ORIGINAL ARTICLE
UDC: 616.8-07:591.181]::[616.134-007.21::616.831-005
DOI: https://doi.org/10.2298/VSP231220035Z

Acoustic evoked potentials characteristics in patients with vertebral artery hypoplasia and posterior circulation stroke

Karakteristike akustičnih evociranih potencijala kod bolesnika sa hipoplazijom vertebralne arterije i moždanim udarom u vertebrobazilarnom slivu

Biljana Živadinović*†, Radomir Damjanović*, Stefan Todorović*, Jelena Živadinović‡, Jelena Stamenović*†, Mila Bojanović†§, Aleksandar Bojanović†‖, Ivana Ćirić Mladenović‖, Hristina Jovanović**

University Clinical Center of Niš, *Clinic for Neurology, ‡Clinic for Anesthesiology, §Clinic for Otorhinolaryngology, ‖Clinic for Radiology, Niš, Serbia; †University of Niš, Faculty of Medicine, **Department of Pharmacology with Toxicology, Niš, Serbia; ‖Special Hospital for Rehabilitation, Prolom Banja, Serbia

Abstract

Background/Aim. Acoustic evoked potentials (AEPs) represent an electrophysiological method used in diagnosing pathological changes of the brain stem (BSt), the acoustic nerve (its peripheral and central part), in patients in coma, in the confirmation of cerebral death, etc. The response includes seven negative waves which are generated in the structures of the BSt vascularized by the arteries of the posterior circulation. However, in everyday practice, due to their constancy, the first five waves are followed. The vertebral artery hypoplasia (VAH) is assumed to affect the AEPs finding. The current definition of VAH includes the criterion that the diameter of the blood vessel is ≤ 2 mm and that the ratio of the diameter of the left and right vertebral artery is ≥ 1 : 1.7. VAH is found in 5.3% of cases of the total population and its presence increases the risk of posterior circulation stroke (PCS). The aim of this study was to show a higher frequency of pathological findings of AEPs in patients with VAH and PCS and demonstrate the characteristics of AEP in that group of patients. **Methods.** This prospective study included 163 patients diagnosed with PCS over a period of two years. Computed tomography (CT) and magnetic resonance (MR) imaging (MRI) established the diagnosis of PCS. Suspicion of VAH was found by Color Doppler ultrasonography and confirmed by CT and MR angiography. All patients underwent AEPs testing. Wave amplitudes and interwave latencies (IWL) were monitored. **Results.** There was no statistically significant difference between gender ($\chi^2 = 1.823$; $p = 0.176$) and age in relation to VAH ($p = 0.815$). A statistically significant greater number of patients with multiple PCS had a positive VAH finding (VAH group, 42.3%) compared to those without VAH (noVAH group, 26.6%) ($\chi^2=4.278$; $p=0.038$). A statistically significant greater number of pathological AEPs was found in the group of patients with PCS and VAH ($\chi^2 = 4.899$; $p = 0.026$). A statistically significant IWL change accompanied by low amplitude waves in the VAH group has been determined ($\chi^2 = 4.465$; $p = 0.034$). **Conclusion.** The distribution of VAH is not gender- or age-related. The frequency of pathological AEPs findings (presence of associated changes in wave amplitudes and prolonged IWL) is statistically significantly higher in patients with VAH and PCS.

Key words:
brain stem infarctions; electrophysiology; evoked potentials, auditory, brain stem; vertebrobasilar insufficiency.

Apstrakt

Uvod/Cilj. Akustični evocirani potencijali (AEP) predstavljaju elektrofiziološku metodu koja se koristi u dijagnostici patoloških promena moždanog stabla, akustičnog nerva (njegovog perifernog i centralnog dela), kod bolesnika u komi, kod potvrđivanja moždane smrti itd. Odgovor uključuje sedam negativnih talasa koji se generišu u strukturama moždanog stabla vaskularizovanih arterijama zadnjeg sliva. Ipak, u svakodnevnoj praksi se zbog svoje konstantnosti prati prvih pet talasa. Pretpostavlja se da hipoplazija vertebrlne arterije (HVA) utiče na nalaz AEP. Važeća definicija HVA obuhvata kriterijum da je dijametar krvnog suda ≤ 2 mm i da je odnos dijametara leve i desne vertebralne arterije ≥ 1 : 1,7. HVA se sreće u 5,3% slučajeva ukupne populacije i njeno prisustvo povećava rizik od infarkta mozga u zadnjem slivu (*posterior circulation stroke* – PCS). Cilj istraživanja bio je da ukaže na veću učestalost patoloških nalaza AEP kod bolesnika sa HVA i PCS i da pokaže karakteristike AEP u toj grupi bolesnika. **Metode.**

Correspondence to: Radomir Damjanović, University Clinical Center of Niš, Clinic for Neurology, Bulevar dr. Zorana Đinđića 48, 18 000 Niš, Serbia. E-mail: rdamjanovic@gmail.com

Sprovedena je prospektivna studija koja je obuhvatila 163 bolesnika sa PCS, u periodu od dve godine. Metodama kompjuterizovane tomografije (KT) i magnetne rezonance (MR) ustanovljena je dijagnoza PCS. Sumnja na postojanje HVA nakon *Color Doppler* ultrasonografije potvrđivana je KT i MR angiografijom. Svim bolesnicima urađeno je AEP ispitivanje. Praćene su promene talasnih amplituda i intertalasne latence (ITL). **Rezultati.** Nije postojala statistički značajna razlika između polova ($\chi^2 = 1,823$; $p = 0,176$) i godina starosti bolesnika u odnosu na prisustvo HVA ($p = 0,815$). Statistički značajno veći broj bolesnika sa višestrukim PCS imalo je pozitivan nalaz HVA (grupa HVA – 42,3%) u odnosu na bolesnike koji nisu imali HVA (grupa bezHVA – 26,6%) ($\chi^2 = 4,278$; $p = 0,038$). Statistički značajno veći broj patoloških AEP nalaza ustanovljen je kod bolesnika u grupi koja je imala PCS i HVA ($\chi^2 = 4,899$; $p = 0,026$). Utvrđeno je postojanje statistički značajne promene ITL praćene talasima niske amplitude u grupi HVA ($\chi^2 = 4,465$; $p = 0,034$). **Zaključak.** Distribucija HVA ne zavisi od pola ni starosti. Statistički značajno je veća učestalost patološkog AEP nalaza (prisustvo udruženih promena amplituda talasa i produženih ITL) kod bolesnika sa HVA i PCS.

Ključne reči:
moždano stablo, infarkti; elektrofiziologija; evocirani potencijali moždanog stabla, auditorni; vertebrobazilarna insuficijencija.

Introduction

Acoustic (auditory) evoked potentials (AEPs) represent an electrophysiological method used in diagnosing pathological changes of the brain stem (BSt), in addition to numerous other indications (neurodegenerative, demyelinating diseases of the nervous system, tumors in the BSt area, damage to the acoustic pathway, determination of brain death, etc.). The stimulation of the acoustic nerve is done by a specific type of sound signal (alternant click), and responses generated along the auditory pathway from the cochlea to the cortical center responsible for hearing are monitored. Both central and peripheral parts are thus observed because the response to the stimulus includes seven negative waves within 10 ms after the stimulation, with different amplitudes and latencies, but because of their constancy and reproducibility, the first five are used. Numerous studies have shown that wave I of AEPs is generated in the cochlear nerve portion, wave II in the cochlear nuclei portion, and wave III in the *medulla oblongata* area (superior olive and projections to the lateral *lemniscus*, as well as the medial nucleus of the trapezoid body). Wave IV is generated in the *pons* region (lateral *lemniscus*), and wave V is generated in the superior *pons* or inferior *colliculus*. Wave VI originates in the midbrain; wave VII is believed to be a response of auditory radiations and the primary motor auditory cortex. The first five responses are considered clinically important since waves VI and VII are only variably present and often cannot be replicated [1]. Each wave has a specific place of origin, and they are all generated in the structures of the BSt, which are vascularized by the arteries of the posterior circulation (acoustic nerve, acoustic nuclei, *medulla oblongata*, lower and upper *pons*, *mesencephalon*) [2, 3]. The method is, therefore, significant as an additional diagnostic tool in diagnosing vascular lesions of the BSt and localizing the lesion. Its significance comes from the logical assumption that damage to the wave 'generator' region or 'chronic vascularization insufficiency' of the region from which the waves originate leads to changes in morphology and other characteristics of the waves that can be monitored and measured [4, 5]. The AEPs method is applicable in cerebrovascular disorders because the point of wave generation is in the regions vascularized by the vertebral artery (VA) and other arteries of the posterior circulation, even though it has long been used only in diagnosing cerebellopontine angle tumors, demyelinating diseases, comatose patients, and brain death [6–9]. It is highly significant that they change very little under the influence of anesthetics and barbiturates [1].

Posterior circulation stroke (PCS) is a common indication for the application of the AEPs method. Although its diagnosis is primarily clinical and radiological, electrophysiology can also give useful information about lesion location, and it can even show predictive potential in estimating clinical outcomes [10].

Alternating syndromes located in the area of the *medulla oblongata* and *pons*, as well as those in the *mesencephalon*, also cause changes in AEPs. The dominant changes occur in the wave form and the amplitudes of waves III, IV, and V. Amplitude variation is noticed in waves I and V. Pathological findings show changes in interwave latency (IWL) of waves III–V [11–13].

In addition to already familiar risk factors in the development of PCS (age, hypertension, diabetes mellitus, male gender, heart diseases, heart rhythm diseases, etc.), VA hypoplasia (VAH) is also becoming one of the risk factors in PCS [14, 15]. The VA is the first lateral branch of the subclavian artery. In rare cases, it can originate directly from the aortic arch. Considering the path of the VA, four topographic points are described: V1 – prevertebral (*pars prevertebralis)*; V2 – cervical or transverse part (*pars cervicalis*); V3 – the part on the final arch of the atlas (*pars atlantica*); V4 – the part in the posterior cranial cavity or intracranial part (*pars intracranialis*) [16]. The basilar artery (BA) is formed by joining the left and right VA at the height of the lower edge of the cerebral bridge (*pons*). At the same time, the common asymmetry of the VA has been observed in the normal population, with a wider lumen of the left VA in 50% of cases and of the right VA in 25% of cases, while the same diameter of both blood vessels has been found in a quarter of the population [14]. The symptoms of 'vascular insufficiency' in posterior circulation, despite asymmetry in the size of the blood vessels, have not been observed in 75% of the population, whereas it has been shown that people with ischemic changes in VA circulation have a significantly higher percentage of VAH. There is no absolute agreement on the definition of

the VAH. The current definition includes the diameter of the blood vessel at 2 mm or less (literature rarely shows ≤ 3 mm) and the ratio of the diameter of left and right VA ≥ 1 : 1.7 [17]. The results of two separate studies show a greater frequency of VAH on the right side than on the left [18]. Another group of authors describes a greater extent of right-sided VAH (6.2%) than the left-sided one (4.6%) [19]. It is more frequent in patients who have migraines with aura (28%) and patients with vestibular neuronitis (65%) [14]. It is often associated with stenosis and hypoplasia of the BA, which increases the risk of PCS [17]. Furthermore, there can be compensatory enlargement of the diameter of the contralateral blood vessel up to 5 mm. In addition to measuring the diameter of the blood vessel, ultrasound examination can be used to monitor hemodynamic parameters of the VA: reduced blood flow (in the VAH group, it was 81.6 ± 1.5 mL/min, and in the noVAH group, it was 123.2 ± 13.5 mL/min), decreased peak systolic velocity (less than 40 cm/sec), and increased resistance index (RI > 0.75) [14, 17].

The aim of this study was to show a higher frequency of pathological AEPs findings in patients with VAH and PCS and to find out specificities of AEPs findings in patients with both conditions.

Methods

The research was conducted as a prospective study, and it included 163 patients diagnosed with PCS, hospitalized, and treated for a period of two years at our department. The research was approved by the Ethics Committee of the Faculty of Medicine, University of Niš (No. 01-2625-6, from April 8, 2014).

All patients were admitted with symptoms of PCS. A computerized tomography (CT) scan established the diagnosis of PCS. In cases where CT was not sufficiently precise or the lesions in the BSt area were small, magnetic resonance (MR) imaging (MRI) of the brain was done to diagnose PCS. A neurological examination was done on admission and during the patient's stay, and it was scored according to the National Institutes of Health Stroke Scale modified for posterior circulation [12]. Standard risk factors for stroke were monitored (hypertension, hyperlipidemia, diabetes mellitus, atrial fibrillation, previous myocardial infarction, heart disorders, malignancies, hematological diseases, etc.). Neck vessel Color Doppler ultrasonography (CDU) was done for all patients. CDU was performed at the Clinic for Neurology, University Clinical Center of Niš, Serbia using the Esaote MyLab 70 apparatus. A linear probe (4–11 MHz) with a pulse repetition frequency of 1–1.8 kHz was applied. Patients suspected of VAH, besides CT or MRI, also underwent CT angiography (CTA) and MR angiography (MRA), which determined the presence or absence of VAH. CTA and MRA examination of extra- and intracranial arteries was done at the Clinic for Radiology, University Clinical Center of Niš, using MSCT General Electronic Healthcare BrightSpeed (Fairfield, Connecticut, United States) with 2.5 mm cross-section thickness and magnetic resonance Avanto Siemens with a magnetic field strength of 1.5 T and 3 mm cross-section thickness. CTA is a contrast method for which an iodine contrast material, Ultravist, was used. MRA included the noncontrast Time of Flight method. All patients in the tested group underwent the AEPs assessment method. The AEPs test was done at the Electrophysiology Cabinet of the Clinic for Neurology in a room with appropriate sound and electromagnetic isolation. Following a specific preparation for recording, with the aim of allowing the patients to relax in order to avoid artifacts caused by swallowing, blinking, and movement, and after the necessary skin preparation (removal of impurities from the surface), superficial silver disc electrodes were taped on the skin. The active electrodes were on the mastoid processes (A1, A2), the referential electrode was on the vertex (Cz), and the ground electrode was on the forehead. After determining the hearing threshold, a click intensity 70 dB stronger than the threshold was added; one ear was stimulated with it, while the other ear was "masked" with a sound of 30 dB (due to the crossing of the acoustic path at the level of the BSt and the conduction of the sound through the skull). Stimulation was performed with 2,048 stimuli, with a frequency of 5 stimuli per second, a time base of 10 ms and a filter range of 100 Hz (low cut) and 3 kHz (high cut). The duration of the click was 0.1 ms. The total number of 5/sec stimuli was 2,048 (Sapphire, Medelec); of the 10/sec stimuli, it was 2,000 (Nihon Kohden Neuropack M1). The degree of amplitude sensitivity was 0.5 μV. Our devices have a limit of 105 dB, so we worked with a volume of 100 dB for all patients whose hearing threshold was above 35 dB. The patients were divided into two groups, depending on the presence or absence of hypoplasia of the VA (VAH group and noVAH group), and all of them had PCS. A pathological finding of AEPs was considered if a decrease in amplitude by more than 50% and a prolongation of IWL occurred, the normal values of which are determined by the standard values of our laboratory.

Statistical data analysis

Statistical calculations were done using the SPSS program, version 20. Out of basic descriptive statistical parameters, standard statistical methods for qualitative and quantitative analysis of the obtained results were used: absolute numbers, relative numbers (%), arithmetic mean (%), and standard deviation. The Kolmogorov-Smirnov test was used to test the normality of the distribution. Comparing arithmetic means between two samples was performed by a *t*-test, while a nonparametric Mann-Whitney *U* test was used in cases where data did not follow a normal distribution. Statistically significant differences between absolute frequencies were tested by the Chi-square (χ^2) test. A statistical hypothesis was tested at a significance level risk of $\alpha = 0.05$, meaning that a *p*-value < 0.05 was considered statistically significant.

Results

The distribution of patients according to gender in relation to VAH findings is shown in Table 1. There is no statistical significance between males and females in relation to

the VAH finding (χ^2 = 1.823; p = 0.176). Both genders have an equal distribution in both groups of patients (Table 1).

The age groups show homogeneity in both study groups, indicating no statistically significant difference in age structure between VAH and noVAH patients (p = 0.815) (Table 2).

The distribution of infarct localization depends on the presence or absence of VAH. VAH distribution in relation to infarct localization is shown in Table 3. It has been determined that a positive VAH finding was significantly less present in patients with *cerebellum* infarction (VAH 13.0% vs. noVAH 25.5%) (χ^2 = 3.843; p = 0.048) in comparison to all other localizations. A statistically significantly greater number of patients with infarction at multiple locations have a positive VAH finding (VAH 42.3% vs. noVAH 26.6%) (χ^2 = 4.27; p = 0.038). No significant difference was observed between other infarct localizations.

Results show that a statistically significantly greater number of AEPs pathological findings were found in the group of patients with PCS and VAH (χ^2 = 4.899; p = 0.026) (Table 4).

There is a statistically significant IWL change accompanied by low amplitude waves in the VAH group (χ^2 = 4.465; p = 0.034) (Table 5).

Table 1

Gender distribution of patients in relation to vertebral artery hypoplasia (VAH) finding

Gender	VAH	noVAH	*p**
Male	40 (60.9)	50 (53.1)	
Female	29 (39.1)	44 (46.9)	0.176
Total	69 (100.0)	94 (100.0)	

Results are shown as numbers (percentages). *Chi-square test.

Table 2

Age distribution of patients in relation to vertebral artery hypoplasia (VAH) finding

Age (years)	VAH	noVAH	*p**
31–40	2 (2.8)	2 (2.1)	
41–50	4 (5.7)	3 (3.2)	
51–60	12 (17.5)	17 (18.1)	
61–70	21 (30.4)	29 (30.9)	
71–80	18 (26.1)	21 (22.3)	
> 78	12 (17.5)	22 (23.4)	0.815
Total	69 (100.0)	94 (100.0)	

Results are shown as numbers (percentages). *Fisher test.

Table 3

Distribution of vertebral artery hypoplasia (VAH) in relation to infarct localization

Infarct localization	VAH	noVAH	*p**
Medulla oblongata	4 (5.7)	11 (11.7)	0.197
Pons	17 (24.6)	18 (19.2)	0.399
Cerebellum	9 (13.0)	24 (25.5)	0.048
Mesencephalon	6 (8.7)	10 (10.6)	0.680
Occipital lobe	4 (5.7)	6 (6.4)	0.877
Multiple localizations	29 (42.3)	25 (26.6)	0.038
Total	69 (100.0)	94 (100.0)	

Results are shown as numbers (percentages). *Chi-square test.

Table 4

Distribution of acoustic evoked potentials (AEPs) findings in patients with posterior circulation stroke in relation to vertebral artery hypoplasia (VAH) presence

Parameter	AEPs finding		*p**
	normal	pathological	
noVAH	24 (25.5)	70 (74.5)	
VAH	8 (11.6)	61 (88.4)	0.026
Total	32 (19.6)	131 (80.4)	

Results are shown as numbers (percentages). *Chi-square test.

Table 5

Distribution of the type of pathological acoustic evoked potentials wave in patients with posterior circulation stroke in relation to vertebral artery hypoplasia (VAH) presence

Parameter	VAH	noVAH	*p**
Low amplitude waves	33 (54.1)	25 (35.7)	0.034
IWL change	10 (16.4)	15 (21.4)	0.464
IWL + low amplitude waves	18 (29.5)	30 (42.9)	0.113
Total	61 (14.0)	70 (100.0)	

IWL – interwave latency. Results are shown as numbers (percentages). *Chi-square test.

Discussion

Anatomic variations regarding the origin, course, and termination of the VA are numerous [18]. Studies dealing with VAH show left-sided dominance in 50–75% of the population. The right side is dominant in 25% of the population, and the same diameter of both VAs is found in about 25% of the population [20]. The reason for left-sided dominance is probably in the origin and "potency" of the site of origin (in 6% of the population, it originates directly from the arch of the aorta and separates without a brachiocephalic trunk). Since VAH is a congenital vessel abnormality, its frequency rate is not age-related. VAH was first described in the 19th century. It is an uncommon embryonic variation of the posterior circulation. The frequency of VAH has been reported to range from 2–6% in normal, healthy individuals on angiography imaging and autopsies [14]. Some authors report its frequency at 5–10% [20], while others report a percentage of 2.6% [21]. The VAH definition states that the VA diameter is ≤ 2 mm. Some authors have accepted the values of 2.2 mm or 2.5 mm in their studies, as well as the ratio between left and right VA of 1 : 1.7. Besides vessel diameter measurements, there are changes in hemodynamic parameters measured by blood vessel ultrasound: reduced flow volume (in the group VAH, it was 81.6 ± 16.5 mL/min, while in the group no-VAH, it was 123.2 ± 13.5 mL/min), peak systolic velocity decrease below 40 cm/sec, and increase in RI (> 0.75) [14, 22]. The fact that 75% of individuals with VA asymmetry have no signs of posterior circulation insufficiency is indicative of multiple-factor significance: collateral circulation, the Circle of Willis, and compensatory mechanisms of brain circulation for blood redistribution depending on the short- and long-term needs of certain brain parts [23]. Left VA dominance is associated with left hemisphere dominance and the dominance of right-handed people in the world's population, but the data about this is scarce. A group of authors introduced the term "VA dominance" [24], with a greater number of PCS in the territory curvature on the side of the non-dominant VA. The incidence of PCS is significantly higher in the group with VA dominance. A greater number of posterior inferior cerebellar artery infarctions were described on the non-dominant VA side, and a greater number of pontine infarctions were described on the side of dominant VA, explained by the traction of BA branches (*rami pontis*) [25]. For a long time, many authors have pointed out the importance of VAH presence in PCS associated with other risk factors for the onset of brain stroke (BS) [19]. In recent years, it has been proven that VAH is an independent risk factor for PCS onset [26]. Our prospective study enrolled 163 hospitalized patients with the diagnosis of PCS. Out of the total number, 69 (42.33%) patients had VAH, and 94 (57.67%) did not have VAH. The prevalence of gender is not seen in any of the groups. Gaigalaite et al. [27] found VA to be wider in males and VAH more common in females than in males (33% vs. 23.5%). Since VAH is a congenital vessel abnormality, its frequency rate is not age-related. Considering congenital variations of VAH, we expected an approximately equal distribution of PCS in VAH age groups. In relation to age, there is a greater number of patients aged 60 to 70 in both groups, which can be attributed to the presence of associated risk factors for PCS onset. Baran et al. [2] described BS sites in PCS in a group of 227 PCS patients and found an incidence of 10.1% at the *mesencephalon*, *pons* infarct in 62%, and *medulla* infarct in 30.5% of patients. Posterior cerebral artery territory infarction was noted in 26% and multiple site infarcts in 9% of patients. As for etiological factors, large artery atherosclerosis was found in > 50% of patients and cardioembolism in 15–30%, depending on the infarct site, mostly at the *mesencephalon* (26%). Small vessel disease of the posterior inferior cerebellar artery was the cause of BS in 6.5% of patients. Rare causes of stroke (vasculitis disorders, arterial dissection, malignancies) were found in 6.7% of patients. Despite diagnostic examinations, in 7.5% of patients, no cause for stroke could be found. In a study by Lin et al. [26] in patients with BSt infarcts, the incidence of *pons* infarcts was found in 85.4% of patients, 10% had *medulla* infarcts, and 1.5% had *mesencephalon* infarcts. Only 3% of patients had infarcts in other localizations. The etiological factors considered were the same as in the previous study. Considering the vascularization of posterior circulation structures, in cases of VAH, a greater incidence of infarction would be expected in the medullary region and lower *pons* (VA vascularization and posterior inferior cerebellar artery) in comparison to BSt parts vascularized by superior cerebellar artery, anterior cerebellar artery, BA (vascularization of *pons*, *cerebellum*, *mesencephalon*, and occipital lobe), or an equal distribution of ischemia in multiple locations or the simultaneous presence of multiple ischemic changes regarding the chronic inadequate circulation of a hypoplastic vessel. In our group of patients without VAH, the greatest number of patients experiencing a PCS (25.5%) with determined statistical significance was in the group with *cerebellum* localization (influence of other

risk factors for BS onset). A similar number of patients (26.6%) was noted in PCS at multiple localizations. In the group with VAH, a slightly greater number of patients had pontine infarction without statistically significant difference in comparison to the group without VAH, while the greatest number of patients showed the expected statistical significance of having PCS at multiple localizations in the posterior circulation region. The number of other PCS localizations in the VAH group is similar. Infarct localization significantly affects AEP wave morphology. It is explained by the fact that each wave of the AEPs is generated by a specific structure of BSt that is vascularized by the posterior circulation, so each vascular damage and other types of damage to these structures (multiple sclerosis, cerebellopontine angle tumor, chemotherapy in malignancies, ischemia, or compression during neurosurgical interventions) results in alternations of the wave morphology of AEPs [1]. In the studies that followed up AEPs in lacunar infarctions of the BSt, a group of authors found altered AEPs in BA dolichoectasia due to BSt ischemia and compression [4]. Thorwirth et al. [28] detected the absence of wave III in pontine lesions. Drake et al. [29] showed absolute latency elongation of waves in patients with posterior circulation transient ischemic attack (TIA). They detected the absence of wave III in pontine lesions. Earlier studies describe AEPs changes in patients with TIA. In this group of patients, improvements in clinical presentation correlate with the regression of findings. In the case of recurrent persistent TIA over a longer period of time (chronic posterior circulation deficiency), wave morphology changes occur; all of them are dominant but exhibit poor shape and often low amplitudes [11]. In Budd-Chiari syndrome, the authors describe the elongation of IWL I–V [30]. Wang et al. [12] describe the elongation of latencies in waves III and V in patients with PCS. In patients who experienced PCS during stent implantation, elongation of IWL I–V was registered [31]. Yoshikatsu et al. [32] reported pathological AEPs findings in 56% of patients in the group with PCS. Pathological findings were mostly associated with the pontine tegmentum and cerebellar peduncle lesions. Normal AEPs findings showed lesions dominantly in the *medulla oblongata*, pontine base, cerebral peduncles, and *cerebellum* hemispheres. Waves III, IV, and V are not seen in the group with tegmentum lesions of the upper to mid *pons*. There was no difference in findings between the group with *medulla oblongata* lesions and the midbrain lesions, implying that they do not generate AEPs, as the authors hypothesized. In our group of patients, there is a statistically significantly greater number of AEPs pathological findings in patients with VAH and PCS. By following changes in the amplitudes of AEPs waves and changes in the IWL of waves I–III, III–V, and I–V in this group of patients, decreased amplitudes associated with prolonged IWL are statistically significant in comparison to the group with noVAH patients.

Conclusion

In our group of patients with PCS, there is a statistically significantly higher rate of VAH. The distribution of VAH is not gender-related. The incidence of PCS was highest in the group of patients aged 60 to 70 in both groups of patients. Our study revealed a higher frequency of pathological AEPs findings in patients with VAH and PCS. Pathological AEPs findings showed the presence of associated changes in wave amplitudes and prolonged IWL in a statistically significant number of patients with VAH.

Acknowledgement

The authors are grateful to all patients for participating in this study.

Conflict of interest

The authors declare no conflict of interest.

R E F E R E N C E S

1. *Berger JR, Blum AS*. Brainstem Auditory Evoked Potentials. In: *Blum AS, Rutkove SB*, editors. The Clinical Neurophysiology Primer. New Jersey: Humana Press; 2007. pp. 475–84.
2. *Baran G, Gultekin TO, Baran O, Deniz C, Katar S, Yildiz GB,* et al. Association between etiology and lesion site in ischaemic brainstem infarcts: a retrospective observational study. Neuropsychiatr Dis Treat 2018; 14: 757–66.
3. *Thai-Van H, Cozma S, Boutitie F, Disant F, Truy E, Collet L*. The pattern of auditory brainstem response wave V maturation in cochlear-implanted children. Clin Neurophysiol 2007; 118(3): 676–89.
4. *Passero S, Nuti D*. Auditory and vestibular system findings in patients with vertebrobasilar dolichoectasia. Acta Neurol Scand 1996; 93(1): 50–5.
5. *Henry-Le Bras F, Fischer C, Nighoghossian N, Salord F, Trouillas P, Mauguière F*. Early and middle latency auditory evoked potentials in vertebrobasilar strokes. Neurophysiol Clin 1994; 24(6): 399–412. (French)
6. *De Biase S, Gigli GL, Lorenzut S, Bianconi C, Sfreddo P, Rossato G,* et al. The importance of polysomnography in the evaluation of prolonged disorders of consciousness: sleep recordings more adequately correlate than stimulus-related evoked potentials with patients' clinical status. Sleep Med 2014; 15(4): 393–400.
7. *Rogowski M, Michalska BI*. The importance of brain stem evoked potentials in the diagnosis of neurosurgical patients. Neurol Neurochir Pol 2001; 35(4): 667–79. (Polish)
8. *Iakupov EZ, Kuznetsova EA*. Evoked potentials in patients with secondary headaches. Zh Nevrol Psikhiatr Im S S Korsakova 2010; 110(1): 73–7. (Russian)
9. *Jiang ZD, Zhou Y, Yin R, Wilkinson AR*. Amplitude reduction in brainstem auditory response in term infants under neonatal intensive care. Clin Neurophysiol 2013; 124(7): 1470–6.
10. *Živadinovic B, Stamenović J, Ljubisavljevic S*. The comparative analyses of the auditory evoked potentials and color Doppler sonography findings in patients diagnosed with vertebrobasilar insufficiency. Neurol Res 2014; 36(11): 939–44.
11. *Živadinović B, Đurić S, Jolić M, Stamenović J*. Diagnostic importance of auditory brainstem potentials of patients with vertebrobasilar insufficiency. Mak Med Pregl 2004; 58(supp1.61): 55.

12. *Wang H, Zhou H, Guo Y, Wang H*. Value of high-frequency stimulation ABR in the diagnosis and treatment of posterior circulation ischemia. Lin Chung Er Bi Yan Hou Tou Jing Wai Ke Za Zhi 2012; 26(16): 724–6.
13. *Stone JL, Fino J, Patel K, Calderon-Arnulphi M, Suss N, Hughes JR*. Modified brain stem auditory evoked potentials in patients with intracranial mass lesions. Clin EEG Neurosci 2012; 43(4): 291–302.
14. *Chuang YM, Chan L, Wu HM, Lee SP, Chu YT*. The clinical relevance of vertebral artery hypoplasia. Acta Neurol Taiwan 2012; 21(1): 1–7.
15. *Katsanos A, Kosmidou M, Kyritsis AP, Giannopoulos S*. Is vertebral artery hypoplasia a predisposing factor for posterior circulation cerebral ischemic events? A comprehensive review. Eur Neurol 2013; 70(1–2): 78–83.
16. *Antić S*. Vascularization of the central nervous system. In: *Pavlović S, Stefanović N, Vučetić R, Antić S, Čukuranović R, Arsić S*, editors. Anatomy of the central nervous system and senses. Niš: Sven; 2006. p. 48–157. (Serbian)
17. *Mitsumura H, Miyagawa S, Komatsu T, Hirai T, Kono Y, Iguchi Y*. Relationship between Vertebral Artery Hypoplasia and Posterior Circulation Ischemia. J Stroke Cerebrovascular Dis 2016; 25(2): 266–9.
18. *Iqbal S*. Vertebrobasilar variants and their basic clinical implications. Int J Med Res Health Sci 2013; 2(4): 799–808.
19. *Szárazová AS, Bartles E, Turčáni P*. Vertebral artery hypoplasia and the posterior circulation stroke. Perspect Med 2012; 1(1–12): 198–202.
20. *Vilimas A, Barkauskas E, Vilionskis A, Rudzinskaitë J, Morkûnaitë R*. Vertebral artery hypoplasia: importance for stroke development, the role of posterior communicating artery, possibility for surgical and conservative treatment. Acta medica Lituanica 2003; 10(2): 110–4.
21. *Demarin V, Škarić-Jurić T, Lovrencić-Huzjan A, Puretić MB, Vuković V*. Vertebral artery hypoplasia-sex-specific frequencies in 36 parent-offspring pairs. Coll Antropol 2001; 25(2): 501–9.
22. *Chen YY, Chao AC, Hsu HY, Chung CP, Hu HH*. Vertebral artery hypoplasia is associated with a decrease in net vertebral flow volume. Ultrasound Med Biol 2010; 36(1): 38–43.
23. *Hendrikse J, van Raamt AF, van der Graaf Y, Mali WP, van der Grond J*. Distribution of cerebral blood flow in the circle of Willis. Radiology 2005; 235(1): 184–9.
24. *Zhu W, Wang YF, Dong XF, Feng HX, Zhao HQ, Liu CF*. Study on the correlation of vertebral artery dominance, basilar artery curvature and posterior circulation infarction. Acta Neurol Belg 2016; 116(3): 287–93.
25. *Hong JM, Chung CS, Bang OY, Yong SW, Joo IS, Huh K*. Vertebral artery dominance contributes to basilar artery curvature and peri-vertebrobasilar junctional infarcts. J Neurol Neurosurg Psychiatry 2009; 80(10): 1087–92.
26. *Lin Y, Zhang L, Bao J, Zhang B, Li H, Chen S,* et al. Risk factors and etiological subtype analysis of brainstem infarctions. J Neurol Sci 2014; 338(1–2): 118–21.
27. *Gaigalaite V, Vilimas A, Ozeraitiene V, Dementaviciene J, Janilionis R, Kalibatiene D,* et al. Association between vertebral artery hypoplasia and posterior circulation stroke. BMC Neurol 2016; 16: 118.
28. *Thorwirth V, Volles E, Lossi C, Grunwald F*. Auditory evoked brain stem potentials, visual pattern evoked and somatosensory evoked potentials in transient ischemic attacks (TIA). Schweiz Arch Neurol Neurochir Psychiatr 1983; 132(1): 41–54. (German)
29. *Drake ME Jr, Pakalnis A, Padamadan H, Hietter SA*. Auditory evoked potentials in vertebrobasilar transient ischemic attacks. Clin Electroencephalogr 1990; 21(2): 96–100
30. *Moncho D, Poca MA, Minoves T, Ferré A, Rahnama K, Sahuquillo J*. Brainstem auditory evoked potentials and somatosensory evoked potentials in Chiari malformation. Rev Neurol 2013; 56(12): 623–34. (Spanish)
31. *Pandey P, Kansara A, Thirumala P, Tamkus AA, Xavier AR*. Neurophysiological monitoring with brainstem evoked potentials can be a valuable tool for patients undergoing vertebrobasilar stenting and angioplasty-initial experience. J Clin Neurophysiol 2013; 30(1): 55–8.
32. *Yoshikatsu S, Masahiro S, Makoto H, Syuichi M*. Topographical Relationships Between the Brainstem Auditory and Somatosensory Evoked Potentials and the Location of Lesions in Posterior Fossa Stroke. Neurol Med Chir 2003; 43(6): 282–92.

Received on December 20, 2023
Revised on March 23, 2024
Accepted on April 9, 2024
Online First May 2024