The Auditory Brainstem Responses in Patients with Unilateral Cochlear Hearing Loss

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Abstract The aim of our study is to analyze changes occurring in the auditory brainstem response (ABR) according to stimulus parameters in unilateral cochlear hearing loss cases. Twenty-nine cases (14 male, 15 female) with unilateral sensorineural hearing loss (SNHL) were investigated. All cases had cochlear SNHL on one side whereas normal hearing on the other side. All cases underwent ABR testing with varying stimulus intensity levels and stimulus repetition rates (SRRs). Results were compared and their correlation with audiogram shapes investigated. As stimulus intensity levels decreased on both ears, latencies expanded and amplitudes decreased in all traces of ABR. Latencies of ears with cochlear hearing loss were observed to be longer than those in normal ears. Responses to SRR increases were similar on both ears. Audiogram shapes should be taken into consideration while performing ABR in order to address asymmetric SNHL. The interpretation of ABR changes with various stimulus levels may provide a better understanding of cochlear pathologies associated with hearing loss in the future.

Keywords The auditory brainstem response · Unilateral cochlear hearing loss · Stimulus intensity · Stimulus repetition rate

Introduction

The auditory brainstem response (ABR) testing is a useful tool to evaluate integrity of cochlea and central auditory pathway. Since it does not require patient compliance, it can easily be performed especially on children and elderly whose hearing levels can not easily be determined by classical audiometric tests.

Previous researches showed that several factors like age, sex, the type of hearing loss may alter ABR results. The most significant changes that occur depending on the human factor are the ones related with the age. In premature or normal infants, wave V latency shortens with age, and comes close to the value of the adults in 12 or 18 months [1, 2]. In women, the latencies are shorter whereas amplitudes are longer compared to men of same age [3]. Furthermore, ABRs may differ with respect to shape of audiograms of patients with hearing loss [4]. Watson [5] found that wave I displayed latency prolongation with increasing levels of high-frequency hearing loss and wave V latency was associated with both degree of hearing loss and slope of audiogram. Prosser et al. [6] found that wave V in patients with cochlear lesions have a linear correlation with patient's pure-tone audiometry at 2 and 4 kHz. ABRs also change with varying several stimulus parameters such as type, polarity, frequency, intensity and repetition rate [7, 8].

ABR testing is one of the most important non-invasive tests used for the diagnosis of retrocochlear lesions. The absence of ABR waveforms is a useful screening index for

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retrocochlear pathologies. The I–V inter-wave interval and the absolute latency of wave V are helpful indices, however they are not specific. As a screening tool for retrocochlear lesions, the interaural differences of ABR are important guides for clinicians. Hwang et al. [9] reported that the interaural differences of wave III and wave V were affected significantly only by degree of hearing asymmetry, not by sex or age. In order to diagnose retrocochlear lesions, ABR results of patients with cochlear pathology should also be known. The effects of varying stimulus parameters of ABRs were seldom evaluated in patients with unilateral cochlear hearing loss. The purpose of this study is to analyze alterations of ABRs after application of various stimulus parameters in patients with unilateral sensorineural hearing loss (SNHL). Contrary to many studies performed on patients with asymmetric SNHL, the better hearing sides of patients in this study were all in normal hearing range. We aimed to compare the ABR changes in both ears of patients by changing testing parameters of stimulus intensities and stimulus repetition rates (SRRs).

Materials and Methods

Twenty-nine cases (14 male, 15 female) between the ages of 18 and 73 with unilateral SNHL were analyzed. Patients whose hearing thresholds on better hearing side were below 20 dB and patients whose hearing thresholds on worse hearing side were above 80 dB in pure-tone audiometry were excluded from study. Prior to ABR testing, patients underwent complete physical examination to rule out any existing otorhinolaryngologic or systemic disease. The control group consisted of normal hearing ears of the same patients. Thus, the effects of age factor which may cause extension of wave V latency were eliminated. The development pattern and the duration of hearing loss were not taken into consideration as a criterion on selection of cases. All cases were evaluated by temporal bone computed tomography and magnetic resonance imaging in order to rule out any structural cochlear pathology that might have caused SNHL.

Amplaid MK12 (Amplaid, Milan, Italy) device was used for ABR testing. In order to minimize the effects of electromyography over responses all patients were administered per oral 10 mg midazolam for sedation 30 min before testing. Tests were performed in a dusk and quiet room. Electrodes were placed over the mastoid area for differential recording. Ground electrode was placed on the forehead area. The electrodes attachment areas were cleansed with alcohol cotton swab. Conductor paste was applied to the electrodes before placing them. Inter-electrode impedance was set to be below 5 kOhm and close to

one another in all channels. Then, 130 dB SPL, 110 dB SPL, 90 dB SPL, 70 dB SPL, 60 dB SPL, 50 dB SPL intensity click stimuli in ipsilateral order with a rate of 11 repetitions per second were performed through TDH-39 earphones. In order to analyze the effect of SRR over ABR, ipsilateral 110 dB SPL click stimulus were also performed with repetition rates of 31 and 71 per second. White noise of 50 dB SPL below the stimulus intensity was given to normal ears for masking. An average of 2,000 stimuli were recorded. Recording was done by measurement of potential between both mastoids related with ipsilateral record vertex. During the test, 150–3,000 Hz band pass filter was used. Click stimulus was given with alternating polarity. In order to minimize artifacts, the automatic rejection command on the system was kept on during the test. All traces were retested for reliability to determine the repeatability of the ABR results. The amplitudes of wave I and V, interpeak latencies (IPL) of waves I–III, III–V and I–V and latencies of wave I, III and V were recorded on obtained traces.

Statistical analyses were performed using commercially-available software (IBM SPSS Statistics 19, SPSS Inc., an IBM Co., Somers, NY). All continuous variables were normal distribution according to Kolmogorov–Smirnov normality test. Therefore; Two Independent Sample *t* test was used to compare the continuous variables between two groups. Repeated measures one way ANOVA was used to compare the latency and amplitude values among 11, 31 and 71 SRR. Repeated measures two way ANOVA was used to compare the alteration of latency and amplitude between two groups. Continuous variables were presented as mean and standard deviation. A *P* values <0.05 were considered as statistically significant.

Results

The total number of cases were 29, including 15 women and, 14 men with an average age of 44.9 ± 11.7 (18–73). As the stimulus intensity decreased on normal hearing ears, latencies expanded and amplitudes diminished in all traces of ABR. Deformation of the waves was limited as the intensity of stimulus decreased, and the determination of latency levels became difficult for intensities close to the threshold. As the intensity of stimulus decreased, wave I and wave III became undetectable, respectively. At 50 dB SPL, wave I was seen only in one case whereas wave III was seen only in three cases. The characteristics of ABR responses of the ears with cochlear hearing loss were almost similar (Figs. 1, 2). As the stimulus intensity decreased, latencies expanded and amplitudes diminished. All latencies were longer than those of normal ears in all traces of ABR, however, the difference was not statistically

Fig. 1 ABR characteristics of ears with normal hearing. Graph shows changes of the latencies of the waves according to stimulus intensity levels

Fig. 2 ABR characteristics of ears with cochlear hearing loss. Graph shows changes of the latencies of the waves according to stimulus intensity levels

significant. The wave morphologies were almost normal at levels above the threshold but deformed substantially at levels close to threshold. Detection of the waves became difficult at levels close to threshold whereas no wave was detected at 60 dB SPL and 50 dB SPL. The data for latency and IPL values obtained at all stimulus intensity levels are shown at Table 1.

On normal hearing sides, the latency delay averages were detected to be 0.19 ms for wave I, 0.3 ms for wave III, 0.49 ms for wave V, between 130 and 90 dB intensity levels. On cochlear hearing loss sides, these values were 0.19 ms for wave I, 0.47 ms for wave III and 0.56 ms for wave V, respectively. No significant difference was detected between IPL values of both groups.

On normal hearing sides, as SRR increased, the latencies expanded and the amplitudes decreased on a

Table 1 Changing latency and IPL values with decreasing stimulus intensity

Intensity	Group	Latency (ms)		Interpeak latency (ms)		
		I	III	V	I-III	III-V
130 dB SPL	I	1.58 ± 0.15	3.68 ± 0.33	5.56 ± 0.41	2.1 ± 0.27	1.87 ± 0.32
	II	1.71 ± 0.19	3.8 ± 0.25	5.61 ± 0.42	2.09 ± 0.28	1.8 ± 0.32
110 dB SPL	I	1.63 ± 0.14	3.7 ± 0.25	5.63 ± 0.33	2.07 ± 0.2	1.93 ± 0.34
	II	1.74 ± 0.19	3.86 ± 0.22	5.69 ± 0.34	2.13 ± 0.29	1.82 ± 0.31
90 dB SPL	I	1.77 ± 0.16	3.98 ± 0.31	6.05 ± 0.34	2.13 ± 0.16	2.05 ± 0.3
	II	1.9 ± 0.23	4.27 ± 0.36	6.17 ± 0.46	2.24 ± 0.18	1.83 ± 0.29
70 dB SPL	I	2.36 ± 0.32	4.52 ± 0.24	6.53 ± 0.37	1.98 ± 0.29	1.98 ± 0.36
	II	-	-	6.63 ± 0.67	-	-
60 dB SPL	I	-	4.87 ± 0.23	6.86 ± 0.24	-	2.01 ± 0.2
	II	-	-	-	-	-
50 dB SPL	I	-	5.25 ± 0.18	7.32 ± 0.29	-	2.12 ± 0.43
	II	-	-	-	-	-

Group I: ears with normal hearing, Group II: ears with cochlear hearing loss

statistically significant level. The ABR responses to SRR changes on ears with cochlear hearing loss were similar to the responses of ears with normal hearing. Although, all latency values were longer than those of normal ears, the elongation rates detected with the SRR increase were not more than those in normal ears. Similar rates of elongation were detected at all latency waves for both groups and the difference was not considered as statistically significant between two groups (Table 2).

In order to investigate ABR changes with regard to SRR increase, we studied SRR rates 11/31 and 31/71 to determine the levels which latencies and IPLs increased further. For ears with normal hearing, the 11/31 and 31/71 rates for wave I latencies were detected as 0.95 and 0.96; rates for wave III latencies as 0.97 and 0.96; rates for wave V latencies as 0.98 and 0.96, respectively. However, these differences were not statistically significant. The rates for ears with cochlear hearing loss were detected as 0.96 and 0.96 for wave I latencies; 0.98 and 0.96 for wave III; 0.97 and 0.96 for wave V latencies, with no statistically significant difference. The I–III IPL value rates for ears with normal hearing were detected as 0.98 and 0.97, whereas 1.00 and 0.97 for ears with cochlear hearing loss. I–V IPL value rates for ears with normal hearing were detected as 0.98 and 1.03, whereas 0.99 and 1.03 for ears with cochlear hearing loss. There was no statistically significant difference.

In order to analyze the correlation of audiogram shapes with ABRs, we grouped and studied the responses of ears with cochlear hearing loss in terms of audiogram slopes such as descending, ascending, flat and spoon shaped. The average pure-tone threshold at 2 and 4 kHz of the cases are shown at Table 3. The data was not analyzed statistically since the number of cases was too small. The highest

Table 3 The average pure-tone thresholds at 2 and 4 kHz of the cases with cochlear hearing loss according to audiogram slopes

	Descending (n = 10) (dB)	Spoon shaped (n = 3) (dB)	Flat (n = 11) (dB)	Ascending (n = 5) (dB)
2 kHz	52.5 ± 17.2	36.6 ± 7.6	49.5 ± 14.1	43 ± 17.5
4 kHz	62.5 ± 14.1	55 ± 15	50 ± 9.2	25 ± 7.9

latency values were observed in cases with descending audiograms, whereas the values of cases with ascending and flat audiograms were close to each other. In cases with descending audiograms, as the intensity of stimulus decreased, more expansion was observed in wave V latency values than those of other groups. Expansion in IPL values were only seen in cases with descending audiograms at low stimulus intensity. All other IPL values were found to be close to the values of ears with normal hearing (Table 4).

Discussion

The ABR testing which enables us to measure hearing objectively has a very important place in audiology and otoneurology [10–12]. In clinic use, the ABR is frequently used for detecting hearing thresholds and in recognizing retrocochlear pathologies. In recent years, it has been stated that the ABR testing can be used in early diagnosis of hearing loss in systemic disorders that can potentially cause hearing loss. Among the ABRs, wave I, III, V latencies and the IPLs of these waves are the significant ones used for diagnosis [8, 12]. Waves I and III cannot always be detected in stimuli levels close to hearing thresholds, whereas wave V can be detected easily in stimuli levels even at

Table 2 The ABRs changing with increasing SRR in 110 dB SPL intensity

Waves		Group	SRR			<i>P</i> value ^b	<i>P</i> value ^c
			11/s	31/s	71/s		
Latency (ms)	I	I	1.63 ± 0.14	1.71 ± 0.14	1.78 ± 0.13	<0.001	0.263
		II	1.74 ± 0.19	1.81 ± 0.19	1.89 ± 0.21	<0.001	
		<i>P</i> value ^a	0.574	0.192	0.139		
	III	I	3.7 ± 0.25	3.85 ± 0.24	3.98 ± 0.24	<0.001	0.489
		II	3.86 ± 0.22	3.96 ± 0.19	4.1 ± 0.23	<0.001	
		<i>P</i> value ^a	0.902	0.353	0.352		
	V	I	5.63 ± 0.33	5.75 ± 0.29	5.98 ± 0.28	<0.001	0.317
		II	5.69 ± 0.34	5.84 ± 0.34	6.09 ± 0.41	<0.001	
		<i>P</i> value ^a	0.494	0.464	0.440		

As SRR increase, elongation in latencies is seen in both groups. Similar rate of elongation is seen at all latency of waves for both groups. Group I: ears with normal hearing, Group II: ears with cochlear hearing loss

^a P value of the comparison between Group I and II

^b P value of the comparison among three SRR

^c P value of the comparison between two groups according to alterations of SRR

Table 4 According to the audiogram shapes, the latency and IPL values of ears with cochlear hearing loss and normal hearing, changing with decreasing stimulus intensity

Intensity	Audiogram shape	Latency (ms)			Interpeak latency (ms)		
		I	III	V	I–III	III–V	I–V
130 dB SPL	Descending	1.79	3.89	5.78	2.1	1.88	3.99
	Ascending	1.66	3.78	5.33	2.12	1.56	3.68
	Flat	1.65	3.73	5.6	2.08	1.87	3.96
	Spoon	1.81	3.84	5.58	2.02	1.74	3.76
	Normal	1.58	3.68	5.56	2.1	1.87	3.98
110 dB SPL	Descending	1.79	3.92	5.82	2.14	1.89	4.03
	Ascending	1.69	3.79	5.44	2.1	1.66	3.76
	Flat	1.67	3.84	5.71	2.16	1.88	4.03
	Spoon	1.86	3.9	5.62	2.04	1.72	3.76
	Normal	1.63	3.7	5.63	2.07	1.93	3.99
90 dB SPL	Descending	2.1	4.53	6.47	2.34	1.96	4.44
	Ascending	1.95	4.16	5.85	2.16	1.68	3.78
	Flat	1.8	4.18	6.13	2.26	1.88	4.2
	Spoon	–	3.96 ^a	6.12	–	1.62 ^a	–
	Normal	1.77	3.98	6.05	2.13	2.05	4.21
70 dB SPL	Descending	–	–	–	–	–	–
	Ascending	–	–	–	–	–	–
	Flat	1.74 ^a	4.86 ^a	6.87	–	–	–
	Spoon	–	–	–	–	–	–
	Normal	2.36	4.52	6.53	1.98	1.98	4.09

^a Means one case

psychoacoustic thresholds. Picton et al. [7] found that detectable amplitudes were 30–40 dB higher than psychoacoustic thresholds for wave I, whereas they were 20–30 dB higher for wave III, and 5–15 dB higher for wave V. According to Sininger [13], this value for wave V was 5–6 dB. Giroux and Pratt [11] reported that this value for wave V was over 10–20 dB. In our study, on normal hearing ears, we observed the existence of wave I in one case, wave III in three cases, and wave V in all cases, at 50 dB SPL. Hence, Wave V is the most frequently used wave of ABR for audiological and otoneurological diagnosis.

There are well established stimulus parameters like intensity, repetition rate, and polarity which alters latency, amplitude, and morphology of ABR waves. With the analysis of parametric changes we can detect the value and type of hearing loss; we can also detect retrocochlear pathologies and even make localization [8, 14]. Therefore we believe determining the purposive parameters is important. For example, in a newborn, when detecting threshold, stimulus can be given 31 times or more per second in order to shorten the test time. However, in order to detect localization of a lesion, a rate of stimulus 11 times per second would be more reasonable [8].

Researches show that, when stimulus intensity decreases, significant changes occur in latency, amplitude, and wave morphology in ABR. In various studies, it has been shown that while mild differences occur in ABR, elongation in wave latencies, decrease in amplitudes and deformation in morphologies occur with decreasing intensities [15, 16]. In our study, we had similar results in both groups. However, the decline which was observed in decreasing stimulus intensity was not same at all intensities. Especially, as stimulus intensities reduced, the expansion in wave latencies occurred in higher levels. In other words, in normal hearing group, for wave V, the expansion of latency for each dB was 3.5 μ s between 130 and 110 dB SPL levels, whereas it was 23 μ s between 70 and 50 dB SPL levels. In cochlear hearing loss group, the expansion for each dB was 4 μ s between 130 and 110 dB SPL, and 23 μ s between 90 and 70 dB SPL levels. For some authors, the expansion of latencies with decreasing stimulus intensity follows a logarithmic pathway. Picton et al. [7], showed that, in high stimulus intensities, the expansion in wave V latency for each dB was 6 μ s. The expansion rose up to 60 μ s in low stimulus intensities.

In our study, in cases with cochlear hearing loss, the response to decreasing stimulus intensity was similar to the response of cases with normal hearing. That is with decreasing stimulus intensities there has been a delay in latencies and decrease in amplitudes. However, in cases with cochlear hearing loss, the expansion in wave V with decreasing stimulus intensities was observed in higher rates than that of the expansion in wave I intensity.

ABR is the distribution of the neuroelectric activity that rises from cochlea to cochlear nerve and to brainstem. In cases with cochlear hearing loss, since the signal produced by cochlea is damaged, the correlation between cochlear hearing loss and ABR may differ. That is, ABR waves that are constituted by stimulus levels above hearing threshold, have almost normal latency, amplitude and morphology whereas, ABR waves that are constituted by the stimulus levels close to hearing thresholds, the latency, amplitude and morphology of the waves are weak and hard to detect [17]. In our study, regarding suprathreshold and stimulus intensities, the ABRs of cochlear hearing loss cases, were similar to the ABRs of normal hearing cases. The morphologies of ABR waves began to diminish and became hard to recognize at intensities around hearing threshold.

The ABR testing is frequently used for diagnosis of retrocochlear lesions. Tumors and vascular lesions are common pathologies that cause retrocochlear hearing loss. The cause of the changes in ABR testing on retrocochlear pathologies is the signal decrease caused by hearing loss. I–V IPL measurement is often used in the diagnosis of retrocochlear lesions. The normal value for I–V IPL is approximately around 4.0 ms [11, 15]. Values higher than

4.70 ms indicate existence of a retrocochlear lesion [6]. Interaural latency measurement is the most frequently used method in the differential diagnosis of retrocochlear hearing loss. Generally, the latency values of wave V in both ears are compared for diagnosis. The interaural difference higher than 0.3 ms indicates retrocochlear lesion [9]. In our study, we did not detect any interaural latency difference higher than 0.3 ms.

In cases with asymmetric SNHL, differential diagnosis is essential but difficult to achieve. The most useful non-invasive test that can help us for this matter is ABR. Swan [18] detected that in cases with asymmetric SNHL 63% of patients have normal ABR findings, whereas all cases with cerebellopontine angle tumors have abnormal ABR findings. Hendrix et al. [19] did not detect normal ABR findings in any of the cases with asymmetric SNHL and retrocochlear pathologies, so they reported that ABR had 98% sensitivity in acoustic neuroma diagnosis. Among the group of authors with opposing view, Cueva [20] reported that ABR has 71% sensitivity and it can show normal results especially in small size tumors.

In ABR applied by using click stimulus, the responses reflect 2,000–4,000 Hz thresholds best. For this reason, audiogram shape has great effect on ABR [21–23]. Therefore, in cases with SNHL, audiogram shape should be taken into consideration in order to avoid misinterpretation of ABR. Keith and Greville [4], studied the effects of audiogram shapes on ABR responses and founded that, in cases with descending and spoon shaped audiogram slopes, the wave V latencies are longer than those in normal group. In cases with flat and ascending type audiogram slopes, wave V latencies were close to the normal group. The elongation of I–V IPL was seen only in cases with spoon shaped audiogram. In cases with descending audiograms, wave V latencies were around normal levels at high stimulus intensities, whereas they expanded at low stimulus intensities. In our study, the latencies of all cases were longer than normal levels whereas the cases with flat and ascending type audiograms had results close to normal levels. In cases with descending audiograms, wave V latencies were recorded to be considerably expanded with decreasing stimulus intensities, compared to the normal and other type audiogram cases. There was no significant difference with regard to IPL values. Because the number of cases in each group was limited, the statistical difference between groups could not be analyzed.

Another stimulus parameter for differentiating cochlear and retrocochlear pathologies is SRR. Expansion in latencies and shortening in amplitudes is expected with the increase of SRR. Various studies revealed that, with increasing SRR, the elongation seen in wave latencies are more significant in retrocochlear pathologies [8, 24]. Rowe [24] reported that, a retrocochlear pathology which doesn't

produce signs in low SRRs may become evident in higher SRRs. It has been reported that [7, 25], with increasing SRR, elongation of latencies in ABR is seen, however, this changes are small in early components and distinct in late components. In our study, both groups had similar responses with increasing SRR. When SRR was increased, elongation in latencies and decrease in amplitudes have been detected. The alteration seen in both groups was statistically significant. However, there was no significant difference in alterations seen with increasing SRR between two groups. With 11/s–71/s SRR, the difference in latency was 0.15 ms for wave I, 0.28 ms for wave III and 0.5 ms for wave V in cases with normal hearing. In cases with cochlear hearing loss, difference in latency was 0.15 ms for wave I, 0.24 ms for wave III, and 0.4 ms for wave V. There was no significant difference between IPL values of both groups.

In conclusion, the evaluation of asymmetric SNHL is crucial for the search of internal auditory canal-cerebellopontine angle lesions. ABR has been a useful tool for recognizing cochlear–retrocochlear pathologies. Audiogram shapes should be taken into consideration while performing ABR in order to address asymmetric SNHL. Though the main stimulus parameters for a regular ABR have been established, the interpretation of ABR changes with various stimulus levels may help enhance our understanding of ABR and provide a better understanding of cochlear pathologies associated with hearing loss in the future.

Conflict of Interest The authors do not have any financial relationship with any organization and have no conflict of interest.

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