

SPET assessment of auditory cortex stimulation and tonotopic spatial distribution in Auditory Brainstem Implant

La SPET nella valutazione della stimolazione della corteccia uditiva e della distribuzione tonotopica spaziale dopo impianto uditivo del tronco

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Key words

Auditory brainstem implant • Single photon emission tomography (SPET) • Auditory cortex

Parole chiave

Impianto uditivo del tronco • Tomografia ad emissione di fotoni (SPET) • Corteccia uditiva

Summary

Activation of the auditory cortex by multifrequency acoustic stimuli has been evaluated using Single Photon Emission Tomography in a case of auditory brainstem implant after activation of 6 and 11 electrodes.

Before implantation, no activation of the auditory cortex has been observed after acoustic stimulation. Following auditory brainstem implant, the stimulation of 11 electrodes showed an activation value, in terms of blood flow increase, of the contralateral temporal cortex similar to that obtained with 6 electrodes (47.70 vs. 43.76%), but a significantly stronger activation was present in the contralateral parietal region (29.59 vs. 14.73%), in the homolateral temporal area (22.02 vs. 10.46%) and, especially, in the homolateral parietal zone (16.6 vs. 4.33%). The strongest activation in the contralateral temporal cortex was detected in the sagittal tomogram at 26.25 mm from the midline, that is in the areas where high frequencies are projected, both with 6 and 11 active electrodes. The medio-lateral auditory cortex, where the middle and lower frequencies are projected, showed an overall lower activation which was however significantly lower with 6-electrode stimulation. Stimulation of the surface of cochlear nuclei determines mainly an activation of the high frequency domain, independently of the electrodes number. This finding may explain the better results of cochlear implants in comparison with auditory brainstem implant and could justify the use of needle electrodes in auditory brainstem implant.

In conclusion, Single Photon Emission Tomography can be considered useful in evaluating auditory brainstem implant placement and function. It is also able to define the effectiveness of acoustic stimulation, the degree and tonotopic spatial distribution of auditory cortex activation.

Riassunto

In questo studio è stata valutata l'attivazione della corteccia uditiva dopo stimolazione acustica multifrequenziale, in relazione all'aumento del flusso ematico, attraverso l'utilizzo della tomografia ad emissione di singoli fotoni (SPET) in un caso di impianto uditivo del tronco, dopo l'attivazione di 6 ed 11 elettrodi. Prima dell'impianto non è stata osservata alcuna attivazione della corteccia uditiva dopo stimolo acustico. Dopo l'impianto la stimolazione di 11 elettrodi ha evidenziato un valore di attivazione della corteccia temporale controlaterale simile a quella ottenuta dopo attivazione di 6 elettrodi (47,70 vs. 43,76%). Diversamente sono state evidenziate attivazioni più elevate nella regione parietale controlaterale (29,59 vs. 14,73%), nell'area temporale omolaterale (22,02 vs. 10,46%) e, soprattutto, nella zona parietale omolaterale (16,6 vs. 4,33%). Sia con 6 sia con 11 elettrodi a livello della corteccia temporale controlaterale la maggiore attivazione è stata evidenziata a livello del tomogramma sagittale a 26,25 mm dalla linea mediana, nell'area di proiezione delle alte frequenze. La corteccia uditiva medio-laterale, verso la quale proiettano le medie e basse frequenze, ha mostrato una bassa attivazione, specialmente con la stimolazione a 6 elettrodi. La stimolazione superficiale dei nuclei cocleari è in grado di determinare un'attivazione prevalente per le alte frequenze indipendentemente dal numero degli elettrodi. Questi dati potrebbero spiegare i risultati migliori che si ottengono con l'impianto cocleare rispetto all'impianto del tronco e giustificerebbero l'uso di elettrodi ad ago nell'impianto del tronco stesso. In conclusione, la SPET può essere considerata un aiuto valido nella valutazione del posizionamento e della funzione dell'impianto del tronco. Tale metodica, infatti, è in grado di definire l'efficacia della stimolazione acustica, il grado e la distribuzione tonotopica spaziale dell'attivazione della corteccia uditiva.

Introduction

At present, Auditory Brainstem Implant (ABI) is the only system leading an improvement in hearing function in patients with bilateral deafness as a result of damage, resection or absence of auditory nerves. A multichannel auditory brainstem prosthesis was presented for the first time in Europe, in 1991 and was implanted one year later¹. During surgery, aimed at tumour removal, auditory nerve function and integrity are almost always destroyed. The stimulation of auditory nuclei in the floor of the IVth ventricle is obtained by an electrode array introduced during surgery in the lateral recess of the IVth ventricle. The implant may improve the awareness of environmental sounds and speech recognition.

Selection criteria for such implants include: an irreversible lesion of both auditory nerves, age > 12 years, adequate linguistic skills, reasonable expectations concerning the implant results, and patient's ability to follow the rehabilitation protocol². If the patient presents a congenital lack of auditory nerves obviously the age of intervention is lower. In type II neurofibromatosis, ABI implantation is carried out at the same time of tumour removal via a translabyrinthine or retrosigmoid approach³. During surgery, intraoperative monitoring of the VIIth and IXth nerves is necessary.

In the immediate post-operative period, electrically evoked auditory brainstem potentials are recorded, in order to evaluate the correct position of the electrodes on the cochlear nucleus complex.

One of the, as yet, unsolved post-surgical problems is the objective evaluation of the effects of cochlear nucleus stimulation by ABI^{4,5}. In fact, no information emerges regarding which part of the nucleus is stimulated and which central area is activated. Moreover evoked auditory brainstem potentials are unable to define which frequencies are activated following cochlear nucleus stimulation.

In a previous report we suggested the use of SPET to study the stimulation modality and the activation of the brain cortex in a patient with a 6 electrode ABI implant, pointing at that this technique provides useful information on ABI function⁶.

The aim of the present investigation was to evaluate the activation of auditory cortex by SPET following an 11 electrode ABI implant, comparing these results with previous data obtained with a 6-electrode ABI implant.

Patient and methods

The patient, a 28-year-old male, with neurofibromatosis type 2 (NF II), who became deaf after removal of bilateral acoustic neuromas received an ABI implant,

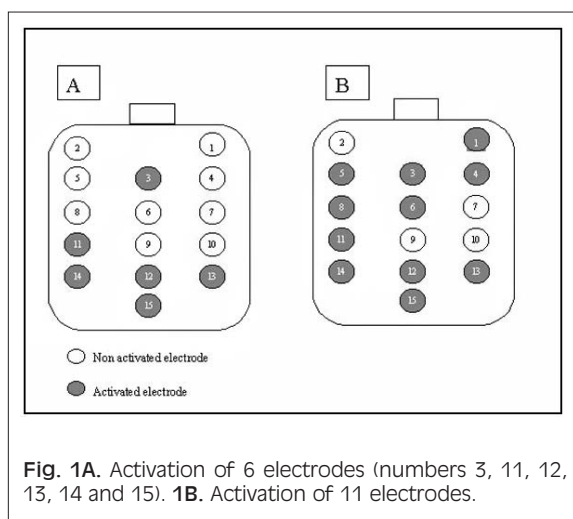


Fig. 1A. Activation of 6 electrodes (numbers 3, 11, 12, 13, 14 and 15). **1B.** Activation of 11 electrodes.

in March 1998, during removal of a residual left tumor via a retrosigmoid approach. A Digisonic DX 10TC multichannel brainstem implant was used. The technical characteristics of the implant and surgical procedures have been described elsewhere⁶.

No auditory responses were obtained at follow-up and, in April 1999, revision surgery, via a translabyrinthine approach, was carried out in order to reposition the electrodes. In June 1999, only six electrodes (nos. 3, 11, 12, 13, 14 and 15; Fig. 1/A) were activated, SPET was performed and results were described⁶.

In June 2000 other 5 electrodes were activated (Fig. 1/B) and SPET performed by CER.TO.96 (SELO, Italy) cerebral tomograph, technical characteristics of which, along with methods used are reported elsewhere⁷.

After the injection of 333 MBq 99mTc-hexamethylpropylene amine oxime (HMPAO), the head of the patient was settled onto a flexible headrest and inserted in the gantry. The position of the canthomeatal line was recorded by means of two light-guides mounted on the gantry at a 90° angle. A first 15-min examination was performed. The acoustic stimulation was delivered through a TDH 49 headphone by means of a total 9.5 min stimulation delivered from 2 min before up to 7.5 min after a second injection of 666 MBq 99mTc-HMPAO. A multifrequency (250, 500, 1000, 2000, 4000 Hz) pure tone with 30 s frequency variation was used at the highest audiometer intensity before ABI and at 20 dB SL after ABI. At the end of the stimulation, a 15-min examination was also performed. Reconstructed transverse, coronal and sagittal slices were obtained according to three spatial planes, using a software program which permitted the realignment of the sagittal sections to the canthomeatal line.

In the pre-stimulation and subtraction frames, temporal uptakes were calculated from two circular regions of interest (ROIs) drawn symmetrically on three consecutive coronal slices (nominal slice thickness 7.5 mm). Parietal uptakes were measured, for the same slice, with two irregular but symmetrical ROIs that did not exceed the maximal size of the circular ROIs. Using a 70% isocontour, a whole-brain ROI was drawn on summed pre-stimulation and subtraction sagittal slices, respectively. The total counts of all selected ROIs (temporal, parietal and whole-brain) in the pre-stimulation and subtraction frames were divided by the respective number of pixels. The counts per pixel of temporal ROIs were calculated in the pre-stimulation and sub-497. The same procedure was performed for parietal ROIs. Mean temporal and parietal values were calculated and then divided by whole brain ROI in pre-stimulation and subtraction images. The ratios were calculated separately contralaterally and homolaterally, to the acoustic stimulus. These values were regarded as the percentage increments of cortical blood flow consequent to audi-

tory stimulation. A circular ROI was then drawn on the temporal acoustic cortex of six consecutive sagittal slices, from 18.75 to 56.25 mm laterally to the midline, on the side contralateral to the stimulus. The counts per pixel of pre-stimulation and subtraction ROI were divided by whole brain ROI and the percentage increase of cortical blood flow was calculated as in coronal slices.

These data were compared with those obtained by SPET performed in the previous study.

Results

Cortical perfusion was found to increase (Table I) after multifrequency pure tone stimulation (mean coronal values expressed as percentages) in temporal and parietal areas (contralateral and homolateral), before ABI, after the activation of 6 and 11 electrodes and in a normal control group.

After ABI, temporal perfusion is twice as in normal controls. The stimulation of 11 and 6 electrodes caus-

Table I. Perfusion (%) of temporal and parietal regions in normal controls, before ABI, after activation of 6 and 11 electrodes.

	Contralateral		Homolateral	
	Temporal	Parietal	Temporal	Parietal
Before ABI	Not significant	Not significant	Not significant	Not significant
After ABI (6 electrodes)	43.76	14.73	10.46	4.33
After ABI (11 electrodes)	47.7	29.59	22.02	16.6
Control Group	23.94 (± 2.74)	12.71 (± 2.14)	9.35 (± 2.17)	4.97 (± 2.9)

Table II. Perfusion (%) of contralateral temporal cortex (mean values in sagittal slices at the indicated distance laterally from the midline) in normal control, before ABI, after activation of 6 and 11 electrodes.

	Slice 18.75 mm	26.25 mm	33.75 mm	41.25 mm	48.75 mm	56.25 mm
Before ABI	N. s.	N. s.	N. s.	N. s.	N. s.	N. s.
After ABI (6 electrodes)	-0.14	51.20	9.13	9.46	11.73	4.16
After ABI (11 electrodes)	8.32	52	9.70	36.11	16.26	16.5
Control Group	11.4 (± 14.5)	9.9 (± 7.4)	10.1 (± 12.5)	5.8 (± 4.7)	8.7 (± 8.9)	8.6 (± 12.3)

N. s. = Not significant

es similar activation values in the contralateral temporal cortex, but a significantly stronger activation in contralateral parietal, homolateral temporal and homolateral parietal areas.

Table II shows perfusion increases within the contralateral temporal cortex obtained when stimulating electrodes in sagittal slices passing from 18.75 mm up to 56.25 mm lateral from the midline, in normal controls, before ABI, and after the activation of 11 and 6 electrodes.

Perfusion increases were stronger using an 11-electrode stimulation if compared with a 6-electrode stimulation at 18.75 mm, 41.25 mm, 48.75 mm and 56.25 mm; while they were similar in the 26.25 mm and 33.75 mm slices. The strongest activation was always found in the 26.25 mm slice.

Discussion

Auditory brainstem response (ABR), middle latency response (MLR), and long latency response (LLR), as well as magnetic recordings have been reported to be highly useful in the evaluation of ABI function⁸⁻¹⁰. However, these methods do not provide clear information on the activation of cortical regions.

Miyamoto et al. were the first to describe the use of Positron Emission Tomography (PET) in ABI monitoring¹¹. Various Authors have supported the reliability and the usefulness of SPET in investigating auditory cortex activation in normal and hearing-impaired subjects. The use of this technique is justified since SPET is able to demonstrate cortical activation after acoustic stimulation in terms of perfusion increase. This increase is asymmetrical, with the highest activity in the contralateral temporal cortex¹²⁻¹⁶.

In the present study SPET findings demonstrated that after the activation of 6 or 11 electrodes a two fold perfusion increase in the contralateral temporal region is observed, if compared to normal controls. In the homolateral temporal and in the homolateral and contralateral parietal regions, 11-electrode activation increased cortical perfusion more than two fold, especially in the homolateral parietal cortex.

The improvement of parietal activation after stimulation of 11 electrodes is difficult to explain. It could be due to the involvement of the associative cortical pathways following the stimulation of a larger cochlear nuclear area.

In a previous investigation, we observed that a multifrequency stimulus activated the entire contralateral temporal cortex and SPET was able to provide some information concerning the tonotopic distribution within the auditory cortex^{7 13 16}.

According to previous findings, low frequency stim-

ulation activated the most lateral primary auditory regions and high frequency stimulation, the most medial areas^{17 18}.

In our ABI patient, after a multifrequency stimulation, the highest SPET perfusion increase was found in the areas where high frequencies are projected.

Hence, SPET provided direct objective evidence concerning the tonotopic distribution of the acoustic stimulus within the primary auditory cortex and indirect information on which portions of the cochlear nucleus were more strongly stimulated by the surgically implanted electrodes.

Our data seem to demonstrate that a superficial stimulation of the cochlear nucleus mainly activate the high frequencies and that the number of activated electrodes does not influence this selectivity. If this characteristic is clinically confirmed in a larger number of brainstem implanted patients, these results may explain the difference between these patients and those undergoing a cochlear implant, whose surgical results are always better.

This may explain why nuclear stimulation is better performed using needle electrodes which stimulate also deep layers of the auditory nuclei.

Recordings of intra-operative auditory-evoked potentials and the evaluation of sound perception may represent reliable methods for a correct location of each electrode^{8 19}. However, the first technique does not provide adequate information on the degree of auditory cortex activation and on the involved frequencies. Using subjective discrimination criteria, the patient studied was able to discriminate two stimuli with different frequencies, but was unable to determine to which frequency the auditory sensation corresponded or to give information on the width of the perceived frequency range.

In conclusion, information about electrodes contact with the cochlear nuclei can be obtained by evaluating the activation of auditory cortex considering the nuclear and cortical tonotopic distribution. The activation of 6 or 11 electrodes leads to the strongest perfusion increase in the tomogram at 26.25 mm which corresponds to the part of the cochlear nuclei which transduces high frequencies. The medial and lateral regions receiving information on middle frequencies, are less activated when only 6 electrodes are active. The 11 electrode activation gives a better distribution pattern of cortical activation, and improves middle and high frequency activation.

On the basis of these results, SPET can be considered useful in providing information on electrode placement and frequency content of the stimulus reaching the auditory cortex.

A future goal should be a technical tool able to provide this information intra-operatively.

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