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Original Article

Normalization of Bone Conduction Auditory Brainstem Evoked Responses in Normal Hearing Individuals

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OBJECTIVES: Auditory brainstem responses (ABR) are used to evaluate the peripheral and central functions of the auditory tract. Air and bone-conduction auditory stimuli are used to evaluate the type and degree of hearing loss. The wave latencies and interpeak latencies (IPLs) are the important diagnostic data in ABR tests. Gender and age of the patients are some of the factors affecting these latencies. This study investigated the effects of age and gender on the wave and IPLs of bone-conduction ABR.

MATERIALS and METHODS: One hundred healthy individuals (50 women and 50 men) aged between 10 and 60 years were enrolled into this study, and both ears of all subjects (200 ears total) were included in the assessments. Based on their age, the subjects were equally divided into five groups, and each group consisted of 10 men and 10 women.

RESULTS: The findings showed a significant difference in wave latencies and IPLs between the two genders (p<0.05). Depending on stimulus intensity, wave latencies also showed statistically significant differences between the age groups (p<0.05). However, no significant difference was noted between the age groups regarding IPLs.

CONCLUSION: Normative values that covered wave latencies and IPLs evoked at stimulus intensities of 50, 30, and 10 dB nHL were established for the clinical use and use as a reference for the bone-conduction ABR testing procedure.

KEYWORDS: Bone-conduction auditory brainstem responses, age, gender

INTRODUCTION

The electrical activity within the pathway that starts from the auditory nerve and elongates up to the brainstem is known as evoked auditory brainstem responses (ABR) [1, 2]. The ABR test is used for two major purposes: estimation of the threshold and defining the location of a lesion. ABR provide information about the possible pathologies of the auditory pathway and threshold information about the subject's hearing level [3-7]. The most appropriate method for the evaluation of the hearing status is the pure tone audiometry (PTA) test. However, PTA is inadequate when testing infants, young children, and individuals with developmental or cooperation problems [6]. Thus, the importance of the ABR test has increased in that it provides closer results to the PTA test results in the measurement of the type and severity of hearing loss when used with the air and bone pathways, two components of the ABR test [8-9]. The main objective is to ascertain whether the hearing loss is a transmission-type hearing loss, a mixed-type hearing loss, or sensory loss through electrophysiological measurements. The second objective is to identify the condition that has led to a transmission-type hearing loss [5].

In general, the wave latencies and interpeak latencies (IPL) are the most important data in air- and bone-conduction ABR tests, used for determining auditory sensitivity. Gender and age of the patients are some of the factors that affect these latencies [5]. In the literature, it is remarkable that studies performed on different age groups have reported different durations of wave latencies [5, 9].

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Therefore, to detect latency anomalies, and to predict the effects of age and gender on the wave latencies, there is need to evaluate the data of those with normal hearing in the various age periods.

This study aims to demonstrate the effects of age and gender on latency and IPL in bone-conduction ABR responses and, subsequently, to establish clinical normative values based on the collected data.

MATERIAL and METHODS

Subjects

This study was carried out at the Audiology Unit of the Ear, Nose and Throat Department of Firat University Hospital after all subjects provided consent for their participation. The study protocol was approved by the Ethics Committee on Human Experiments of Firat University Medical Faculty (05.23.2014)/39542). In total, 50 healthy women and 50 healthy men (100 cases) aged between 10 and 60 years were enrolled into this study, and both ears of all subjects (200 ears total) were included into the assessments. Based on their age, the subjects were equally divided into five groups, each group consisting of 10 men and 10 women. The group distribution of the individuals who participated in the study and the mean age are given in Table 1.

The inclusion criteria in this study were determined as having normal otological findings, normal middle ear pressure, a bilateral acoustic reflex, a pure sound average within normal limits, and the ability to distinguish normal speech [10, 11].

Table 1. The group distribution of the individuals participating in the study and their mean age

Groups		Men	Women
		Mean	Mean
Group 1 (n=20)	10-20 years	17.5±2.21	17.5±2.23
Group 2 (n=20)	21-30 years	25.87±2.77	24.5±2.77
Group 3 (n=20)	31-40 years	35.07±2.73	34.1±3.16
Group 4 (n=20)	41-50 years	43.5±3.21	45.13±3.16
Group 5 (n=20)	51-60 years	54.73±3.21	53.5±3.16

Table 2. Test parameters used in bone-conduction ABR measurements

	Test parameters
Stimulus	0.1 ms click
Polarity	Alternate
Intensity	50, 30, 10 dB nHL
Stimulant repetition rate	7/s
Recording filter band	30-1500 Hz
Averaging	1000
Bone vibrator location	Superior–posterior mastoid area

ABR: Auditory Brainstem Responses; ms: millisecond

Table 3. Right/left ear bone-conduction ABR wave and IPLs

			Ear				
			Right		Left		
	Wave	Intensity (dB)	n	mean±sd (ms)	n	mean±sd (ms)	p
Wave latency	I	50	100	2.27±0.30	100	2.29±0.36	0.68
		30	100	3.21±0.46	100	3.20±0.53	0.90
		10	55	4.22±0.64	65	4.20±0.65	0.82
	III	50	100	4.30±0.31	100	4.24±0.31	0.17
		30	100	5.16±0.43	100	5.20±0.44	0.59
		10	59	6.21±0.70	69	6.18±0.62	0.74
	V	50	100	6.18±0.33	100	6.19±0.30	0.71
		30	100	7.02±0.58	100	7.07±0.57	0.53
		10	98	8.15±0.73	100	8.15±0.61	0.68
IPL	I–V	50	100	3.90±0.29	100	3.92±0.49	0.68
		30	100	3.87±0.51	100	3.93±0.52	0.43
		10	55	3.97±0.54	65	4.01±0.54	0.69
	I–III	50	100	2.07±0.53	100	1.96±0.35	0.08
		30	100	2.04±0.62	100	2.00±0.51	0.66
		10	55	2.02±0.37	65	2.02±0.41	0.95
	III–V	50	100	1.88±0.21	100	1.96±0.29	0.01*
		30	100	1.87±0.30	100	1.96±0.37	0.06
		10	59	2.09±0.96	69	2.02±0.40	0.59

Mean: arithmetic mean; sd: standard deviation; IPL: interpeak latencies; ABR: Auditory Brainstem Responses; ms: millisecond
* p<0.05 considered statistically significant

Auditory Evaluation
The following tests were applied to all cases.

- Basic audiological evaluation: All audiological assessments were performed in rooms with appropriate acoustic isolation and standard quiet cabinets (Industrial Acoustic Company Inc., New York, USA) using an Inter acoustics AC 40 clinical audiometer (Interacoustics, Assens, Denmark) with TDH 39P Telephonics earpieces and Radioear B-71 bone vibrator (Radioear Corporation, Pennsylvania, USA). Air and bone-conduction hearing thresholds were determined. Speech audiometry was also performed to determine the speech recognition threshold and word discrimination scores. The subjects with normal hearing and normal word discrimination scores were included into this study [11]. Acoustic immittance measurements by interacoustics AZ 26H impedance were using a low-frequency 226 Hz probe tone (Denmark). The middle ear pressure, static impedance, and acoustic reflex thresholds of all subjects were checked before inclusion in the study, and the subjects with type A tympanogram and bilateral acoustic reflexes at 85 dB were included [9, 10].

- Bone-conduction ABR: Bone-conduction ABR tests in the present study were performed using a Medelec Synergy T (Oxford Instruments, Abingdon, Oxfordshire, UK) device with a B-71 bone vibrator. Bone-conduction ABR behaviors of all subjects were retrieved ipsilaterally using the 0.1 ms alternating click stimuli. Gold-cased, reusable metal plate electrodes were used in the ABR recordings. The stimulant repetition rate was set to ≤10/s to achieve the best possible description of the waves [5]. A frequency number of 7 clicks/s were applied. The stimulus levels detected for 7 clicks/s were 50–30–10 dB nHL. With the bone-conduction stimulation in normal hearing adults, the Wave I is recorded only at the upper limits for the stimulus intensity level [5]. The bone vibrator was placed on the ipsilateral mastoid, a negative electrode was placed to the ipsilateral lobule, an active electrode was placed on the hairline, and the grounding electrode was placed on the contralateral lobule during the recordings. Results were filtered at the 30–1500 Hz frequency band and amplified. The impedance difference between the electrodes was kept below 3 kΩ. Two separate traces of 1,000 sweeps were generated for each wave to test the reproducibility of response, and analyses were performed for both ears separately. No masking was performed because all subjects included in the study had normal hearing functions. Test parameters used in the bone-conduction ABR measurements are presented in Table 2.

Statistical Analysis
Statistical analysis was performed using the The Statistical Package for the Social Sciences (SPSS) version 22.0 software (IBM Corp., Armonk, NY, USA). Student's t-test was used to perform comparisons between genders and right/left ears. The one-way ANOVA test was used to assess the differences between different age groups, and possible statistically significant differences were analyzed. Any significant finding was further analyzed by the Tukey method to show which groups represented the significant difference. A p-value of <0.05 was considered to be statistically significant.

Table 4. Women/men bone-conduction ABR wave and IPLs

			Ear				
			Women		Men		
	Wave	Intensity (dB)	n	mean±sd (ms)	n	mean±sd (ms)	p
LATENCIES	I	50	100	2.24±0.29	100	2.32±0.37	0.11
		30	100	3.07±0.46	100	3.34±0.49	0.00*
		10	70	4.14±0.63	50	4.31±0.65	0.14
	III	50	100	4.22±0.27	100	4.31±0.34	0.03*
		30	100	5.10±0.42	100	5.26±0.45	0.03*
		10	73	6.16±0.66	55	6.23±0.65	0.58
	V	50	100	6.11±0.30	100	6.26±0.31	0.00 *
		30	100	6.91±0.53	100	7.17±0.59	0.00*
		10	100	8.04±0.68	98	8.27±0.64	0.01*
IPL	I–V	50	100	3.87±0.31	100	3.96±0.47	0.09
		30	100	3.93±0.61	100	3.87±0.41	0.41
		10	70	4.00±0.57	50	3.99±0.49	0.97
	I–III	50	100	2.02±0.55	100	2.01±0.33	0.84
		30	100	2.13±0.74	100	1.92±0.29	0.01*
		10	70	2.04±0.41	50	2.00±0.35	0.56
	III–V	50	100	1.90±0.24	100	1.94±0.26	0.23
		30	100	1.86±0.28	100	1.97±0.38	0.03*
		10	73	2.05±0.89	55	2.06±0.36	0.94

Mean: arithmetic mean; sd: standard deviation; IPL: interpeak latencies; ABR: Auditory Brainstem Responses; ms: millisecond
* p<0.05 considered statistically significant

RESULTS

Bone-conduction ABR responses of all cases were recorded twice at three different stimulus intensities (50, 30, 10 dB nHL) and calculated according to age, gender, and right/left ear. Two separate traces were created to test the repeatability of ipsilateral responses in all stimulus intensities. The wave peaks of these cases were found to be compatible with each other.

Right/left ear's wave and IP latency values were separately recorded at 50, 30, 10 dB nHL stimulus intensities, and their statistical comparison is presented in Table 3. The right and left ear mean latency differences were not found to be statistically significant, except the III–V IPL difference at 50 dBnHL.

The mean wave and IPLs values according to gender are shown in Table 4. Wave latency differences according to gender were found to be statistically significant at Wave I (30 dB nHL), Wave III (50 /30 dB nHL), Wave V (50/30/10 dBnHL). The comparison of the mean wave latencies showed that the mean wave latencies of men were more prolonged than those of women. However, there was no remarkable gender difference in the assessment of IPLs.

Table 5. Mean bone-conduction ABR latencies and IPLs estimated at 50 nHL from all cases included in the study according to age groups and their statistical comparisons

			Women		Men		
	Wave	Intensity (dB)	n	mean±sd (ms)	n	Difference	p
LATENCIES	I	1	10-20	40	2.23±0.36	X	X
		2	21-30	40	2.17±0.24		
		3	31-40	40	2.36±0.42		
		4	41-50	40	2.32±0.31		
		5	51-60	40	2.32±0.29		
	III	1	10-20	40	4.21±0.27	2-4	0.05*
		2	21-30	40	4.16±0.28		
		3	31-40	40	4.31±0.40		
		4	41-50	40	4.35±0.32		
		5	51-60	40	4.30±0.24		
	V	1	10-20	40	6.17±0.26	2-4	0.04*
		2	21-30	40	6.05±0.27	2-5	0.05*
		3	31-40	40	6.21±0.36		
		4	41-50	40	6.25±0.37		
		5	51-60	40	6.24±0.25		
IPL	I–V	1	10-20	40	3.94±0.31	X	X
		2	21-30	40	3.94±0.61		
		3	31-40	40	3.84±0.36		
		4	41-50	40	3.92±0.37		
		5	51-60	40	2.10±0.81		
	I–III	1	10-20	40	1.98±0.22	X	X
		2	21-30	40	2.04±0.43		
		3	31-40	40	1.95±0.23		
		4	41-50	40	2.02±0.28		
		5	51-60	40	2.10±0.81		
	III–V	1	10-20	40	1.95±0.24	X	X
		2	21-30	40	1.89±0.25		
		3	31-40	40	1.92±0.27		
		4	41-50	40	1.89±0.31		
		5	51-60	40	1.94±0.20		

Mean: arithmetic mean; sd: standard deviation; IPL: interpeak latencies; ABR: Auditory Brainstem Responses; ms: millisecond
* p<0.05 considered statistically significant, X: no significant difference between the groups

Table 5 shows the mean latencies and IPL values at 50 dB nHL according to the age groups and their statistical comparison. The assessment of wave latencies according to the age groups showed statistically significant differences between Groups 2 and 4 for Wave III, and between Groups 2 and 4, as well as Groups 2 and 5 for Wave V at 50 dB nHL stimulus intensity (p<0.05) (Table 5).

Table 6 shows the mean latencies and IPL values at 30 dB nHL according to the age groups and their statistical comparison. The assessment of the wave latencies according to the age groups at the 30 dB nHL intensity showed statistically significant differences between Groups 2 and 4 for Wave I, between Groups 1 and 4 as well as Groups 2 and 4 for Wave III, and between Groups 1 and 4 for Wave V (p<0.05).

Table 7 shows the mean latencies and IPL values at 10 dB nHL according to the age groups and their statistical comparison. The assessment of the latencies per age groups recorded at 10 dB nHL stimulus

Table 6. Mean bone-conduction ABR latencies and IPLs estimated at 50 nHL from all cases included in the study according to age groups and their statistical comparisons

			Descriptive		Tukey		
	Wave	Intensity (dB)	n	mean±sd (ms)	n	Difference	p
LATENCIES	I	1	10-20	40	3.11±0.49	2-4	0.03*
		2	21-30	40	3.05±0.39		
		3	31-40	40	3.26±0.54		
		4	41-50	40	3.37±0.51		
		5	51-60	40	3.22±0.49		
	III	1	10-20	40	5.07±0.42	1-4	0.02*
		2	21-30	40	5.02±0.37	2-4	0.00*
		3	31-40	40	5.24±0.42		
		4	41-50	40	5.35±0.42		
		5	51-60	40	5.22±0.48		
	V	1	10-20	40	6.81±0.65	1-4	0.00*
		2	21-30	40	6.95±0.45		
		3	31-40	40	7.10±0.45		
		4	41-50	40	7.24±0.47		
		5	51-60	40	7.11±0.72		
IPL	I–V	1	10-20	40	3.77±0.29	1-5	0.01*
		2	21-30	40	3.89±0.41	3-5	0.05*
		3	31-40	40	3.82±0.37		
		4	41-50	40	3.87±0.35		
		5	51-60	40	4.14±0.89		
	I–III	1	10-20	40	2.00±0.46	X	X
		2	21-30	40	1.94±0.27		
		3	31-40	40	2.02±1.09		
		4	41-50	40	1.98±0.26		
		5	51-60	40	1.96±0.26		
	III–V	1	10-20	40	1.82±0.28	1-5	0.02*
		2	21-30	40	1.95±0.37	3-5	0.02*
		3	31-40	40	1.83±0.26		
		4	41-50	40	1.93±0.30		
		5	51-60	40	2.05±0.41		

Mean: arithmetic mean; sd: standard deviation; IPL: interpeak latencies; ABR: Auditory Brainstem Responses; ms: millisecond

* p<0.05 considered statistically significant, X: no significant difference between the groups

intensity showed statistically significant differences between Groups 1-3, 1-4, 1-5, and 2-5 for the Wave I, and between Groups 1-3, 1-5, 2-4, and 2-5 for the Waves III and V (p<0.05). IPLs were not statistically significantly different between the age groups.

The mean wave latencies at three stimulus intensities and IPLs were analyzed according to the age groups. Statistically significant differences were found at wave latencies between younger and older age groups (p<0.05). Younger groups' wave latencies were shorter than older age groups.

DISCUSSION

Although normative data have been previously published for ABR test, studies highlight the necessity to use the normative data that are specifically generated for each device and tested on the local population [8, 12]. There are physiological differences between bone- and air-conduction ABR results, and these differences reflect on the precision of the pathways. Studies have shown that the range of precision for bone-conduction pathway is localized below 2500 Hz and localized between a higher range of 3000-4000 Hz for the air-conduction pathway [5, 15, 16]. Therefore, the response to bone-conduc-

Table 7. Mean bone-conduction ABR latencies and IPLs recorded at 10 nHL from all cases included to the study according to age groups and their statistical comparisons

			Descriptive		Tukey		
	Wave	Intensity (dB)	n	mean±sd (ms)	n	Difference	p
LATENCIES	I	1	10-20	40	3.77±0.70	1-3	0.02*
		2	21-30	40	4.01±0.53	1-4	0.00*
		3	31-40	40	4.33±0.56	1-5	0.00*
		4	41-50	40	4.59±0.48	2-4	0.00*
		5	51-60	40	4.36±0.66		
	III	1	10-20	40	5.71±0.59	1-3	0.00*
		2	21-30	40	5.96±0.46	1-4	0.00*
		3	31-40	40	6.31±0.55	1-5	0.00*
		4	41-50	40	6.62±0.67	2-4	0.00*
		5	51-60	40	6.45±0.65	2-5	0.01*
	V	1	10-20	40	7.76±0.64	1-3	0.02*
		2	21-30	40	7.97±0.49	1-4	0.00*
		3	31-40	40	8.19±0.59	1-5	0.00*
		4	41-50	40	8.45±0.76	2-4	0.00*
		5	51-60	40	8.41±0.61	2-5	0.02*
IPL	I–V	1	10-20	40	3.87±0.44	X	X
		2	21-30	40	3.98±0.57		
		3	31-40	40	3.92±0.46		
		4	41-50	40	3.94±0.53		
		5	51-60	40	4.25±0.59		
	I–III	1	10-20	40	1.97±0.30	X	X
		2	21-30	40	1.99±0.39		
		3	31-40	40	2.04±0.49		
		4	41-50	40	2.03±0.43		
		5	51-60	40	2.09±0.31		
	III–V	1	10-20	40	1.89±0.30	X	X
		2	21-30	40	2.06±0.38		
		3	31-40	40	2.23±1.46		
		4	41-50	40	1.91±0.36		
		5	51-60	40	2.17±0.47		

Mean: arithmetic mean; sd: standard deviation; IPL: interpeak latencies; ABR: Auditory Brainstem Responses; ms: millisecond
* p<0.05 considered statistically significant, X: no significant difference between the groups

tion ABR stimulus is obtained from the apical region of the basilar membrane in adults, where lower frequencies are located. As a result, bone-conduction ABR gives longer latencies. Moreover, the longer Wave V latencies obtained by bone-conduction ABR compared to the air-conduction procedure may be due to the localization of vibrator in the bone pathway or may be attributed to the differences between the mechanisms of bone-conduction and air-conduction pathways [13-17]. Three different regions were defined on the temporal bone, superior, superior–posterior, and posterior temporal regions, and the findings of each region were compared to the Wave V latencies in bone-conduction. The authors concluded that the most convenient region to obtain ideal measurements was the superior–posterior region that was also used in this study [15].

Cornacchia et al. [18] reported that the bone-conduction Wave V latencies are 0.59 ms longer than air-conduction latencies. Another study performed in adults showed that the bone-conduction ABR latencies were 0.50 ms longer compared to the air-conduction latencies [17]. Mauldin and Jerger [19] reported that the Wave V latencies in bone-conduction ABR were on average 0.46 ms longer than the latencies in air-conduction ABR. In our study, bone-conduction Wave V latencies in adults were found to be approximately 0.50 ms longer than air-conduction ABR latencies. The Wave V latency difference may originate from the difference between the energy conversion principles of these two conduction pathways; the air-conduction stimulus affects the mechanisms of the outer and middle ear on its pathway, whereas bone-conduction stimulus reaches the cochlea through different structures [15].

Ness [9] reported that the interwave latencies are longer in men than women and concluded that this finding was in line with the literature. Dehan and Jerger [20] argued that the differences observed between men and women in wave latencies may depend on the head size. In the present study, comparisons between genders showed that the wave latencies were 0.2 ms longer in men than women. We suggest that the head size difference between genders may not have any delay effects on wave latencies. Probably, the bone structure and density may affect the prolongation in men's wave latencies. In line with the literature, the reason behind the age-dependent bone-conduction ABR wave latencies could be the effectiveness of bone and skin thickness [5, 21].

CONCLUSION

The wave and interpeak latency data from normal hearing subjects that were obtained in the present study serve standard values for bone-conduction ABR procedure for our clinic. These values will be taken as a reference while assessing our patients. Moreover, the collected normative data will guide the interpretation of bone-conduction ABR test results in cases aged between 10 and 60 years and will be instructive for the East Anatolian Region. The data will provide the clinicians with the ease, time, and confidence if needed for the differential diagnosis and detection of the pathologies.

Ethics Committee Approval: The study protocol was approved by Ethics Committee on Human Experiments of Firat University Medical Faculty (05.23.2014/ 39542).

Informed Consent: Written informed consent was obtained from all subjects who participated in this study.

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