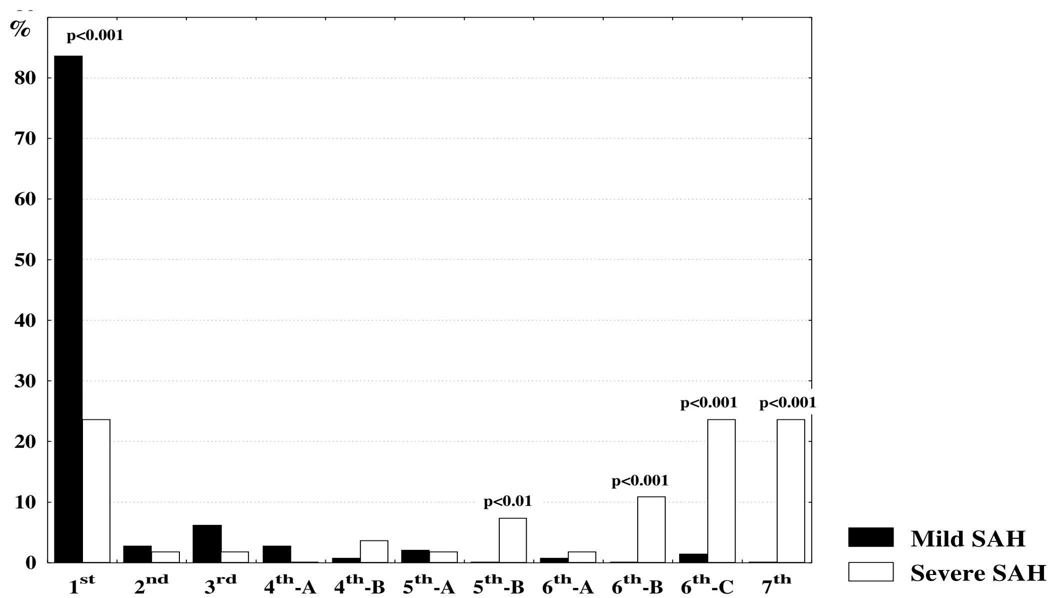

Fig. 3 Percentage of types of BAEP related to mild and severe SAH

In the patients with severe SAH, potentials of types 5th-B ($p < 0.01$), 6th-B, 6th-C and 7th ($p < 0.001$) were registered much more often. The high percentage (47.2%) of expressed waveform BAEPs changes were founded, such as desynchronised activity and absent evoked activity (6th-C and 7th types). This is due to the fact that three patients with atonic-nonreactive coma and four patients with clinical and laboratory evidence of brain death were studied. With two patients with areactive coma after surgery of an aneurysm in the vertebral-basilar system, potentials classified as 6th-C were recorded in all three types of stimulation. These patients also had – unilaterally with ipsilateral stimulation - abnormally prolonged L in wave I, which justifies a classification of the potentials as 6th-C"p".

Changes in the auditory afferentation, registered through BAEP, occur in dependence of the recurrence severity and the development of late complications. Control BAEPs studies performed after changes in the neurological status demonstrate potentials of varying configuration, even with the same type of stimulation. For example, normal BAEPs (1st type) were recorded on first investigation in the patients with left frontal hemorrhage and SAH due to ruptured aneurysm of the anterior connective artery, without evidence of dislocation of the median cerebral structures. Later, when a perifocal edema develops, complicated by secondary brainstem dysfunctions control investigation of BAEPs showed abnormal potentials classified as 6th-C for all three types of stimulation. Another patient showed potential of 5th-B type on the first cross-stimulation study. After an application of Mannitol the potential altered its nature and is classified as 5th-A"p".

Another rare and interesting to study case is one of SAH caused by a dissecting aneurysm of the basilar artery, where initially normal BAEPs were found with clinical evidence of locked in syndrome. The control BAEP tests, done after few days, demonstrated patterns of 7th type for all three types of stimulations, which corresponded to the clinical symptoms of brain death.

Discussion

This study claims that the use of classified BAEPs patterns in patients with different degrees of SAH enhances the comparison of potentials. Comparison is necessary between potentials of the same patient in the course of the disease as well as between potentials of patients with different degrees of SAH. The two pattern sets facilitate the investigation of the dynamics of the potentials, from normal to brain death, that occur in the various types of stimulation. The Hunt and Hess scale is a convenient method of discerning patients with different degrees of SAH. Such an in-depth study of BAEP in patients with SAH, and their comparison with the Scale of Hunt and Hess, can only be found in [9] and [10]. Unlike their work, we made use of binaural stimulation in addition to ipsilateral and cross types of stimulation when looking for changes in BAEPs patterns specific to particular degree of SAH severity. The patterns of the BAEPs with binaural stimulation often differ from those with ipsilateral or cross-stimulation. This is due to the summing of abnormality of differing gravity with the two types of monaural stimulation [11]. Significant deviations in potential patterns with monaural stimulation remain also with binaural stimulation. We registered a case of retaining an abnormal potential component present in one of the two monaural stimulations in the configuration of the binaural stimulation. Another case showed however that a component of abnormal type but close to the normal pattern (IPL or AR) existing in one of the monaural stimulations, is not found in the binaural stimulation. We consider this to be the reason why Chiappa [2] generalises this masking phenomenon and does not recommend the application of binaural stimulation alone.

A third case of special combination was found in a mild-SAH patient: the monaural stimulation potentials were normal but close to the upper limit, while the binaural stimulation potentials were abnormal. This is due to summing patterns close to normal with monaural stimulation, that are abnormal with binaural stimulation. We think that the presence of abnormality in binaural stimulation, together with abnormality in one of the monaural stimulations, is a manifestation of decompensation in hearing afferentation. Normal potentials in binaural stimulation together with abnormality in one of the monaural stimulations, is characteristic of compensation. Therefore, monaural stimulations may be used to obtain a precise estimation of the status of cross and direct auditory brainstem pathways, and binaural stimulation serves to investigate the status of compensatory mechanisms. Intact compensatory mechanisms are featured by abnormal potentials but missing clinical signs for brainstem impairment. In one of the studied cases, for example, abnormal I/V AR only with ipsilateral stimulation on the side of the lesion in patients with SAH and hemispheric secondary focal ischemic dysfunction indicates affected brainstem auditory structures with missing clinical manifestation of this.

Some authors [3, 9, 10] assume that the reason for the abnormal BAEP is the increased intracranial pressure as a result of SAH. Wada et al. [23] believe that brainstem secondary ischemia, resulting from increased intracranial pressure, affects the III/V AR. Although the experimental studies [22] had not detected any influence of the increasing intracranial pressure on the BAEP components. In our opinion, the intracranial pressure has an effect on the BAEP patterns, due to the fact that abnormal potentials are found not only in patients with brainstem clinical signs.

Although the BAEPs could be initially normal, there were a high percentage of potentials combining abnormal IPL and AR from the control study, as a result of an acute development of cerebral edema and intracranial hypertensive syndrome and exchanged cerebral perfusion leading to brainstem dysfunction. In contrast, Lebedev et al. [18] have found mainly prolonged I-V IPL in such a group of patients. Hashimoto et al. [8] describe such a prolongation of the “brainstem conduction time” intraoperatively. Similarly, we used BAEP to prove whether auditory brainstem structures were affected after surgery of an aneurysm in the vertebral-basilar system. Prolonged I-V IPL was not found in our patients subjected to postoperative tests. Our data had poor prognostic value for the effect of the surgical intervention.

The registered $1^{st\text{“p”}}$ patterns were characteristic of peripheral otoneurological syndrome, which is probably due to spasm of the auditory artery of the affected inner ear.

In our SAH patients there were some potentials demonstrating combined abnormality at the peripheral and the brainstem level. In these cases, combined-type potentials were registered, such as 4^{th}-$B^{\text{“p”}}$, 5^{th}-$A^{\text{“p”}}$, 6^{th}-$C^{\text{“p”}}$, $7^{th\text{“p”}}$. We regard the reason for this to be, apart from the cochlea, a probable spasm both of the auditory artery and of the circumference arteries of the basilar artery in the brainstem, which impaired the blood supply to the tegmentum.

The use of a set of patterns for categorized BAEP with cross-stimulation improves the analysis of information about the involvement of crossed pathways in patients with quantitative consciousness disturbances. One of the criteria for this disturbance is amplitude abnormality of AR III/V. While the I-III, III-V and I-V IPL and I/V AR are recommended in ipsilateral and binaural stimulation in cases with brainstem damage**,** III/V AR is missing [1]. For this reason, most authors do not use it.

The absence of evoked activity when BAEP were recorded in patients who had developed atonic and apneic coma is a criterion for brain death. The recordings demonstrate incoherent noise activity with low amplitude and absence of I wave bilaterally in case of ipsilateral and binaural stimulation. Many studies leading to similar results have been devoted to this problem. For example, Goldie et al. [4] and Machado et al. [19] have not recorded any wave in more than 70% of the patients investigated. According to [14], the absence of I wave in patients with verified brain death is due to complete destruction of the labyrinth, as a result of interrupted perfusion of the inner ear. Our experience has shown that BAEP analysis is among the most informative methods for objective evaluation of the brainstem dysfunction - a method which continues to demonstrate its advantages over the routine EEG-investigations, especially for SAH patients.

Conclusion

We have shown that normal BAEPs are registered in the patients with mild SAH, whereas the abnormal types are relatively uniformly represented. In the group of patients studied, there is a frequent occurrence of abnormal III/V AR, especially with cross-stimulation. In the patients with SAH we demonstrated that the indices II-III and II-V IPL, and of the III/V AR, are connected with violation of the crossed auditory pathways from the auditory nuclei to colliculi inferiores of tectum mesencephali in brainstem lesions. The existence of a peripheral type of BAEP suggests auditory disorders caused by ischemisation of the inner ear or by direct damage to the SAH part of the auditory nerve. In the patients with combined peripheral-brainstem damage, it is attributed to the abnormal latency of the I wave, in combination with or without abnormal I-V IPL and I/V and III/V AR.

On the basis of the results obtained and the analysis of the data of the clinical and paraclinical investigations, compared to the BAEP results in our experiments, we believe that BAEP analysis should be applied to patients with brainstem lesions, irrespective of its severity and volume, caused by vascular incidents of varying etiology. The analysis of BAEPs according to the side of the stimulation - ipsilateral or contralateral - shows that the study of crossed and non-crossed auditory pathways is informative to the same degree. A set of patterns of cross-stimulation fills a gap in the analysis of the configurational disturbances, which is often omitted or avoided by most authors.

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