J. Biomed. Eng. Res.
Vol. 25, No. 3, 195-200, 2004

The Comparisons of 4 Channel Auditory Brainstem Response for Tracking Auditory Neuro-Pathway

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(Received September 9, 2003. Accepted April 23, 2004)

Abstract : The Auditory Brainstem Response (ABR) with a click stimulation in guinea pigs was used to examine the auditory neuro-pathway from the cochlear nucleus to brain. Using multi-channel active electrodes, the 3-dimensional auditory pathway was examined from the cochlea to the inferior colliculus through the brainstem. These results are similar to the well-known neuro-pathway. This study on the multi-channel ABR shows that the positions of the ABR generators move to the central brain and the contralateral pathway. It is generally agreed that the ABR is generated by some structures along the auditory pathway. This study provides some information on the neuro-pathway where the ABR peak is generated.
Key words : ABR, Multi-channel, Auditory pathway

INTRODUCTION

The auditory brainstem response (ABR) is defined as a group of averaged potentials occurring within the first 10ms after an auditory stimulus through the ear. The ABR was developed to provide a reliable and valid test for the hearing ability and to detect the retrocochlear pathology like a vestibular schwannoma[1].

It is important to note the presence of waves and their relative amplitude. It is generally known that each wave originates from a certain part of the brainstem auditory pathway, from the cochlea up to the inferior colliculus in the midbrain[2]. For example, wave I is related to the distal part of the auditory nerve, Wave II- is related to the cochlear nucleus, Wave III- is related to the superior olivary complex etc.

Evoked response potential(ERP) is the electrical physiological methods of the response measurement for the special stimuli. ERPs, as better time resolution than fMRI or PET, are used clinically for the brain diseases[3]. Yasuhara et al.[4] reported a 3-dimensional auditory brainstem response. They recorded the 3D ABR in children and compared the clinical efficacy of the technique to that of conventional 2D ABR. They used the X channel, Y channel and Z channel. They just analyzed it by vector sum amplitude for a single point in the voltage-space. Their methods show the vector directions and the amplitudes of ABR, but do not give the information about the auditory neuro-pathway. Hafner et al.[5] compared the auditory pathway using ABR, which was recorded with three orthogonal differential electrode configurations. However, the 1-channel system, which is widely used in diagnostic ABR, does not provide sufficient information as to where it is activated.

The aim of this study was to determine the relationship between the ABR and the location of its generation. This can be found from macroscopic analysis of the auditory pathway. This study also provides energy comparison methods based on the neuronal action potential conduction theory[6].

MATERIALS AND METHODS

All the tests were performed using a Neurophysiology workstation from Tucker-Davis Technologies(Gainsville, USA). A standard square-wave click stimulus with a 0.1ms duration, was used.

In order to measure the 1-channel ABR, the electrode on the vertex was used as the active electrode, another on the ipsilateral mastoid as the reference electrode, and the one on the contralateral mastoid as the ground. The electrode impedances were all less than 1 kohm. Generally, the measuring skin impedances should be low and less than 2~3 kohm. If impedance is high, then the skin should be rubbed again and more electrolyte jelly put on the contact surface[7][8]. In our experiment, as we used the needle electrodes, the experienced skill could make it possible. The cut-off points for the band-pass filter were set to 300-3,000Hz and for notch filter to 60Hz. The sweep time was set to 10ms.

This work was supported by grant No.R01-2002-000-00392-0 from the basic research program of the Korea Science & Engineering Foundation.
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For the 3-channel ABRs, one reference electrode was positioned on the ipsilateral mastoid and one ground electrode was positioned on the contralateral mastoid (Figure 2-A). Three active electrodes were positioned in a midline from the vertex to the neck..

For the 4-channel ABR, channel 1 was recorded from the electrode positioned at the mid-plane between the midline and the inlet of the external ear canal ipsilaterally(Figure 2-B). Channel 2 was recorded from the contralateral side at the same point. These two electrodes were positioned in the same plane to the channel 1 in the 3-channel recording coronally. The positions of channel 3 and channel 4 are the same as for the channel 2 and channel 3 in 3-channel recording.

The auditory stimuli signal was a click with a duration of 0.1ms. The clicks were presented using inserted-tube type speaker. All the stimuli were presented at a rate of 11.1 per second. The band pass filter parameters for the 3- and 4-channel recordings were same as for the 1-channel recording.

The guinea pig was anesthetized with a mixture of ketamin and xylazine and tested in a acoustically insulated and electrically shielded chamber.

The ABRs are the signal detected with body surface/needle electrodes. these sources are generated by cellular activity. We consider a active cell lying in an extensive conducting medium and carrying an action potential propagating in the all direction. Since this current emerges essentially from a point into an unbounded space, it behaves like a point source of current that lies in an extensive conducting medium[4]. Current flow is uniform and radial from the aforementioned point source, so that

$$\Phi_e = I_0/(4\pi\sigma_e r)$$

where r is the distance from the point source to the field point, σ_e is the extracelluar conductivity, and I_0 is the source magnitude. So, if we assume that σ_e is constant in local area, the potential, which represents the evoked response, is inverse-proportion to the distance between the source of ABR and the position of active electrode[9].

In this study, as compared with the energy of response from each electrode, we will get some information on the neuro-pathway where the ABR peak is generated.

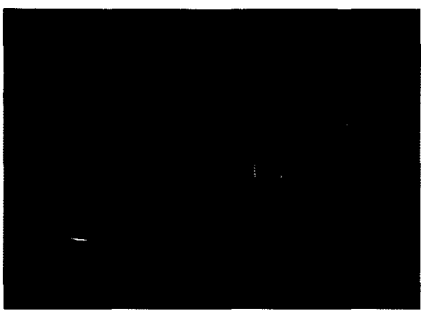


Fig. 1. Experiment with a guinea pig. The 3 channel ABR recording to the auditory stimuli from the vertex to the ipsilateral mastoid and grounded from the mastoid contralateral

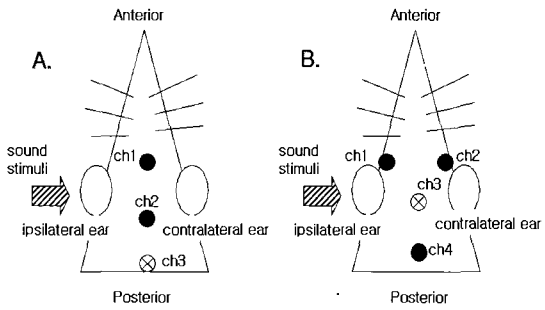


Fig. 2. Electrode position for the 3 or 4 channel ABR. The figure on the left shows the positions of the 3 active electrodes, and on the right , 4 active electrodes. In case B: the ch 1 electrode is the forehead-ipsilateral to the auditory stimuli

RESULTS

Experiment I.

Three responses averaged 500 times at the same stimulating intensity from each channel are shown in Figure 3. As shown in Figure 3, the latency of wave I from each channel was almost the same, but the peak amplitude was different. The largest amplitude was from the most posteriorly positioned channel 3 and the smallest was from the most anteriorly positioned channel 1. This means that the primary generator site(s) for the ABR were near the position of electrode 3 and far from the position of electrode 1.

On the other hand, between 4ms and 6ms, the ABR from channel 2 was larger than others. For a similar reason, the generator site(s) for this peak were closer to the position of electrode 2 than the others.

To ensure the origin of the ABR, three channel data were compared and sorted according to the amplitude at each time sequence. The analysis algorithms are as follows: The time-window($\triangle$w) was set to 1.6ms. it was selected by the general value of inter-peak latency of ABR[1]. From the data from each channel, the mean value of each time-window was calculated by Equation (1).

$$avg\_data(channel, i) = \sum_{i}^{i+\Delta w} \frac{|\ abr\_signal(channel, i)\ |}{\Delta w} \quad (1)$$

the value of avg_data(channel,i) represents the averaged amplitude of ABR during the time-window. These results were applied to equation 2. Each time area ranged from 0ms to 10ms, which were divided by the time-window of 1.6ms. Because the wave peaks of ABR are occurred generally with the interval of 1.6ms, we set the time-window with 1.6ms. Three channel ABRs were sorted. The channel data with the maximum amplitude among the three channel was given by the value 3, the second large amplitude a value of 2 and the

third a value of 1. The concept of equation 2 was shown as below.

$$sort(avg\_data(channel,i)) \text{ for channel=1,2,3 or 4, at each index } i \quad (2)$$

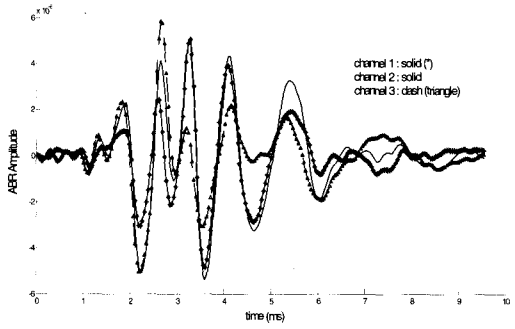


Fig. 3. ABR from 3 different channels. The positions of the electrodes is followed from Fig 2-A. Wave I occurs approximately 2ms after the onset of the rarefaction click stimulus with successive waves following at about 0.8 to 1 ms intervals.

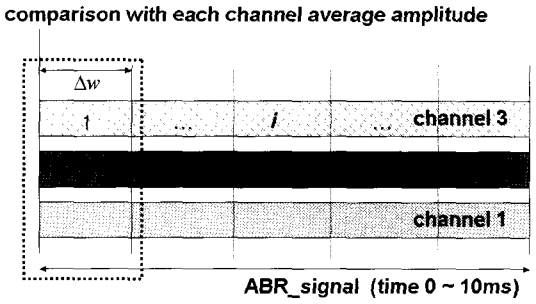


Fig. 4. The method for sorting each channel data as the amplitude. The average amplitudes from each channel were compared

The sorted and re-valued data was visualized using a color-map technique. In Figure 5, the bright portion showed more activated channels at the just sequence and the dark portion shows less activated channels. The axes are as follow: The X-axis represents the time from 0ms to 10ms after the onset of the click stimulus. The Y-axis is the electrode position. The data are the relative normalized amplitude of ABR. Within 2ms after the onset of the click stimuli, channel-3 was colored brightly. As previously pointed out, this means that near this position, the ABR is generated by the auditory nerve as well as the subsequent fiber tracts and nuclei within the auditory brainstem pathway.

Between 2ms and 4ms, the white-amplitude widely spreads from the vertex to the neck meaning that the distances between the wave generators and each electrode are similar.

As another method for analyzing the location where the ABR is activated at any time, the cumulative method, which integrates the ABR absolute values between each given interval, was used.

$$cumul\_data(channel, i) = \int_{k=i}^{i+\Delta w} | abr\_signal(channel, k) | \quad (3)$$

where the channel is the variable for each ABR channel and the k is the divided portion as time interval.

In this study, each time interval was 1.6ms. The full acquisition time was divided into the following 4 intervals: (0ms~1.6ms), (1.6ms~3.2ms), (4.8ms~6.4ms), and (6.4ms~9ms). Figure 6 shows the results of the integral power of each channel data.

At the first interval from 0ms to 1.6ms, all the channels had a similar power, as time goes on. However, after 1.6ms, the three electrodes have a different power. From 1.6ms to 3.2ms, channel 1 is high and from 3.2 ms to 4.0 ms, channel 2 is high. The 'high' means that the generation of ABR is more dominated at the position near the electrode than others. Some information can be obtained by these graphs such as the position of the activation. We can know that the source of auditory electric-signal moves from position 3 to position 2.

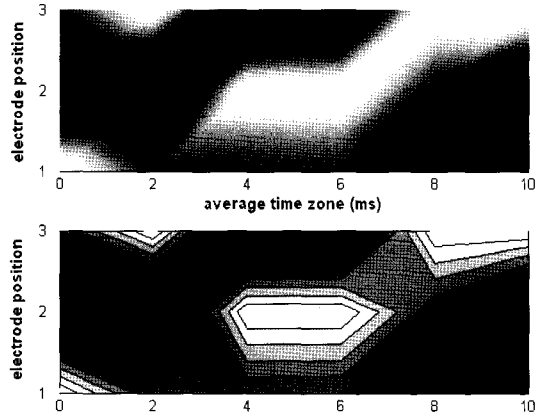
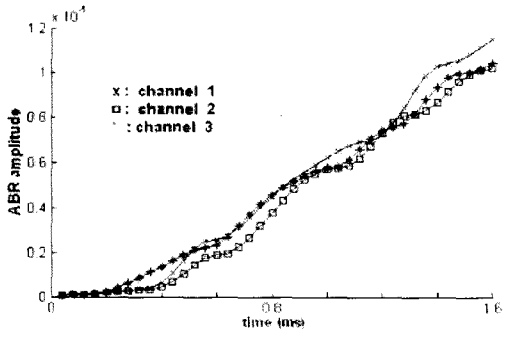


Fig. 5. Comparison of the 3 channel ABRs based on Eq 1. The Y-axis shows the position of electrode and the X-axis indicates the time. The time interval for averaging and sorting the data was 1.6 ms.



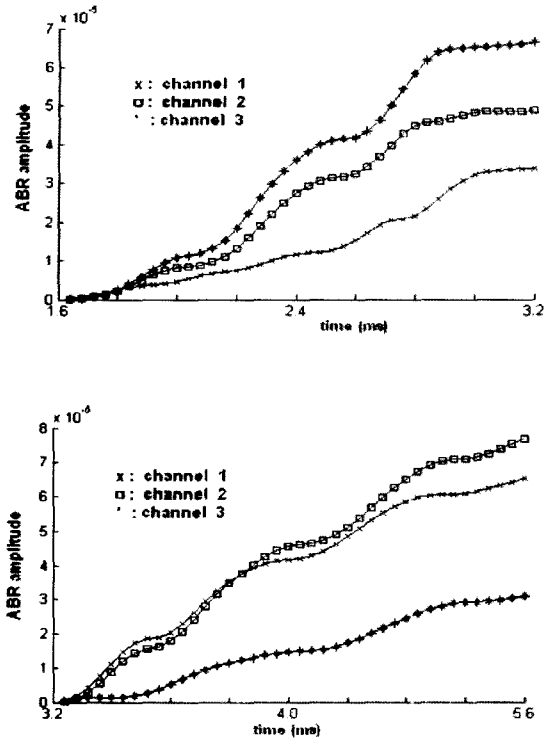


Fig. 6. Cumulative ABR of the 3 channels at each time interval. The integral method in eq.2 was used. Time interval was 1.6ms. The data at each graph was measured from the multi-channel x : channel 1, channel 2, * : channel 3, o : channel 4. The time intervals range from 0 to 1.6ms, from 1.6ms to 3.2ms, from 3.2ms to 4.8ms and from 4.8ms to 6.4ms. The left-upper graph shows that the ABR around channel 4 dominates. The right-upper graph shows that the data from channel 1, 2 and 3 are increasing. At the left-down graph, the data from channel 2 and 3 dominates.

Experiment II.

Another experiment was based on the 4 electrode-channels. One extra electrode was used to observe the response sequence in more detail. The electrode map is followed from Figure 2-A. As well as the sagittal-line response, the characteristic of the coronal-line response could be estimated. Figure 7 shows 500 averaged ABR recorded within 10ms after the rarefaction click stimulation.

From 1.5ms to 6ms, the full waves were present in the ABR waveform. The peak amplitudes from each channel were different which is similar to the previous 3-channels experiment. For the first period, the response of the most posteriorly positioned channel 4 is dominant, which is quite similar to channel 3 in the 3-channel recordings.

It was reduced with increasing time. However, the peak amplitudes of ABR from channel 2 and 3 are gradually increasing. The whole relative activations are shown in Figure 8, where the variation in the generator locations can be seen.

The signal powers in each time interval were compared using the proposed method in equation 2. As seen in Figure 9, the power of channel 2 is for the most part higher than that of channel 1. This means that the main ascending auditory pathways of the brainstem are widely distributed in the contralateral portion.

The data from channel 3 and 4 in Figure 8 provide the information on the origin of the activation along the sagittal-line. The results are similar to the previous result shown in Figure 6.

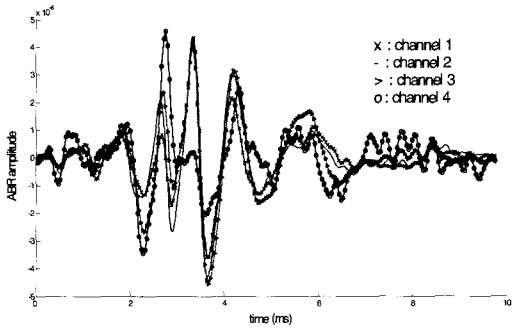


Fig. 7. 4-channel ABRs. The positions of electrodes are followed from Fig 2-B.

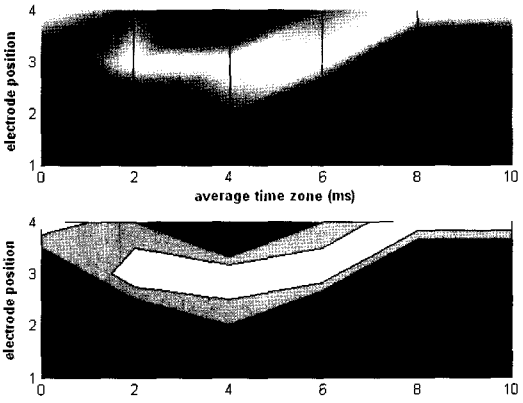
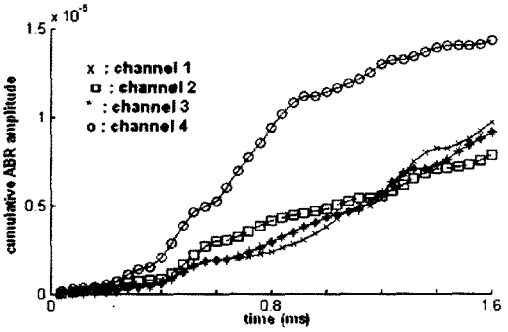


Fig. 8. Comparison of 4 channel ABRs based on Eq



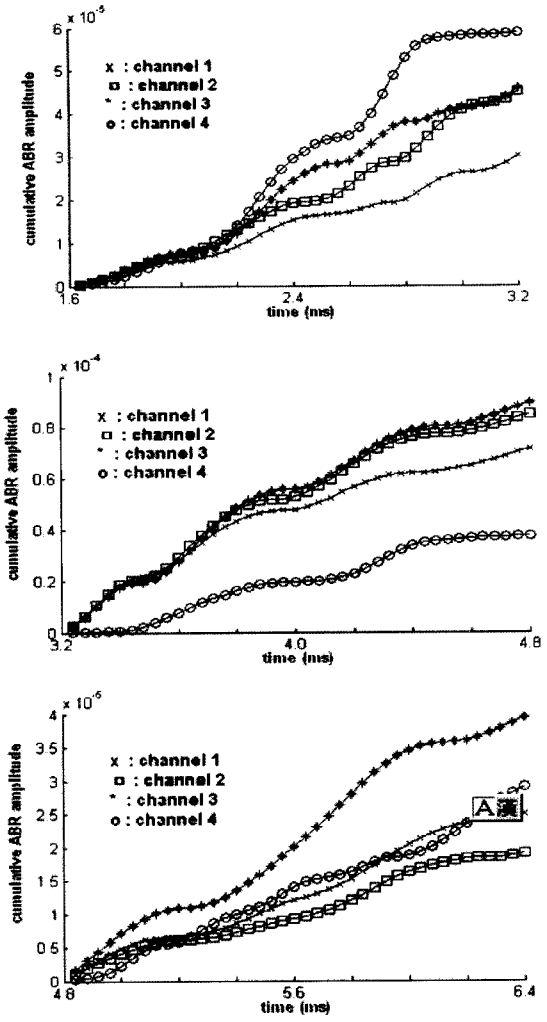


Fig. 9. Cumulative ABR for each time interval. Integral method in eq.2 was used. The time interval was 1.6ms. The data at each graph is measured from the multi-channel x : channel 1, channel 2, * : channel 3, o : channel 4. The time intervals are from 0 to 1.6ms, from 1.6ms to 3.2ms, from 3.2ms to 4.8ms and from 4.8ms to 6.4ms. Left-upper graph shows that the ABR around channel 4 dominates. The right-upper graph shows that the data from channel 1, 2 and 3 are increasing. At theleft-down graph, data from channel 2 and 3 dominate

DISCUSSION

The auditory pathways are discussed in many other references. In general, on entering the brainstem, the first-order neurons terminate on the cochlear nuclei, where the cell bodies of the second-order neurons are located. From this point, some of the auditory fibers climb up to the midbrain and the others cross the midline of the brainstem to the superiorolivary complex (SOC) in the opposite side[11]. The third-order neurons in the superior olive impartaxons that course centrally through the lateral lemniscus to terminate at the midbrain level in the inferior colliculus. From this point, the fourth-order neurons ascend to one of several nuclei of the thalamus, which is the medial geniculate body.

These results are similar to the well-known neuro-pathway. This study on the multi-channel ABR shows that the positions of the ABR generators move to the centralbrain and the contralateral pathway. It is generally agreed that the ABR is generated by some structures along the auditory pathway. However, the precise generators of the various waves are controversial. The positions could be analyzed more accurately if more electrodes are used because the difference in the response amplitudes from the different electrodes is strongly related to the distances from the generators and its vector as mentioned early.

Retrocochlear pathological conditions may be severe enough to completely disrupt the generation of the components of the ABR, resulting in absent waves. The presence of a lesion at a given location can eliminate the waves generated at the lesion site. If this localization method of the ABR is applied to a patient whose ABR waves are missing, it might be used to help make a diagnosis[11].

Further studies on the multi-channel ABR signal processing techniques are currently underway. These studies are aimed at mapping the data into a 2-D talarirach brain atlas. These mapping figures may provide more information as to where and when the activation occurs following stimulation. Furthermore, a 16 channel ABR using the microelectrodes will be used in future studies.

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