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The effect of optimizing EABR parameters in artificial cochlear implantation for auditory rehabilitation

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Abstract. – OBJECTIVE: The objective of the present study was to observe the relationship between V extraction rate and threshold value of electrically evoked auditory brainstem response (EABR) waves in artificial cochlear implantation, in order to optimize EABR parameters for improving auditory rehabilitation.

PATIENTS AND METHODS: Thirty patients without residual hearing and treated with artificial cochlear implants were selected. The experimental group included 17 cases with normal cochlear morphology, four with large vestibular aqueduct syndrome (LVAS), six with Mondini malformation, and three with internal auditory canal stenosis. Thirty patients with residual hearing and approximate conditions, treated with artificial cochlear implantation to conduct matching were taken as the control group. For artificial cochlear implantation, Remolded Cochlear Freedom artificial cochleas and platinum-iridium alloy spheroid electrodes were used to provide electric stimulation of different pulse widths (50 μs, 100 μs and 200 μs) to patients in the two groups. A Bio-logic Navigator Pro auditory evoked potentiometer was used to record V extraction rate and threshold value of EABR waves under the different pulse widths.

RESULTS: There were no significant differences in V extraction rates of EABR waves at pulse widths of 50 μs, 100 μs and 200 μs (p >0.05). All EABR threshold values in the experimental group were higher than those in the control group, and the differences were statistically significant (p <0.05).

CONCLUSIONS: The monopole stimulation within the cochlea can induce good EABR waves and EABR threshold values of patients without residual hearing were significantly higher than those of patients with residual hearing (p <0.05). Waveform differentiation of pulse width 100 μs was better, dynamic range was broader and it was necessary to increase stimulation when the malformation was serious.

Key Words

Artificial cochlea, EABR wave, Pulse width, V extraction rate, Threshold value.

Introduction

Artificial cochleas represent the most successful application of biomedical engineering. They have helped several patients with deafness obtain or restore hearing. Correcting the structure of the auditory pathway is the functional basis for artificial cochlear implantation. Objective and accurate assessments are key for improving their curative effects[1]. Clinically, audiological tests are commonly used[2]. These include functional tests which assess hearing (i.e. pure tone test), behavioral audiometry with sound field audiometry, the auditory brainstem response (ABR), multi-frequency steady-state evoked potential/40 Hz relevant potential, distortion otoacoustic emission as well as imageological examinations which reflect auditory organ structure. Imaging includes computed tomography of the temporal bone lamella, cranial magnetic resonance imaging (MRI), internal auditory canal MRI and inner ear fluid imaging[3]. However, audiological tests and radiological assessment have notable limitations for adiaphoria of maximum stimulus, auditory neuropathy, internal auditory canal stenosis, inner ear malformation and cochlear ossification[4]. Electrically evoked auditory brainstem responses (EABRs) are similar to ABRs in reflecting the bioelectrical activity of auditory pathways. They differ in that electrical simulation replaces auditory simulation and directly conduct electrical simulation of auditory nerve ganglion cells by skipping over damaged hair cells. Furthermore, EABR induces auditory nerve and brainstem auditory centers of all levels to generate a series of electrical activities. It is an important and objective neuroelectrophysiological detection method used to understand the functional status of auditory conduction pathways[5]. In the present study, we analyze the relationship between extraction rate

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and threshold value of EABR waves of artificial cochlear implantations under different pulse widths, providing optimized EABR parameters for improving auditory rehabilitation effects.

Patients and Methods

Patients

We selected patients treated by artificial cochlear implantation in our hospital from January 2011 to January 2016. Thirty patients without residual hearing, following objective and subjective hearing tests before surgery constituted the experimental group. Patients in the experimental group did not have facial paralysis or equilibrium disorders. There were 17 males and 13 females, implanting age was from 1–29 years old and median implanting age was 5.6 years. Twenty-five cases were of prelingual deafness and five were of postlingual deafness. Brain lesions were excluded by temporal bone lamella computed tomography (CT) and brain magnetic resonance imaging before surgery. Seventeen had normal development of cochlear morphology, four had large vestibular aqueduct syndrome (LVAS), six had Mondini malformation, and three had internal auditory canal stenosis. Thirty patients with residual hearing after therapy for artificial cochlear implantation of similar symptoms were taken as the control group. There were 16 males and 14 females. Implanting age was from 1.5-26 years, and median age was 5.3 years. Twenty-six were cases of prelingual deafness, four of postlingual deafness, 18 of normal development of cochlear morphology, five of LVAS, four of Mondini malformation, and four of internal auditory canal stenosis. Baseline parameters between the two groups were comparable. The study was approved by the Ethics Committee of our hospital and informed consent was obtained from patients and their family members.

Equipment

Electrical stimulation equipment: Remolded Cochlear Nucleus 24R (Centennial, CO, USA) Freedom artificial cochleas were used for implanting. The stimulation parameters were set by Custom Sound TMEP2.0 software (Cochlear company), No. 3 electrodes were used as the stimulating electrodes and MP1 (Moving Picture 1) bridging was used as reference electrodes. Recording equipment: auditory evoked potentiometers were connected to corresponding recording and reference electrodes through high frequency filters using Bio-logic Navigator Pro (San Carlos, CA, USA), and the recording parameters were set by AEP (Ver.7.0.0) software. Electrode wire: the stimulating electrode was a multistrand platin-iridium alloy wire with diameter of 0.1 mm and a silica gel insulation layer on its surface. The free end was formed into a sphere with diameter of 0.3 mm, and there was no insulation layer on the spherical surface. Both recording electrodes and reference electrodes were oxidized silver needle-type electrodes.

Stimulation Method

Electrode placement recording: after patients were placed under compound general anesthesia, auditory evoked potentiometers were installed for recording electrodes. Electrodes were needle type on the body surface and non-inverting electrodes were placed under the skin in the middle of the hairline. Inverting electrodes were placed under the skin of the mastoid process at offside of operation. Common electrodes were placed under the glabella, a high-frequency filter was connected in series between the electrode and preamplifier. Impedance among body surface electrodes was less than <5 KΩ. Internal trigger interface of the evoked potentiometer was connected with single-phase square-signal triggered and evoked potentiometer by a sync cord. Generated by a portable speech processor, a 5 V single-phase square-signal triggered and evoked potentiometer was used to conduct average superposition. Electrode placement stimulation: a conventional small incision of the postaurem was made, and open mastoidectomy was performed for access to the recess. After the round window niche was exposed, sclerotin was ground, the round window membrane was exposed and part of it was opened. A test electrode was then gently implanted 2-3 mm into the scala tympani, an electrical simulation generator was connected through the electrode wire and a simulation cathode (needle electrode) was fixed under the skin of the mastoidale. Electrical simulation parameters: Averaging-alternating mode, number of sweeps = 1000, Stimulus Active Electrode-3, Stimulus Indifferent Electrode: MPl, pulse width = 50-200 μs, repetition rate = 23-70 Hz, current level = 1-255 CL. Parameters of evoked potentiometer: recorded window width = L0.8-8.0 ms, high-pass filtering wave = 100 Hz, low-pass filtering wave = 3000 Hz, average number of superposition = 1000, triggering mode was external, and the gain was 300 K.

Test procedures:

1. Fifteen KΩ stimulating electrode impedance: 23 Hz stimulating velocity: 50 μs, stimulating pulse width and 200 CL stimulating strength were set as the initial stimulating parameters. If EABR waveform was extracted, then recording was continued at decreased stimulating strength by taking 10 CL as step length until wave V disappeared. Stimulating strengths of the last two times were repeated and recorded. The minimum stimulation strength current level which could extract wave V was set as the EABR threshold value. If evoked potentiometer amplifier saturation occurred, baseline drifted, which indicated that stimulation strength was too high, and it was lowered as necessary. If the EABR waveform could not be extracted, we slightly changed the location of the platinum ball electrode, and then repeated the above procedures. If the EABR waveform still could not be extracted under 255 CL stimulating strength, this indicated that EABR could not be extracted under 50 μs pulse width and 23 Hz stimulating velocity for the patient.
2. We then set 100 μs simulating pulse width and 170 CL stimulating strength as the initial stimulating parameters, and the procedures were the same as in 1. EABR waveform and threshold values under the corresponding conditions were recorded.
3. We set 200 μs stimulating pulse width and 140 CL stimulating strength as the initial stimulating parameters and the procedures were the same as 1. EABR waveform and threshold values under the corresponding conditions were then recorded.

Following implantation, we conducted EABR recording with the same parameters and method for verifying the effect of test electrodes.

Observational Indexes

According to EABR sequence waveforms recorded by AEP (Ver7.0.0) software, the built-in analytical tools were used to calibrate EABR threshold values and incubation period (V wave) values under the various stimulating pulse widths.

Statistical Analysis

SPSS20.0 software (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Measurement data are expressed as mean ± standard deviation. A *t*-test was used for comparisons between groups. Enumeration data are expressed as case number in percentage (%), and calibration. χ^2-test was used for comparisons between groups. $p < 0.05$ was taken as statistically significant.

Results

Comparison of V extraction rates under different pulse widths

The V extraction rates of EABR waves at pulse widths of 50 μs, 100 μs and 200 μs, did not have any statistically significant differences ($p > 0.05$) (Table I).

Comparison of V threshold values under different pulse widths

At pulse widths of 50 μs, 100 μs and 200 μs, EABR threshold values in the experimental group were higher than those of the control group, and the differences were statistically significant ($p < 0.05$) (Table II).

Discussion

According to Kileny et al[6], the indications for EABR testing before artificial cochlear implantation include: age less than 2 years; candidates without residual hearing; questionable audiological testing results; congenital malformations of the temporal bone including Mondini malformation; common cavity malformation; internal auditory canal stenosis; all forms of vestibular cochlear developmental malformation; auditory neuropathy, brain white matter abnormalities, cochlear ossification and radiotherapy for internal auditory canal tumors.

Inner ear malformations were emphasized for auditory neuropathy without residual hearing. Presently, there are three primary ways of testing the EABR[7]: a stimulating needle electrode is inserted by auripuncture on the promontory surface. A needle electrode is then placed in the round window niche through small tympanic membrane incision, and spherical electrodes are placed in the round window through the flap of the external auditory canal of the tympanic membrane. Stimulation of the outer cochlea did not injure the inner ear, and testing outer cochlea stimulation from the angle of injury was more ideal[8]. The test should be conducted under general anesthesia and separately from implantation surgery. There is risk of middle ear infection with great interference. The EABR test results differed according to electrode position, and false-negative results occurred easily. Multiple replications could not acquire EABR waves, and the integrity of the auditory pathway could not be completely excluded[9].

Table I. Comparison of V Extraction Rates under Different Pulse Widths (%).

Group	Number of Cases	50 μs				
		Normal cochlear morphology	LVAS	Mondini malformation stenosis	Internal auditory canal	Total extraction rate
Experimental Group	30	17	3	5	3	28(93.3)
Control Group	30	18	5	3	4	30(100.0)
χ^2						0.517
P						0.472
Group	**Number of Cases**	**100 μs**				
		Normal cochlear morphology	**LVAS**	**Mondini malformation stenosis**	**Internal auditory canal**	**Total extraction rate**
Experimental Group	30	17	3	4	2	26(86.7)
Control Group	30	18	5	2	4	29(96.7)
χ^2						0.873
P						0.350
Group	**Number of Cases**	**200 μs**				
		Normal cochlear morphology	**LVAS**	**Mondini malformation stenosis**	**Internal auditory canal**	**Total extraction rate**
Experimental group	30	17	2	3	2	24(80.0)
Control group	30	18	5	2	3	28(93.3)
χ^2						1.298
P						0.255

All stimulating electrodes used in this study were located within the cochlea at fixed locations, which could directly stimulate spiral ganglion cells. This also allowed for stable and differentiated EABR waveforms to be obtained. Artifacts related to stimulus included:

Table II. Comparison of V Threshold Values under Different Pulse Widths

Group	50 μs		100 μs		200 μs	
	Current Level(CL)	Electric Quantity ($\mu A \times \mu s \times 10^3$)	Current Level	Electric Quantity	Current Level	Electric Quantity
Experimental group	176.8±10.2	18.9±1.3	154.6±12.5	20.3±1.5	146.2±13.6	22.6±1.9
Control group	165.9±11.3	15.7±1.0	143.2±12.7	17.2±1.4	128.9±13.5	29.4±2.0
T	6.528	6.234	7.023	6.649	7.128	6.954
P	0.036	0.038	0.033	0.036	0.027	0.030

1. A charge-balance biphase pulse current was used and positive and negative charges generated locally after electrical pulse stimulation were mutually offset[10].
2. Currents in alternating stimulation mode were used. Two-way square-waves alternating between positive and negative, further reduced artifacts related to electrical simulation[11].
3. Appropriate stimulating current pulse widths were controlled[12].
4. Inverted electrodes were placed offside of the mastoid process[13].
5. High-frequency filters in parallel series between the electrodes and pre-amplifiers were recorded[14].
6. General anesthesia was used and evoked potentiometers were placed away from large-scale electromagnetic equipment.
7. With the monopole stimulation method, there was stimulation of relative dispersion of the electric field[15].
8. Stimulation of the inner cochlea was adopted and the location was relatively fixed, therefore impedance was low and interference was small[16].

At pulse widths of 50 μs, 100 μs and 200 μs, differences in the comparisons of V extraction rates of EABR waves were not statistically significant, and all extraction rates were high. EABR threshold values in the experimental group were higher than those in the control group, and the differences were statistically significant. When pulse widths were low, EABR waveform differentiation was good, but when the pulse width of patients with serious malformation were low, it may not have been able to induce meaningful EABR waveforms, and it needed high levels of stimulation. Considering that there were abnormalities in auditory nerve cells including reduced number and distribution as well as synchronization of residual auditory nerve fibers, EABR differentiation in patients with serious malformations were worse than in patients with normal inner ear structure. Consequently, reactions could be induced only by larger stimulations. Inner auditory canal malformations were usually accompanied by maldeveloped and undeveloped vestibular nerves. The difference of postoperative effects were large and some did not have any reaction. Considering that this might have been related to slim cochlear nerve structure, small number of residual nerve cells and poor synchronization of nerves, larger electrical simulation was needed to extract the corresponding waveforms, dynamic range was narrow, and fatigue occurred easily in frequent tests.

Conclusions

The inner cochlear monopoles could induce good EABR waveforms, and the EABR threshold values of patients without residual hearing were significantly higher than in patients with residual hearing. At pulse width of 100 μs, waveform differentiation was improved and dynamic range was broader. The amount of stimulation was increased when malformations were severe. For patients without residual hearing and with inner ear malformations and inner auditory canal stenosis, the structure and functional status of the auditory conduction pathway could be objectively judged before surgery. EABR testing can be used to judge hearing ability and integrity of the auditory pathway of patients and estimate whether patients can achieve auditory reactions after surgery. It can improve the confidence of physicians and patients, reduce medical disputes and expand surgical indications.

Conflict of interest

The Authors declare that they have no conflict of interests.

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