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Research Article

Intraoperative Electrically Auditory Brainstem Responses to Monitor Auditory Functionality Preservation During Auditory Brainstem Implant Application

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Abstract

Background: Perceptual outcomes of individuals with neurofibromatosis type II implanted with auditory brainstem implant are poor, and many factors seem to be involved. Undoubtedly, the preservation of neural functionality is the crucial aspect. The aim of this study is to verify that the use of intraoperative electrically auditory brainstem responses can help to understand if there is neural damage related to the tumor, and / or surgery.

Material and Methods: A retrospective case series analysis was performed to review data from 6 adult patients affected by neurofibromatosis type 2 who received an auditory brainstem implant. A correlation was sought between intraoperative electrophysiological data, auditory performance at 1 and 2.5 years of follow-up, and auditory brainstem implant stimulation levels.

Results: Patients with a better perceptual outcomes were those with more intraoperative peaks and peaks with wider amplitudes in the electrically auditory brainstem response recordings.

Conclusions: Electrically auditory brainstem responses used for auditory brainstem implant placement can be a valuable tool for monitoring the preservation of neural acoustic functionality.

Key words : ABI; eabr; intraoperative monitoring; nf2; perceptive outcomes

Introduction

The multichannel auditory brainstem implant (ABI) is a device which can restore auditory functionality. However, so far, its use is controversial both in the pathologies for which it is indicated and for the perceptive hearing results obtained [1-5].

In the intraoperative phase, implant placement is crucial. Different evaluation procedures have been developed for Cochlear Nucleus ABIs, based on different combinations of electrode stimulation [1,6-9], but all with the common aim of obtaining a favorable implant placement to provide patients with auditory sensations. In fact, it has been demonstrated that intraoperative evoked auditory brainstem responses (EABRs) are correlated with postoperative auditory sensations [8,10,11]. A correlation between intraoperative EABR and the level of perceptual outcomes achieved by the patient has not yet been demonstrated. Obtaining auditory sensations does not mean obtaining good perceptual results and there is a clear difference, also in terms of quality of life, between sound awareness (minimum obtainable level) and understanding of words and phrases without lip reading (maximum obtainable level).

The first pathology for which the application of ABI is indicated is neurofibromatosis type II (NF2). Patients with NF2 are those with the worst perceptual outcomes [12]. This leads to the question whether, in case of anatomical preservation of the acoustic nerve during the tumour removal surgery, it is advisable to insert a cochlear implant (CI), whose hearing performance is generally better [13,14]. It should be noted that even with an CI, the perceptual outcomes of individuals with NF2 are not always optimal [15,16]. This means that for this type of patient it is not possible to predict what the results will be, whatever the rehabilitation aid used, even if the neural structure appears anatomically preserved before and during the tumour removal surgery.

The aim of this study is to verify that the use of intraoperative electrically auditory brainstem responses (EABRs) can help to understand if there is neural damage related to the tumour and / or surgery.

Materials and Methods

Surgical and electrophysiological procedures were approved by the Ethics Committee of Verona Hospital. For these procedures, an informed written consent was acquired from the patients. This study was carried out in accordance with the Declaration of Helsinki.

Subjects

A retrospective case series analysis was performed to examine the data from 6 adult patients affected by neurofibromatosis type 2 who received ABI (Nucleus 24 ABI, Cochlear Corporation) at the ENT Department of Verona between October 2004 and March 2009. There were 2 female and 4 male patients in the age range 22,5 to 56,3 years.

See Table 1 for tumor characterization and further demographic details.

Patient no.	Sex	Age at surgery [years]	ABI side	Koos classification of tumor	Controlateral side
Pt1	M	32	Right	grade IV	tumor grade IV (Koos)
Pt2	F	28	Right	grade IV	complete deafness – previous AN exeresi
Pt3	M	22	Left	grade IV	tumor grade I (Koos)
Pt4	M	56	Right	grade I	complete deafness – previous AN exeresi
Pt5	F	22	Right	grade III	tumor grade II (Koos)
Pt6	M	23	Right	grade II	partial deafness - previous AN exeresi

ABI, Auditory Brainstem Implant; AN, acoustic neuroma; F, female; M, male; Pt, patient.

TABLE 1: Patient Demographics.

Surgery

A retrosigmoid approach was used for auditory brainstem implantation [17,18]. One patient was implanted on the left side. The other five patients were implanted on the right side.

During all of the surgery, the facial and lower cranial nerves were monitored to detect unwanted stimulations that may cause non-auditory sensations. After electrode paddle insertion and before closure, all 6 patients underwent EABR measurements, for ABI placement optimization. Details on equipment and stimulation procedure utilized for EABR recordings and on interpretation of the obtained waveforms are described in Veronese et al. [9]. The new stimulation protocol presented in this study was used for Pt1, Pt3, and Pt6, while Cochlear's standard protocol was utilized for Pt2, Pt4, and Pt5.

Activation

ABIs were activated 5 to 6 weeks after surgery based on patient recovery.

Tests were performed at activation using the Cochlear Nucleus R126 V2.1 (Cochlear Corporation) software. During activation, each electrode was tested in monopolar stimulation mode through a down-up-down procedure to define the electrodes auditory threshold levels (T-levels). The active electrodes were identified and the presence of non-auditory sensations was recorded. The T-levels of all the active electrodes were converted into µA, using the formula:

$$T(\mu A)=10*175^{T(CL)/255}$$

where T(CL) represents the electrodes threshold values, expressed in the software unit of measure, the clinical level (CL).

To improve the comparison of patients T-levels, the pulse width (PW) utilized was also considered and µA were converted in nC, using the formula:

$$T(nC)=PW*T(\mu A)/1000$$

Perceptive evaluations

All patients underwent auditory rehabilitation for, at least, 1 year after activation. For all patients, perceptual results were collected during the activation and at 1, and 2.5 years of implant use. The performed tests were: sound awareness test, sounds and Italian phonemes detection, identification of words in close set of 10 items, words and sentences recognition, words and sentences comprehension [19].

The tests were performed in auditory mode only, in a quiet common environment. The examiner was seated about 1 meter away from the patient, in a latero-posterior position and ipsilaterally to the implant. If the patient presented contralateral auditory residue, adequate auditory masking was performed.

Data analysis

For each follow up, the patients were divided into two groups, based on perceptual results:

group A = without result, awareness of environmental noises and detection of sounds and voices;

group B = identification, recognition and understanding of words and sentences;and a difference between the groups was sought based on the technical parameters.

Subsequently, the same analyzes were repeated considering different groups:

group C = group A + identification and recognition of words and sentences;

group D = understanding of words and sentences.

Fisher's exact test was used to compare the distribution of intraoperative EABR. To compare the differences in peak characteristics (percentage presence and amplitude of single peaks), in the number of active electrodes, in the number of electrodes presenting side-effects and in T(µA) and T(nC) an unpaired t-test was applied.

Results

Table 2 presents the main characteristics of intraoperative EABR recordings and the technical data of the activations. Table 3 summarizes the perceptive results at the various follow up.

Patient no.	No. of recordings	No. of peaks				Peak presence			Peak amplitude (nV)			Activation			
		0	1	2	3	P1	P2	P3	P1	P2	P3	No. elec.	No. elec. s-eff.	T (μA)	T (nC)
Pt1	58	9	29	19	1	12	29	29	107	62	94	11	13	172	9
%		15.52	50.00	32.76	1.72	20.69	50.00	50.00							
Pt2	20	0	3	16	1	16	8	14	8	172	441	14	6	483	48
%		0.00	15.00	80.00	5.00	80.00	40.00	70.00							
Pt3	24	0	5	16	3	3	23	20	133	313	211	19	2	144	4
%		0.00	20.83	66.67	12.50	12.50	95.83	83.33							
Pt4	21	3	10	8	0	2	16	8	50	226	118	13	8	196	10
%		14.29	47.62	38.10	0.00	9.52	76.19	38.10							
Pt5	14	0	4	8	2	3	14	9	150	520	186	19	2	105	4
%		0.00	28.57	57.14	14.29	21.43	100.00	64.29							
Pt6	59	15	28	9	7	9	41	17	254	223	352	13	8	179	4
%		25.42	47.46	15.25	11.86	15.25	69.49	28.81							

EABR, electrically evoked auditory brainstem response; elec., electrodes; No., number; Pt, patient; s-eff., side effects; T, auditory threshold.

Table 2: Intraoperative EABR waveforms characterization and activation data.

Patient no.	Activation	1 year	2.5 year
Pt1	2	2	2
Pt2	2	2	2
Pt3	3	5	5
Pt4	2	3	2
Pt5	3	3	4
Pt6	2	3	3

no., number; Pt, patient. Legend: 0=no results; 1=sounds awareness; 2=sounds and Italian phonemes detection; 3=identification of words in close set of 10 items; 4=words and sentences recognition; 5=words and sentences comprehension.

TABLE 3: Perceptive results.

Tumor size and perceptive results

No correlations were found between tumor size in the various patient groups and perceptual results at the different follow up (p=1.000).

EABR morphology and perceptive results

The intraoperative EABRs were 1-peak to 3-peak waveforms.

The distribution of peaks in the intraoperative waveforms recorded for group A vs group B was statistically different:

- at activation since patients of group A presented 44.38% of intraoperative recordings with a single peak, while patients of group B presented 63.16% of recordings with two peaks (p=0.000);

- at 2.5 years of follow up since patients of group A presented more intraoperative recordings with two peaks (+9.41%) and less with three peaks (-10.35) than patients of group B (p=0.025).

The distribution of peaks was not statistically different at 1 year of follow up (p=0.134).

The distribution of peaks in the intraoperative waveforms recorded for group C vs group D was analyzed at 1, and 2.5 of follow up as no patient reached comprehension level during perceptive tests at activation. The distribution was statistically different at all follow ups (p=0.003) with differences stable over the time and group C presenting more intraoperative recordings with no peaks (+15.70%) and one peak (+22.19%) and less with two peaks (-31.79%) than group D.

Intraoperative peaks presence was statistically different between group A vs group B:

- at 1 year of follow up since for group A patients the P1 peak was more present (+15.63) while the P2 peak was less detected (-22.71) than for group B patients (p=0.000);

- at 2.5 years of follow up since for group A patients the P1 peak was more present (+11.60) while the P2 peak was less detected (-16.57) than for group B patients (p=0.007).

Intraoperative peaks presence was not statistically different at activation (p=0.082), even if the trend of presence of these two peaks was the same identified in the subsequent follow-ups.

Differences in the P3 peak presence were less substantial.

For peaks of the groups C and D the presence was not statistically different at all follow up (p=0.099), but this is attributable to the small number of recordings considered for group D.

The number of patients in the various groups was limited and this made it impossible to perform a statistical analysis to correlate the amplitude of intraoperative EABRs peaks to perceptual results at the different follow up.

Nevertheless, by comparing group A and group B patients at activation and at 1 year of follow up, the intraoperative amplitude of the P2 peak turned out to be wider for group B. At 2.5 years of follow up, both the intraoperative P1 and P2 peaks were wider for group B than for group A patients.

Comparing group C and group D patients at the different follow up was not possible because at activation no patient reached the comprehension level and at the other follow up only a patient (Pt3) reached that level. Considering the average intraoperative amplitudes of all three peaks for the patient of group C and comparing these values with the three amplitudes of the Pt3 peaks, a clear difference was noted for the P2 peak, which was wider for Pt3 compared to the patients of the group C (343 against 240 nV).

Activation data and perceptive results

The number of patients in the various groups was limited and this made it impossible to perform a statistical analysis to correlate activation data to perceptual results at the different follow up.

Nonetheless, clear trends can be underlined (Table 4):

Group	Activation				1 year follow up				2.5 years follow up			
	No. elec.	No. elec. s- eff.	T (µA)	T (nC)	No. elec.	No. elec. s-eff.	T (µA)	T (nC)	No. elec.	No. elec. s-eff.	T (µA)	T (nC)
A	13 ±1	9 ±3	258 ±151	18 ±20	13 ±2	10 ±5	328 ±220	28 ±28	13 ±3	9 ±4	284 ±37	22 ±23
B	19 ±0	2 ±0	125 ±28	4 ±0	16 ±3	5 ±3	156 ±40	5 ±3	17 ±3	4 ±3	143 ±37	4 ±0
C	-	-	-	-	13 ±2	10 ±5	328 ±220	28 ±28	14 ±3	9 ±3	227 ±147	15 ±19
D	-	-	-	-	16 ±3	5 ±3	156 ±40	5 ±3	19	2	144	4

elec. electrodes; No., number; s-eff., side effects; T, auditory threshold.

Table 4: Activation and follow up data for the different groups.

- group A patients presented fewer active electrodes and more electrodes that caused side-effects than group B patients;

- group C patients presented fewer active electrodes and more electrodes that elicided side-effects than group D patients;

- group A patients presented lower T-levels than group B patients, considering the T-levels expressed in both µA and nC;

- group C patients presented lower T-levels than group D patients, considering the T-levels expressed in both µA and nC;

- at 2.5 years of follow up, only a patient reached comprehension level in perceptive tests. This patient presented a higher number of active electrodes, fewer electrodes which elicited side-effects and lower T-levels than all other patient groups.

Discussion

Poor results are reported on the use of ABI in patients with NF2 [12,16]. A small number of these patients are able to obtain speech recognition results [22]. The results described in this study confirm the variability of the perceptual outcomes of NF2 subjects using ABI.

Several factors seem to influence perceptual outcomes [22,23,24], but its extent is not yet clear [24]. Undoubtedly, it can be said that a key role for the success of the ABI rehabilitation process is the pre- and post-surgical preservation of neural functionality. In this study, while considering a limited number of patients, this aspect was investigated. As Behr et al. (2014) [22] pointed out, it's not the size of the tumour that makes the difference. Pt2 reached a performance level of 2 after 2.5 years, despite being the patient with the smallest tumour compared to the group of subjects considered. It is believed that the degree of infiltration of the tumour into the neural tissue, the toxicity that this entails, and the subsequent surgery (more or less conservative) are particularly relevant factors for the results.

Although assessment of neural function, performed prior to surgery [25], is critical, this particular type of surgery can significantly change final functionality [26], even over time [27]. For this reason, the development of new minimally invasive surgical techniques for the removal of tumours is essential [28,29].

The results obtained in this study demonstrate that intraoperative EABR tests for ABI placement can also be used to monitor neural functionality, as already advanced by Møller (2011) [30]. Patients who had better perceptual outcomes at 2.5 years of follow-up were patients who had more peaks (particularly P1 and P2) and peaks with wider amplitudes, both after tumor removal and after ABI insertion. This improved electrophysiology appears to be related to functional acoustic conservation. The fact that the amplitude and presence of the P3 peak are similar between different groups could coincide with the fact that hearing loss sometimes occurs after surgery [27]. Further studies with larger numbers of patients are needed to investigate this aspect.

Also, of interest is the fact that improved electrophysiology is associated with lower postoperative ABI stimulation currents (Table 4), which means that a conserved neural system is stressed with fewer currents. Furthermore, lower stimulation currents are essential to avoid the occurrence of channel interactions, the appearance of non-auditory side-effects, and to improve perceptual outcomes [31].

Conclusions

Intraoperative EABRs used for ABI placement can be a valuable tool for monitoring the preservation of neural acoustic functionality. If after the removal of the tumour the preservation of neural functionality is evident, does it make sense to continue with the ABI, the results of which are not certain? Or is it worthwhile to retrace our steps and, if the auditory nerve is intact (even if only partially), apply a CI? This is the dilemma!

Conflict of Interest

The authors have no conflicts of interest to disclose.

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