Acta Otolaryngol (Stockh) 1999; 119: 239–243

Changes in the Cerebral Blood Flow in Postlingual Cochlear Implant Users

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Suárez H, Mut F, Lago G, Silveira A, De Bellis C, Velluti R, Pedemonte M, Svirsky M. *Changes in the cerebral blood flow in postlingual cochlear implant users*. Acta Otolaryngol (Stockh) 1999; 119: 239–243.

Five postlingually deaf patients (age range 28–58 years) with multichannel cochlear implants were examined with single photon emission tomography (SPECT) (triple-head rotating gamma camera). Changes in the regional cerebral blood flow (rCBF) after intravenous administration of technetium-99m ethyl cysteinate dimer (Tc-99m ECD) were assessed through a stimulation paradigm, consisting of: *i)* click stimuli (75 dB SPL) in the ear that was to be implanted, 2 weeks before surgery; *ii)* stimulation with the same click, one month after initial fitting; *iii)* stimulation with hearing sequential Spanish sentences one month after initial fitting. The results showed a significant increase in the rCBF in the primary left auditory area and in the right auditory cortex, in conditions *ii)* and *iii)*. The rCBF also showed a significant asymmetrical increase in the frontal lobes when the patient was hearing sequential sentences (condition *iii)*) with asymmetrical distribution among patients. These results are discussed, principally the correlation between speech discrimination scores and the rCBF distribution in the frontal and temporal lobes. *Key words*: *cerebral blood flow*, *cochlear implant*, *SPECT imaging*.

INTRODUCTION

Cochlear implantation improves communication ability in most adults with severe to profound deafness and frequently leads to positive psychological and social benefits.

New tools, such as functional imaging of the brain, might be applied to unexplored variables such as the ability of the implant to activate the central auditory system. Investigations into the role of higher level cognitive processes in cochlear implant performance are needed (1).

Using non-invasive techniques it is now possible to assess regional cerebral blood flow (rCBF) or metabolism, and thus measure the levels of neuronal activity in the depths of the human brain. Investigations using positron emission tomography (PET) have demonstrated decreased metabolism and rCBF in the auditory cortex in deaf patients and its increase by sound stimulation through the cochlear implant (2, 3). Information about rCBF behaviour in cochlear implant users has been described in profoundly deaf patients before and after implantation when these patients were stimulated with clicks and sequential sentences (4), showing the increase in the rCBF in the left auditory association area, the bilateral auditory association areas and the posterior part of the bilateral inferior frontal gyri. Comparative studies in patients with prelingual and postlingual deafness, assessed with PET, demonstrated some differences in the distribution of the rCBF after the patients were using the cochlear implant. In the postlingually deaf patients, speech sound is thought to be processed by means of auditory cortices analogous to those in normal subjects. In the prelingually deaf patients speech sound induced much less rCBF increase in auditory association cortices. The authors suggested underdevelopment in the brain areas involved with complex sound analysis and speech recognition (5).

The aim of this study was to measure rCBF distribution in multichannel cochlear implant users assessed using single-photon emission computed tomography (SPECT) and to correlate this with the speech recognition scores in these patients a month after initial fitting.

METHODS

Five postlingually deaf patients (age range 18–58 years) with multichannel cochlear implants were included in this study, one using a Med-El Combi 40 and the rest using Nucleus 22 devices (Table I). Full consent to procedures was given by all subjects. None of the patients had a history of neurological or psychiatric disorders apart from profound bilateral hearing loss.

The patients lay supine on a SPECT bed in a silent dark room, with both eyes covered with a mask. The sound stimulation paradigm consisted of: *i)* a previously recorded click of 75 dB SPL, 1 ms duration with a frequency of 4/s, stimulating the deaf ear to be implanted two weeks before surgery through a earphone placed in the external auditory canal; *ii)* the same click, stimulating the implanted ear directly in the speech processor; *iii)* Spanish sentences of approximately 30 words per minute, without lip-reading. Conditions *ii)* and *iii)* were performed a month after initial fitting.

The brain perfusion agent utilized was Technetium-99 ethyl cyteinate dimer (Tc-99m ECD) at a dose of

ISSN 0001-6489

740 MBeq given intravenously. Imaging started 30 min post-injection. A SPECT study was obtained, using a large rotating field of view, gamma camera with a low-energy, high-resolution collimator. A total of 64 projections were acquired over a 360° circular orbit, and reconstruction of cross-sectional images was done by filtered back projection using a fourth order Butterworth filter with a cut-off at 0.25 of the Nyquist frequency.

Images were analysed by displaying transverse, sagittal and coronal slices measuring the blood flow of the temporal, parietal and frontal lobes, specifically. In addition, a semiquantitative method was used by comparing a surface three-dimensional mapping of cortical perfusion of each patient, under conditions *i)*, *ii)* and *iii)*. Changes in cerebral blood flow were also measured, in terms of standard deviations from the basal condition (6, 7).

Significant changes in rCBF were determined using Student's t-test for independent samples, and as level of significance of error, an alpha ≤ 0.05 was accepted.

Vowel and consonant scores were measured by the corresponding confusion matrix and the reception of the speech tracking was evaluated according to the method of Lee and Filippo (8).

RESULTS

The analysis of the SPECT images of the 5 patients showed activation in the left auditory area on noise and speech stimulation, with a significant increase in blood flow compared with the values before implantation ($p < 0.01$) (Table I).

The right auditory areas also showed higher changes in the blood flow in conditions *ii)* and *iii)* in all patients ($p < 0.01$) (Fig. 1).

The frontal lobe blood flow increased bilaterally and symmetrically in patients 1, 4 and 5 when the speech discrimination task was applied (condition *iii)*) ($p < 0.01$) (Fig. 2).

Patient 3 had a significantly higher value in the frontal lobe perfusion ipsilateral ($p < 0.01$) to the implant during speech discrimination. Patient 2 did not show any significant increase in the frontal lobe perfusion with sound or speech stimulation.

Excellent results were measured in patients 1, 2 and 3 through the vowel and consonants confusion matrix and the speech tracking score. All of them achieved fluent telephone communication.

Patient 4 had an intermediate result in the speech discrimination score and patient 5 had the poorest improvement in his communication skills (Table I).

Patients 1, 4 and 5 had hearing loss thresholds in the stimulated ear similar to the click stimulation level and they perceived a minimum sensation of sound.

Patients 2 and 3 had hearing loss thresholds below the click stimulation and neither of them had sound sensation. Thus the basal condition (condition *i)*) was different from another paradigm stimulation in PET studies (4, 5) that was performed after cochlear implant, with the speech processor switched off.

DISCUSSION

The results for the changes in the rCBF in the SPECT images, the temporal brain areas activated with sound and speech stimulation were similar to previous findings with PET (4, 5). However, our findings showed an asymmetrical rCBF in the frontal lobes among patients during the speech discrimination task. These differences acquire relevance for the analysis of results for patients 1, 2 and 3 who had the most significant improvement in their communication skills. In condition *iii)*, patient 1 had the highest homogeneous increase in the rCBF in both frontal lobes. Patient 2 had no modification in the rCBF in the frontal lobes in condition *ii)* or *iii)*.

Finally, patient 3 showed an asymmetrical change in the rCBF, increasing only in the ipsilateral (right) frontal lobe in condition *iii)*.

Table I. *Clinical features, speech recognition and rCBF distribution*

Patient	Age (years)	Gender	CD	Time of deafness	Threshold level (before cochlear implant)	Vocal recognition	Consonant recognition	Speech tracking	Implanted ear	Significant increase in condition 3 of rCBF
1	47	F	U	10	75	92%	68%	48	RIGHT	LT RT BFL
2	28	M	U	12	90	96%	76%	87	RIGHT	LT RT
3	37	M	PHL	6	95	88%	65%	48	RIGHT	LT RT IFL
4	58	F	OT	5	80	58%	34%	37	RIGHT	LT RT BFL
5	29	M	M	12	80	68%	64%	5	RIGHT	LT RT BFL

LT, left temporal lobe; RT, right temporal lobe; BFL, bilateral frontal lobe; U, unknown; PHL, progressive sensory-neural hearing loss; OT, otoesclerosis; M, meningitis.

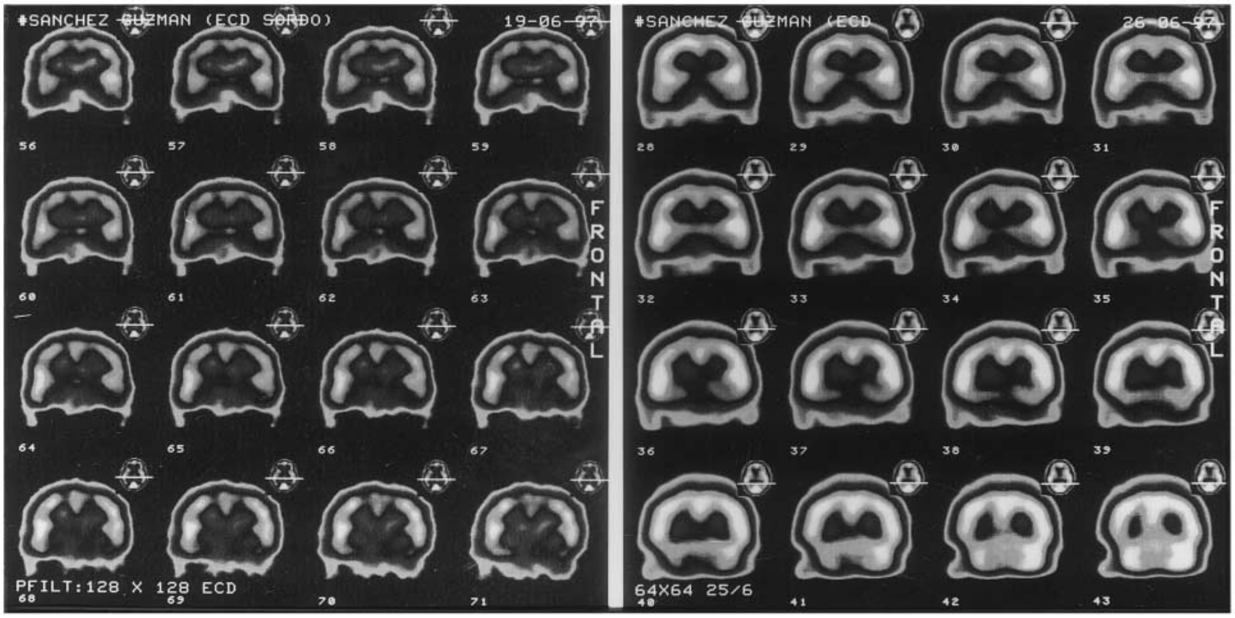

Fig. 1. SPECT images of the brain coronal slices marked with Tc-99m ECD in the two conditions. *Left*, 2 weeks before the cochlear implant, stimulated with a click (80 dB) (condition *i*). *Right*, the same patient a month after the initial fitting undergoing speech recognition stimulation (condition *iii*). A significant increase in the rCBF in left and right auditory areas ($p < 0.01$) is visible.

Although these three patients had similar scores in speech discrimination, achieving fluent speech understanding, including telephone communication, the rCBF in the frontal lobes was notably different. Thus the role of the frontal lobe in speech discrimination in these three implanted postlingually deaf patients is unclear.

In order to evaluate the contribution of neuroimaging to our knowledge of auditory central processing, two aspects are of interest for discussion. One relates to functional aspects of the frontal lobe (mainly the pre-cortex area) and the other to some limitations of the imaging methods.

In relation to functional aspects, like the temporal lobes the frontal lobes contain functional areas involved in the perception of speech sounds (9). However, sound and speech recognition have at least three different cognitive functions; memory, set and inhibitory control. All may be taxed by the target task, and thus in the subtracted frontal image one function may mask another. That another variable, such as vigilance, consumes energy and could be different among subjects, cannot be dismissed (the prefrontal cortex receives so many subcortical inputs related to drive and motivations).

In relation to the imaging methods, PET and SPECT scanning allow the visualization of changes in regional blood flow and metabolism related to neuronal activity. But there are some problems to be solved, such as the insufficient understanding of the physiological relationship between blood flow, neurone discharge and energy metabolism. Particularly troublesome are the uncertainties concerning the temporal aspects of the correlation between these three variables (neurovascular coupling) (10).

Although the implanted patients with similar postoperative speech discrimination scores (patients 1, 2 and 3) had significant differences in the rCBF in the frontal lobes, it cannot be interpreted that each one uses different cognitive procedures in the auditory process. The complexity of the auditory cognitive functions and the limitations of the imaging methods do not allow us to draw any firm conclusion, based on the images, to understand that there is one main brain cortex area involved in speech discrimination success in cochlear implanted postlingually deaf patients.

Perhaps assessment using combinations of different tools, such as psychophysics, cognitive test and neuroimaging, could give us more accurate data about the role of the different brain cortex areas in the auditory recognition process now that it is possible to restore this sensory information through the cochlear implant procedure.

ACKNOWLEDGMENT

Support was received from the Bid-Conicyt (Grant 2/94).

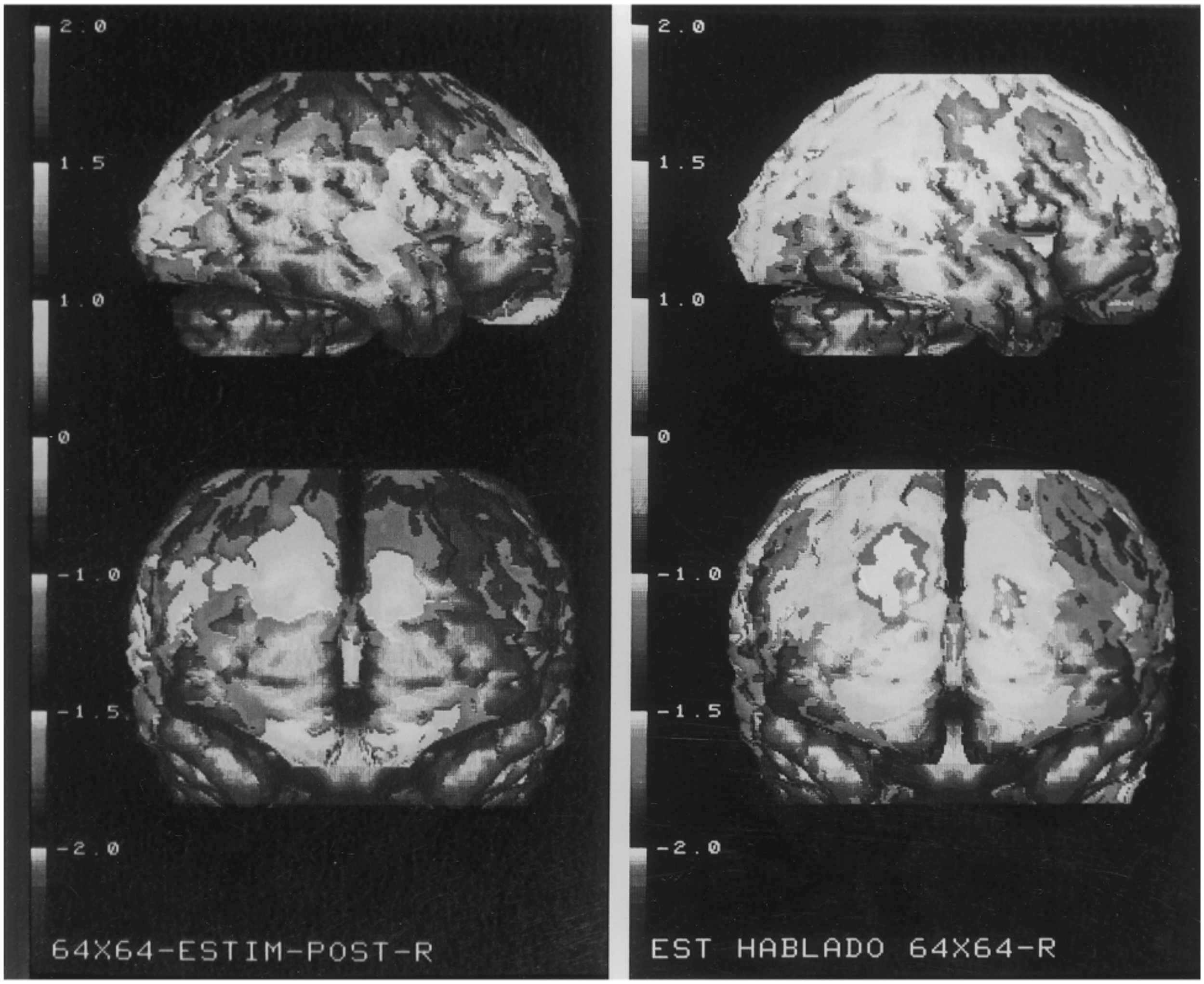

Fig. 2. Three-dimensional mapping of cortical blood perfusion marked with Tc-99 m ECD. *Left*, right hemisphere (*up*) and frontal lobe (*bottom*) 2 weeks before implantation stimulating with click at 75 dB (condition *i*). Right, the same patient, right hemisphere (*up*) and frontal lobe (*bottom*) during speech recognition (condition *iii*) with a increase in the rCBF to the frontal lobes.

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