

Original Article

Analysis of P1 Latency in Normal Hearing and Profound Sensorineural Hearing Loss

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Objectives. P1 is a robust positivity at a latency of 50-150 msec in the auditory evoked potential of young children. It has been reported that over the first 2-3 years of life, there is a rapid decrease of the latency and the mean P1 latency in adults with normal hearing is approximately 60 msec. This study was designed to evaluate the change of the P1 latency in Koreans with normal hearing according to age and to compare this with the P1 latency of young patients with profound sensorineural hearing loss before and/or after cochlear implantation.

Methods. Among the patients who visited the Department of Otorhinolaryngology at Seoul National University Hospital from June 2007 to September 2009, the P1 response was recorded in 53 patients in the normal hearing group, in 13 patients in the pre-cochlear implantation (CI) group and in 10 patients in the post-CI group. A synthesized consonant-vowel syllable /ba/ was used to elicit the evoked responses. The evoked responses were collected using the center of the frontal head. For each subject, an individual grand average waveform was computed by averaging the ten recordings. The P1 latency was visually identified as a robust positivity in the waveform.

Results. For the normal hearing group, the P1 latency showed the pattern of shortening as the age increased (coefficient, -0.758; $P < 0.001$). For the pre-CI group, 10 cases showed delayed latencies and 3 cases did not show the P1 wave. For the post-CI group, the P1 latencies showed a less delayed tendency than those of the pre-CI group, but this was not statistically different.

Conclusion. This report provides the standard value of the P1 latency at each age in Koreans for the first time and the findings support that the maturation of the central auditory pathways could be measured objectively using the P1 latency.

Key Words. Auditory evoked potentials, Auditory pathways, Cochlear implantation

INTRODUCTION

Normal maturation of the central auditory system affects the development of speech recognition and the ability to speak. This central auditory pathway shows a progressive change in anatomy and physiology as a person's age increases (1). The cortical

auditory evoked potential (CAEP) reflects the cerebral maturation through the change in latency and the shape of the waveform. P1 shows robust positivity in the CAEP and the P1 latency ranges from 50 msec to several seconds. It is known that the latency of the P1 continuously changes as age increases, and mainly from infancy to adolescence with a range of 50-150 msec latency (1, 2). There have been several studies that focused on the developmental status in the auditory pathway using this characteristic of P1 (3, 4). Because the P1 latency reflects the developmental status of the central auditory pathway (5-7), it has been used to evaluate the change of maturation in the auditory pathway for congenitally deafened children after they have been fitted with hearing devices such as hearing aid or a cochle-

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ar implant (8, 9).

The objective of this study was to collect the data for P1 latency at each age for Koreans with normal hearing and to estimate the P1 latency in Koreans with profound sensorineural hearing loss before and/or after auditory rehabilitation using a cochlear implantation.

MATERIALS AND METHODS

Subjects

Between June 2007 and September 2009, the P1 response was recorded from the patients who visited Department of Otorhinolaryngology at Seoul National University Hospital. The patients were divided into 3 groups: the patients unrelated with any hearing disorder and whose hearing was proved to be normal (the control group), the patients with profound sensorineural hearing loss and who were waiting for cochlear implantation (the pre-CI group) and those patients after cochlear implantation (the post-CI group). For the normal control group, the patients with a history of chronic otitis media or a speech and language disorder were excluded. For the other two groups, the patients with syndromic sensorineural hearing loss, a neurologic disorder such as mental retardation or a history of brain surgery, cerebral palsy and epilepsy were excluded. The study was approved by the Internal Review Board of Seoul National University Hospital.

Stimulation method

The CAEP was recorded in response to a synthesized consonant-vowel (CV) speech syllable /ba/. The sound wave file was provided by Dr. Arnu Sharma at the University of Colorado. Briefly, the duration of the speech sound was 90 msec and the 5 formant CV stimulus was generated using the Klatt speech synthesizer. The starting frequencies of F1 and F2 were 234 Hz and 616 Hz, respectively. The center frequencies for the formants of the vowel /a/ were 769 Hz, 1,232 Hz, 2,862 Hz, 3,600 Hz, and 4,500 Hz for F1, F2, F3, F4, and F5, respectively. The amplitude of voicing was constant for 80 msec and then this fell linearly to 0 in the last 10 msec of the stimuli. The fundamental frequency began at 103 Hz, it increased linearly to 125 Hz over 35 msec and then it decreased to 80 Hz over 55 msec.

The stimulus was presented at an offset-to-onset interstimulus interval of 510 msec. The stimulus was delivered via a loudspeaker placed at an angle of 45° to the right of the normal hearing subjects. For the profound hearing loss groups, the speaker was moved to the aided side (the side with a hearing aid or cochlear implant). The subjects were instructed to conduct an experiment with a speech processor at a comfortable loudness level or with a fitted hearing aid. The stimulus was presented at a constant level of 70 dB SPL as measured at the head location in the sound booth for the control group and post-CI

group. For the pre-CI group, a stimulus 10-20 dB HL larger than the aided level with a hearing aid was presented.

Electrophysiologic recording

Evoked potentials were collected using the Cz as the active electrode. Generally, the reference electrode was placed on the right mastoid and the ground was placed on the forehead. For the post-CI group, the reference electrode was located on the nonimplanted side. Eye movements were monitored using a bipolar electrode montage (lateral outer canthus-superior outer canthus). The subjects were seated comfortably in a reclining chair placed in a sound booth. The subjects watched a video tape movie or cartoon of their choice on a TV monitor placed in front of them in the sound booth. The videotape audio levels were kept below 45 dB SPL. Averaging was automatically suspended by the recording computer when eye blinks were detected. The window for observation of the waveform included 100 msec prestimulus and 440 msec poststimulus intervals, and the waveform was recorded from the time of the stimulus. During the prestimulus period, we could observe a consistently flat waveform, which was apparently different from the P1 waveform. The incoming evoked responses were analog filtered from 0.1 to 100 Hz. The averaged responses were elicited in a block of 100 stimuli. Ten blocks were collected for each subject. The test session, including application of the electrodes and recording the evoked response lasted about 30 minutes.

Data analysis

For each patient, an average waveform was computed through ten blocks. P1 was defined as the first robust positivity in the 50-150 msec in the normal hearing. In the case of a double-peaked P1 wave, the P1 latency was typically marked on the first peak. If the P1 response showed a plateau pattern, then the P1 latency was marked on the mid-point. The linear regression analysis and correlation coefficients for the P1 latencies were computed using SPSS ver. 12.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Control group

P1 was recorded in the control group (n=53), which was composed of 34 males and 19 females with a mean age of 8.0 years (range, 1.7 to 17.5 years). The number of patients and the mean value of the P1 latency at each age are shown in Table 1. A sample of the P1 response in a 4 year-old male is shown in Fig. 1. A robust positivity at a latency of 100 msec was visible and this was considered as P1. The measured P1 latency of the control group is shown with the 95 percentile confidence level in Fig. 2. The P1 latency decreased as the age increased and there was a statistically significant negative correlation between the P1 latency and age (correlation coefficient, -0.758; $P < 0.001$).

Table 1. Distribution of the P1 latency in the control group according to age (n=53)

Age (years)	No.	Mean P1 latency (msec)*
2	2	122.5
3	6	104.1
4	5	106.8
5	5	85
6	8	87.8
7	5	77.8
8	3	82.6
9	2	84
10	4	80.3
11	4	69.8
12	4	65
13	2	79
14	2	61
17	1	61

The P1 latencies of all the subjects are plotted in Fig. 2
 *Correlation coefficient=-0.758, P<0.001.

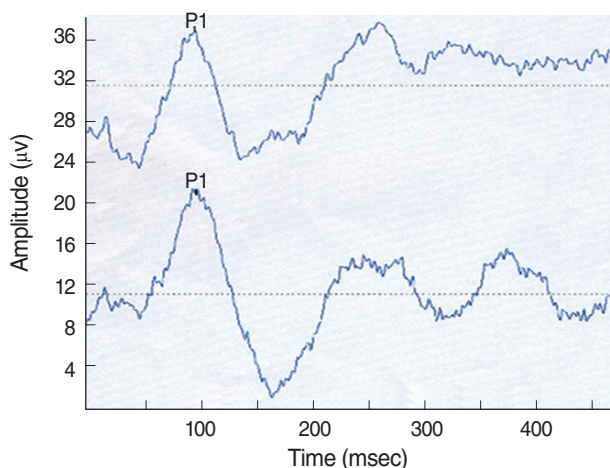


Fig. 1. Two blocks of the P1 response in the control group. A robust positivity is observed at approximately 100 msec, followed by a prominent negative N1.

Pre-CI group

The pre-CI group (n=13) was composed of 9 males and 4 females (mean age, 6.6 years; range, 1.4 to 12.8 years). For the pre-CI group, there was a tendency that the P1 latencies were delayed compared to those of the control group (Table 2, Fig. 2). Among the 6 patients whose hearings were scaled out bilaterally, 3 patients did not show the P1 waves even though they had used hearing aids for a long time. These 3 patients showed measurable hearing levels with wearing a hearing aid, but the speech performances were very poor. Two examples of the P1 responses in this group are shown in Fig. 3: one is a measurable P1 in 110 msec (top) and the other is a sample in which the P1 is absent, showing just a sawtooth wave form (bottom).

Post-CI group

The post-CI group (n=10) was composed of 5 males and 5 fe-

Table 2. Distribution of the P1 latency in the pre-cochlear implantation group according to age (n=13)*

No.	Age (years)	Age of HA (months)	HA use (months)	PTA (dB) (R/L)	Aided PTA (dB) (R/L)	IT-MAIS/ open sentence (preop)	P1 latency (msec)
1	1.4	13	4	95/95	55/55	3/40	181
2	2.6	6	25	85/80	60/60	40/40	110
3	2.7	27	5	S.O	80/85	0/40	160
4	3.3	33	7	95/90	L) 75	40/40	135
5	3.3	36	4	95/85	85/65	18/40	198
6	4.3	41	10	100/85	L) 60	40/40	112
7	5.3	58	5	S.O	80/70	15/40	135
8	7	19	65	110/105	55/55	0%	119
9	9.4	18	95	S.O	90/50	33.3%	166
10	12.4	92	57	S.O/75	L) 40	82%	170
11	10	15	105	S.O	75/65	0%	-
12	11.8	17	124	S.O	80/70	0%	-
13	12.8	36	118	S.O	80/85	0%	-

*Three patients did not show a P1 wave.
 HA: hearing aid; PTA: pure tone audiometry; IT-MAIS: infant-toddler meaningful auditory integration scale; S.O: scale out.

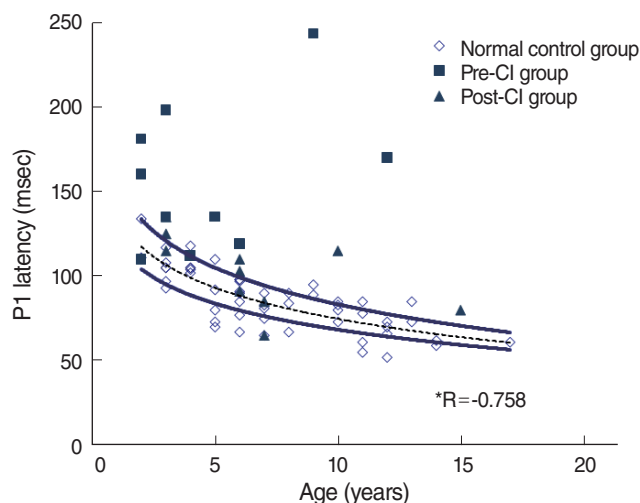


Fig. 2. Distribution of the P1 latency in the three groups. The dotted line shows the mean value of the control group and the other two lines show the 95% confidence intervals at each age. Compared with the control group, there is overall delayed pattern of the P1 latency at each age both in the pre-cochlear implantation (CI) and post-CI groups. The P1 latency in the post-CI group is less delayed than that in the pre-CI group, but there was not any statistical significance. *Correlation coefficient of the control group.

males (mean age, 7.1 years; range, 3.3 to 15.5 years). The P1 latency in the post-CI group is shown in Table 3. For the post-CI group, there was a tendency that the P1 latency showed a less delayed pattern than that in the pre-CI group, but this could not be tested statistically because of many confounding factors such as age at the time of the operation, the duration of hearing aid use and the duration of usage of a cochlear implant (Table 3, Fig. 2). The preoperative aided hearing levels were measurable and

Table 3. Distribution of the P1 latency in the post-cochlear implantation group according to age (n=10)

No.	Age (years)	Age of HA (months)	HA use (months)	PTA (R/L)	Aided PTA (R/L)	IT-MAIS/ open sentence (preop)	Age at operation (months)	IT-MAIS/ open sentence (postop, months)	P1 latency (msec)
1	3.3	31	8	100/95	75/75	16	36	40/40 (3)	135
2	3.7	33	11	95/90	L) 75	40	42	40/40 (2)	125
3	3.9	32	15	S.O	80/75	2	39	12/40 (8)	115
4	6.1	12	61	S.O	95/95	-	27	40/40 (46)	103
5	6.3	36	40	105/85	75/50	20	37	90% (4)	91
6	6.9	46	37	100/95	60/70	0	57	99% (26)	110
7	7.3	82	5	S.O	85/85	0	78	-	65
8	7.5	22	68	S.O	80/90	0	37	40/40 (53)	85
9	10.3	19	104	S.O	60/60	0	63	73% (60)	115
10	15.5	36	150	S.O	80/80	0	114	0% (72)	80

HA: hearing aid; PTA: pure tone audiometry; IT-MAIS: infant-toddler meaningful auditory integration scale; S.O: scale out.

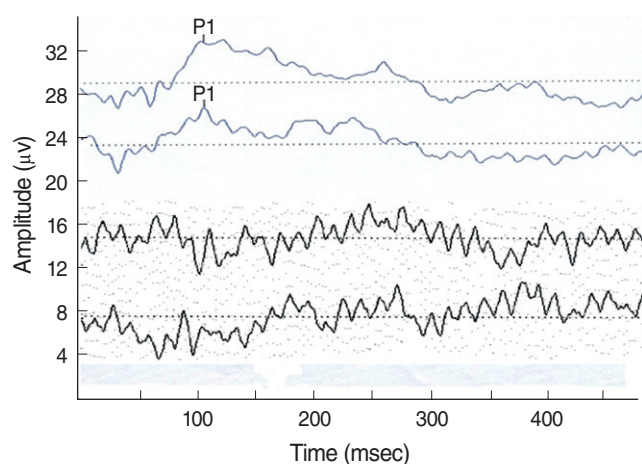


Fig. 3. Samples of the P1 response in the pre-cochlear implantation (CI) group. For subject 2, a positive P1 wave at 110 msec is detected with a similar pattern for the control group (top). For subject 11, there is a just sawtooth wave form and no positive wave that was considered as P1 (bottom).

maintained between 60 dB and 95 dB, whereas the speech performances were very poor.

DISCUSSION

P1 is a robust positivity generated by the auditory thalamic and cortical area. The P1 response occurs through projections of the ascending thalamocortical fibers (10). Especially, the secondary auditory cortex located in the dorsal side of the medial geniculate nucleus is called the lemniscal adjunct pathway and this terminates mainly in layer IV and it is considered as the main source of P1 (10). It is presumed that the P1 response reflects reactivation or re-entry of the specific auditory cortex rather than activation of the auditory efferent nerve (11).

The latency of P1 reflects the accumulated sum of delays in the synaptic propagation through the peripheral and central au-

ditary pathways. Therefore, the gradual decrease in latencies probably results from a gradual increase in neural transmission speed, which is related with changes of myelination as well as an increase in synaptic synchronization (12).

Sharma et al examined the latency and amplitude of P1 in a group of subjects with normal hearing (2, 13). In those studies, the mean P1 latency was approximately 300 msec in the normal hearing newborns and the latency decreased rapidly over the first 2-3 years to approximately 125 msec at 3 years old and then it gradually decreased into the second decade of life. The mean P1 latency in normal hearing adults (range, 22 to 25 years) was approximately 60 msec (13, 14). Thus, it was suggested that the latency of P1 could be a biomarker for maturation of the central auditory pathway. In our study, the P1 was estimated at a latency of 50-150 msec and it had a tendency to decrease as age increased. Our data showed a similar pattern of negative correlation between P1 latency and age, the same as the previous reports. To the best of our knowledge, this is the first recording to evaluate the P1 latency in Koreans during development.

Proper auditory stimulation is the most important factor in the development of the central auditory system, and especially for children younger than 3.5-4 years because that period is considered as a critical period for brain plasticity (15, 16). In our study, the pre-CI group showed delayed P1 latency and we could not identify the tendency of decreasing P1 latency as age increased. This suggests that fitting a patient with a hearing aid simply for a long time would not guarantee sufficient stimulation for the development of the central auditory pathway in pediatric patients with profound hearing loss.

Although the P1 latency between the pre-CI and post-CI groups was not statistically different in this study, the P1 latency in the post-CI group was more closely plotted to the 95% confidence interval of the control group than that in the pre-CI group at each age (Fig. 2). This implicates the possible role of using the P1 latency as a predictive marker for determining the success of auditory rehabilitation with using a CI.

For the post-CI group, there was no statistical correlation between the P1 latency and the duration of usage of a cochlear implant. This result may be influenced by many confounding factors such as the preoperative aided hearing level, the preoperative speech performance, the preoperative P1 latency, the age at operation and the postoperative speech performance. There may also be a ceiling effect that the maturation of the central auditory pathway reaches a limit at months or years after usage of an implant. Taken together, it is thought that there was a limitation for the cross-sectional analysis for the pre-CI group and post-CI group. Therefore, investigating the P1 change before and after CI in the same patient with profound hearing loss could give additional evidence to support the role of the P1 as a biomarker for the central auditory pathway in the future.

This is the first report that has demonstrated the P1 latency in Koreans with normal hearing according to the age during development. There was a statistically significant negative correlation between the P1 latency and age. Establishing the standard value of the P1 latency at each age in patients with normal hearing could be a cornerstone for further evaluation of the central auditory system in patients with hearing loss.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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