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Extensive monitoring during auditory brainstem implant surgery

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Abstract

In patients with reduced auditory nerve function, for example due to tumour removal or an accident, hearing rehabilitation can be elicited by an auditory brainstem implant (ABI). The electrode array of the ABI manufactured by Cochlear Ltd., Sydney, consists of 21 circled contacts in a silicon carrier. This is inserted in the lateral recess of the fourth ventricle.

Since 1996, in Hannover eight patients have been implanted with a cochlear ABI Nucleus 21 + 1. All of them were profoundly deaf on both sides due to neurofibromatosis type 2 (NF2). To find the optimal electrode position during surgery, a multimodal monitoring by auditory evoked potentials (AEP), electromyography (EMG) and somatosensory evoked potentials (SEP) was performed.

When monitoring AEPs, the function of the implant can be checked first by the stimulus artefact. By analysing the AEPs in more detail, the optimal positioning of the electrode on the cochlear nucleus can be found. If systems other than the auditory system are stimulated this will be revealed in one or more of the AEP, EMG and SEP recordings. According to the literature, AEPs stimulated by an ABI consist of three vertex positive peaks with latencies shorter than 4 ms. Typical AEPs are correlated with good post-operative hearing sensation. Comparing these AEPs with AEPs stimulated acoustically or electrically at different sites of the auditory system, it can be assumed that the first peak corresponds to J3, the second to J4 and the last to J5. From this comparison it can also be concluded that no potentials should occur later than 5 ms. This corresponds to our findings. Post-operatively, side-effects occurred when areas of the electrode array were stimulated that showed potentials with latencies longer than 5 ms intra-operatively.

Our results indicate that monitoring is an essential aid for the surgeon in finding the optimal electrode position. Positioning solely with reference to anatomical landmarks may not be enough to find the optimal functional position.

Key words: Brain Stem; Prosthesis Implantation; Auditory Evoked Potentials

Introduction

The auditory brainstem implant (ABI) is especially designed for patients with functional loss of both auditory nerves, e.g. patients deafened by bilateral acoustic neuromas due to neurofibromatosis type 2 (NF2). The function of an ABI is similar to that of a cochlear implant except for the electrode array. The electrode array consists of 21 contacts on a flat silicon carrier (Figure 1). In contrast to the cochlear implant where the electrode is inserted into the bony structure of the cochlea, the ABI electrode has to be inserted into the lateral recess to be placed on the surface of the dorsal cochlear nucleus; this means that there is no bony structure that guides the surgeon to the correct electrode position. The electrode array has to be positioned by anatomical landmarks that might be difficult in cases of distortion by a tumour. Electrodes that lie outside the auditory area of the cochlear nucleus will evoke side-effects when stimulating post-operatively. Therefore, an extensive monitoring of auditory evoked potentials, as well as of their side-effects, is necessary to find the optimal functional coupling between the electrode array and the auditory system.

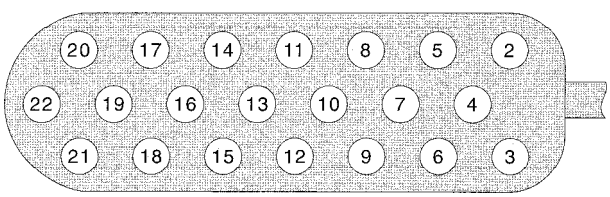

Fig. 1
Auditory brainstem implant electrode array.

Method

Eight patients bilaterally deafened due to NF2 were implanted with a Nucleus Mini 22 ABI. They were aged between 24 and 52 years, with duration of

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TABLE I
PATIENTS' DEMOGRAPHICS

Patient	Age at deafness (years)	Age at implantation (years)	Recurrent tumour size at implantation (cm)
AC	50	52	No recurrent tumour
CO	24	36	5
KU	27	31	4
LU	29	29	1
PA	48	49	2
PE	34	34	3
PR	24	24	3
W-P	42	43	1.5

deafness ranging between three and 15 years (Table I). All patients had an implantation at the time of an acoustic neuroma removal on the implanted side except one. The size of the recurrent tumour in the other patients was between 1 and 4.5 cm.

The electrodiagnostic system Viking IV by Nicolet was used to record auditory evoked potentials (E-AEP) (Figure 2). The recording electrodes were placed as follows: the ground electrode on the forehead, the positive electrode on the vertex and the negative electrode of the first channel on the ipsilateral earlobe, and of the second channel on the contralateral earlobe. The recorded signal was filtered between 10 Hz and 1.5 kHz.

Prior to implantation a multichannel probe electrode of the same design as the implant electrode was placed onto the cochlear nucleus. Only in cases where auditory evoked potentials were recorded was an implantation performed.

The stimulation of the ABI was performed by the Nucleus fitting station DPI. The stimulus pulse width was 150 μs and the amplitude up to 1 mA. A stimulation rate of 16 Hz was used. A bipolar stimulation mode was used, usually first along the entire electrode array, subsequently along half of the array, and so on. An example is given in Figure 3.

In order to detect non-auditory stimulation, the facial nerve was monitored by electromyographic (EMG) recordings of the orbicularis oris and orbicularis occuli muscles, the glossopharyngeal nerve by EMG of the palate and the vagal nerve by EMG recording of the vocal fold, and the medianus nerve by somatosensory evoked potentials.

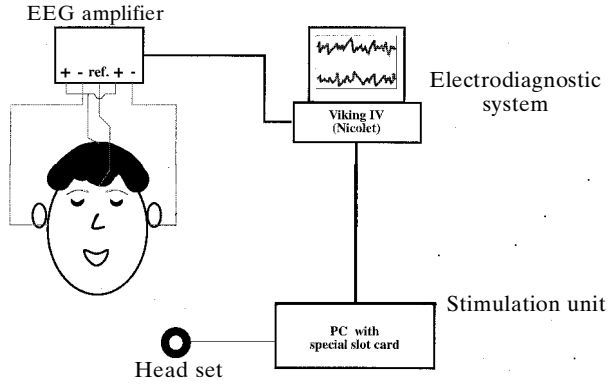

FIG. 2
Block diagram of recording devices.

Results

In all eight patients, evoked potentials were recorded when stimulated by an ABI. Typical E-AEPs consist of three vertex positive peaks (Figure 4). Ipsi- and contralateral recordings show the same pattern. The latency of the first peak is below 1 ms, the latency of the last peak below 4 ms. The first peak has the largest amplitude, with the two following peaks being smaller. The pattern of the E-AEPs does not change with changing stimulating electrodes. In six of our eight patients typical E-AEP recordings were obtained. In patient PA the third peak was missing, but the first two peaks had the typical pattern and typical latency. In patient CO there was a wide peak in the ipsilateral recording and a difference between the ipsi- and contralateral recording. In this patient most electrodes were eliciting vertigo or other non-auditory sensations. In some electrode configurations an additional peak could be seen at 7 ms. In parallel reactions in the EMG recording of the IXth nerve could be seen (Figure 5). Post-operatively the patient had a sensation of tickling in the tongue when these electrodes were stimulated.

Post-operatively the speech processor was usually programmed in the monopolar mode. Table II summarizes the E-AEP characteristics, the number of switch-on channels and the principal side-effects.

All patients are at present using their ABI and are experiencing an auditory benefit. A comparison of speech test results with lip-reading data are presented in Table III.

TABLE II
INTRA-OPERATIVE AND POST-OPERATIVE FINDINGS

Patient	E-AEP characteristics	Main side-effects	Numbers of activated channels		
			Total	Monopolar	Bipolar
AC	Typical, 1st peak big	Vertigo, sensation in the leg	15	12	3
CO	One peak only	Vertigo, tickling in the tongue	5	2	3
KU	Typical	Sensation in the arm and leg	12	9	3
LU	Typical, 3rd peak weak	Vibration in the head	12		
PA	Typical	Vertigo	9	9	0
PE	3rd peak missing	Vertigo, sensation in the whole body and in the arm	7	1	6
PR	Typical	Pounding in the ear	9	9	0
W-P	Typical	Vertigo	10	10	0

E-AEP = auditory evoked potentials recorded on Viking IV electrodiagnostic system (Nicolet).

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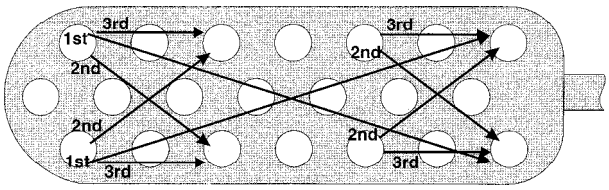

FIG. 3

Electrode configuration during recording of auditory evoked potentials on the Nicholet Viking IV electrodiagnostic system (order of the electrode pairs for stimulation).

Discussion

In order to optimize the functional coupling between the ABI electrode array and the cochlear nucleus, extensive monitoring is necessary. Two questions must be addressed urgently: a) Is the electrode stimulating the auditory system? b) Is the electrode stimulating other neural systems at the brainstem resulting in side-effects? If side-effects are detected in the monitoring, the corresponding regions of the array causing the side-effects must be determined. Via this mapping the surgeon can be guided in which direction the electrode should be moved.

Study of the E-AEP recordings when stimulating at different onsets of the auditory system revealed a decline in latency with more central stimulation.[1,2] Even the first peaks of the E-AEP are missing if the related sources of the auditory system are bypassed by the electrical stimulus. It is known from well-studied E-AEP recordings that, when stimulating by a cochlear implant, peak J1 is missing and peak J2 is superimposed by the stimulus artefact.[3–5] If the inter-peak-latencies between peaks J3, J4 and J5 are compared, these are not changed by alteration in the stimulus onset. Therefore we assume that the three peaks occurring after stimulation by an ABI correspond to peaks J3, J4 and J5. The generator

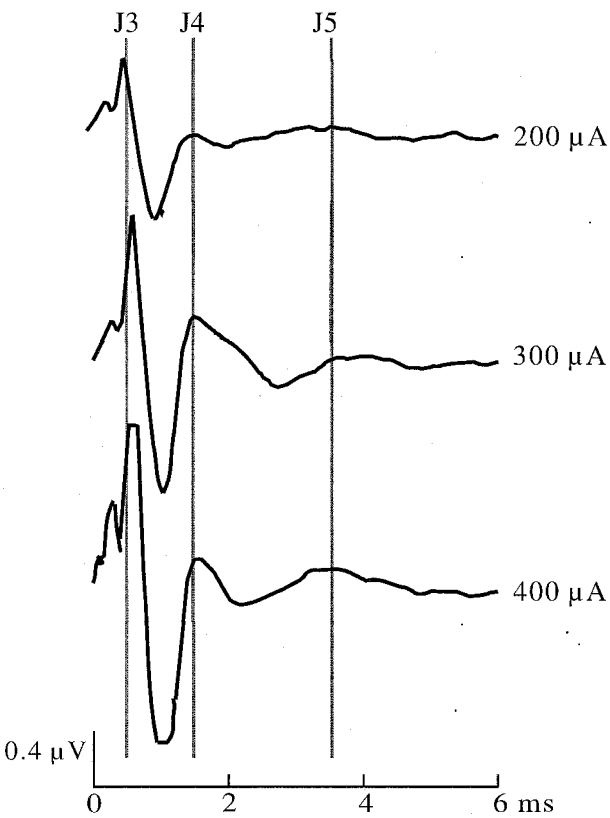

FIG. 4

Example of evoked auditory potentials after auditory brainstem implant stimulation, recorded on the Viking IV electrodiagnostic system (Nicholet).

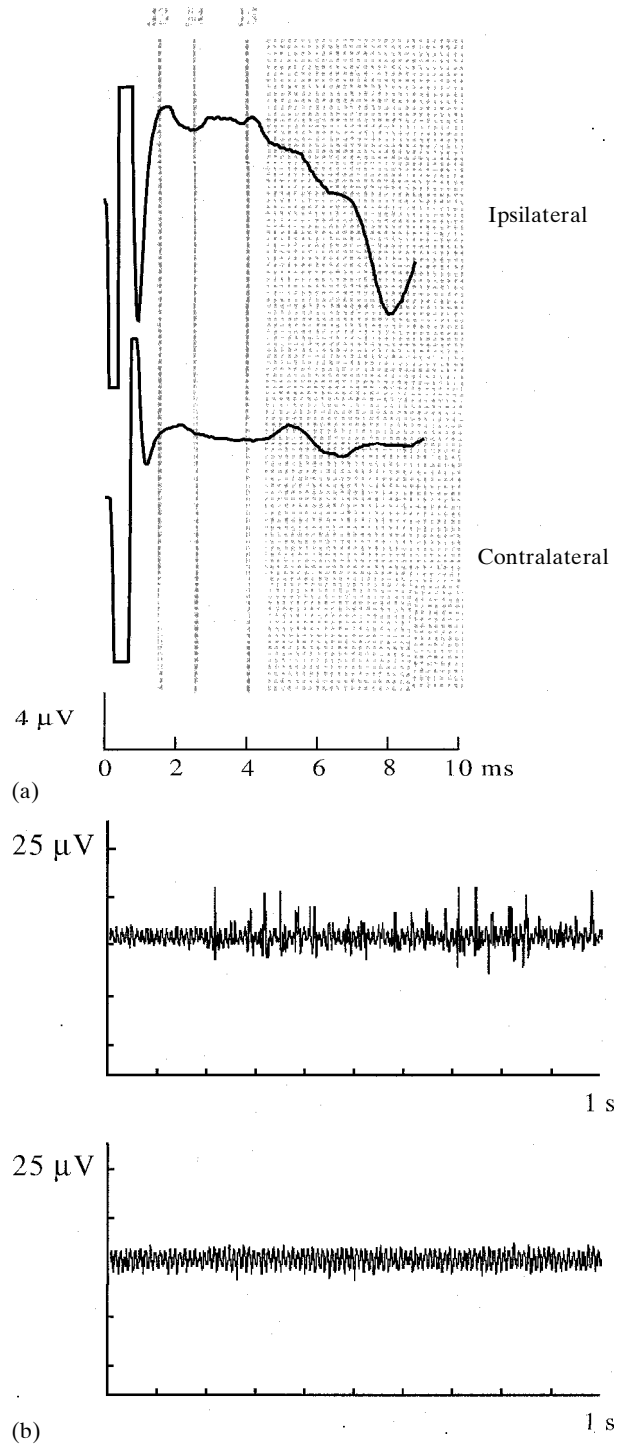

FIG. 5

(a) Evoked auditory potentials, recorded on the Viking IV electrodiagnostic system (Nicholet), for patient KU.
(b) Electromyography recording of the glossopharyngeal (upper) and vagal (lower) nerves of patient KU when stimulating electrodes 3–8.

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TABLE III
SPEECH TEST RESULTS

Patient	Freib. numbers (ABI only; %)	Speech tracking (lip-reading + ABI; w/min)	Speech tracking (lip-reading only; w/min)	Speech tracking (ABI only)
AC	70	46.8	7.8	Could not test
CO	80	12.8	9.0	Could not test
KU	35	9.0	Could not test	Could not test
LU	100	24.4	11.6	Could not test
PA	20	21.2	Could not test	Could not test
PE	Could not test	17.0	15.6	Could not test
PR	55	54.4	9.0	37.4 w/min
W-P	20	30.2	16.2	Could not test

ABI = auditory brainstem implant; w/min = words per minute.

of peak J1 and J2 is peripheral to the electrical stimulus; it is therefore bypassed and the peaks do not occur in the E-AEP pattern. Intra-operatively no peaks later than J5, corresponding in this case to 5 ms, should occur because they indicate non-auditory sensations.[6] The results from patient CO prove these assumptions.

In addition to the inter-peak-interval, E-AEPs have the same characteristics when stimulating with the ABI as when stimulating acoustically: the ipsi- and contralateral recordings have the same morphology. However, the amplitude of the first peak is the largest, whereas the last peak is very low. In some cases it was not visible at very low stimulus intensities. This might be because of the artificial synchronization by the electrical stimulus which is synchronized at a higher physiological level. The neuronal activity is synchronized at the cochlear nucleus and a local potential maximum will be generated that is not optimized for further passage. It might also be the case that only parts of the auditory system are stimulated, as suggested by Waring. Waring described E-AEP recordings with two or three vertex positive peaks when stimulating by an ABI. The second peak of a two peak recording has a latency between the latency of the second and third peak in a three peak recording.[7,8] Waring therefore hypothesized that the ABI stimulates part of the auditory system, whereas an acoustic stimulus activates the whole system with natural synchronicity and different locations of active units in the auditory system.

If any parts of the non-auditory system are stimulated and monitored by EMG, they could be detected in the recorded EMG potential. Depending on the exact electrode configuration it might also be that the ABI stimulus potential is visible; this must not be misinterpreted as a reaction.

Conclusion

Our results indicate that typical intra-operative E-AEPs with the same pattern on the ipsi- and contralateral recording and no later peaks than 5 ms correspond to a hearing sensation free from side-effects when stimulation follows post-operatively via the ABI. Stimulations of non-auditory systems could be detected either by the side-effect monitoring or as untypical potentials in the E-AEP recordings. Extensive monitoring is, therefore, necessary in order to find the optimal position of the ABI electrode array.

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