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Blood flow measurements in the ears of patients receiving cochlear implants

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Abstract

We measured cochlear blood flow in 12 patients who received cochlear implants using a laser-Doppler probe with an outer diameter of 0.8 mm. The subjects included congenital deafness, idiopathic progressive sensorineural hearing loss, Waardenburg syndrome, narrow internal auditory canal, and sudden deafness. Putting the probe tip to the site of drilling for cochlear implantation, we measured blood flow before, during and after the cochlear bony wall was opened. The laser-Doppler output was confirmed even after the tip of the probe was inserted into the perilymphatic space in all cases. Our results revealed that blood flow was maintained in all cochleas though there was a probability of reduction in blood flow volume. We conclude that laser-Doppler flowmetry is both safe and useful for measuring blood flow in the ears during cochlear implantation procedures.

KEY WORDS - cochlear blood flow, cochlear implant, laser-Doppler flowmetry, deafness, narrow internal auditory canal, Waardenburg syndrome.

Introduction

Impairment of cochlear blood flow (CBF) may be one of the factors implicated in the pathophysiology of sensorineural hearing loss.[1,2] To evaluate CBF, various methods have been used including intravital microscopy,[3,4] impedance plethysmography,[5] laser-Doppler flowmetry,[1,6] and microspheres.[7,8] However, at present, only laser-Doppler flowmetry is clinically available for measuring human CBF.[1,9-14] For this approach, the tip of a probe is normally placed on the bony promontory over the cochlea. In this situation, the degree of contribution of the bone blood flow to the laser-Doppler output must be evaluated. Laser-Doppler flowmetry gathers more signals from the blood flow in the area closest to the tip of the probe, and the bone's blood supply, which probably comes from the external carotid artery system, may behave differently from the CBF, which comes from the vertebral arterial system.[15] At present, the degree of contribution of the bone blood flow to the laser-Doppler output in humans is not clear.

When assessed by laser-Doppler flowmetry, the degree of contribution of the bone blood flow is associated with the thickness of the bone, the wavelength of the laser, the permeability of the bone, the size of the probe, and the position of the probe tip.[10,16,17] Based on results of simultaneous measurement using laser-Doppler flowmetry and microspheres in rats, it has been estimated that between 30% and 40% of the laser-Doppler output depends on bone blood flow.[18] Because the bone surrounding the cochlea is thicker in humans than in experimental animals, the actual contribution of the bone blood flow to the laser-Doppler output is likely to be greater in clinical situations.

Patients receiving cochlear implants offer clinicians a unique opportunity to evaluate the contribution of the bone blood flow systematically, as the bone surrounding the cochlea is opened. We believe that the true component of CBF can thus be measured most accurately by laser-Doppler flowmetry in such a situation. Here we report on the measurement of CBF in the ears of patients receiving cochlear implants.

Methods

The subjects for this investigation were 12 patients who received cochlear implants. There were seven males and five females, and their ages ranged from 2 to 55 years. All parents of the children and all adult patients received an explanation of the method and purpose of the study, and provided informed consent. The causes of deafness were unknown, except for one patient who had Waardenburg syndrome. One child had bilateral narrow internal auditory canals (Fig. 1). Three adults had been diagnosed as having idiopathic progressive sensorineural hearing loss. One adult patient had experienced idiopathic sudden sensorineural hearing loss two years previously.

CBF was measured using a laser-Doppler flowmeter (model ALF 21, Advance, Tokyo, Japan) under general anesthesia with sevoflurane and nitrous oxide. Systolic blood pressure was between 85 mmHg and 123 mmHg and diastolic blood pressure was between 35 mmHg and 70 mmHg at the measurement in 12 patients. The outer diameter of the probe was 0.8 mm, and the fiber separation between the exciting and receiving optic fibers was 0.3 mm. The tip of the probe was attached manually to the site of drilling for cochlear implantation. Blood flow was measured before, during, and after the cochlear bony wall had been opened, as demonstrated in Figs 2a-e. For drilling, we used a skeeter drill (Medtronic Xomed, Jacksonville, FL, USA) with an outer diameter of 0.8 mm.

Fig. 2a shows the tip of the laser-Doppler probe attached to the mucous membrane of the promontory before drilling commenced. Fig. 2b shows the placement of the tip of the probe when the mucous membrane of the promontory had been removed by the drilling. Fig. 2c shows the placement of the tip of the probe when half of the bony wall had been drilled. Fig. 2 d shows the tip of the probe attached to the lateral membrane of the scala tympani. Fig. 2e shows the placement after the bony wall had been opened, with the tip of the probe inserted into the perilymphatic space. It took less than one minute to drill through half of the bone. The drill speed was about

12,000 rpm. We used saline several times to cool the bone during the drilling.

Results

Table gives the values of the laser-Doppler output measured at the positions shown in Fig. 2a-e. The laser Doppler output was largest when the tip of the probe was attached to the mucous membrane of the promontory (ANOVA test, $p < 0.01$). As shown in Table, measurements could not be done at some positions when it was considered that the drilling proceeded too deep for the measurement. An example of the recording is demonstrated in Fig. 3. Fig. 3 shows that the laser-Doppler output became stable within several seconds after the placement of the probe. It took about ten minutes for the evaluation of blood flow including five measurements (Fig. 2a-e). Fig. 3 also shows a tendency that pulsatory movement of the output was wide when the output was large.

The output was confirmed in all situations and cases, except in two patients for whom output was zero when measured at the position shown in Fig. 2d. Even in the patient with narrow internal auditory canals, output was confirmed in all situations as shown in Table. There was no significant difference among the values of the laser-Doppler output measured at positions shown in Fig. 2b-e. A correlation was observed between the values of the laser-Doppler output measured when the tip of the probe was attached to the mucous membrane of the promontory and those measured when the tip of the probe was inserted into the perilymph ($r = 0.78$, $p < 0.01$). However, there was no significant correlation between the values of the laser-Doppler output measured when the tip of the probe was attached to the mucous membrane of the promontory and those measured at the positions shown in Fig. 2b-d.

There was no correlation between the laser-Doppler output and blood pressure. When patients were analyzed as two groups; adults (aged 16 years or older) and children (aged three years or younger), the laser-Doppler output was not significantly different for any measurement taken in the positions shown in Fig. 2.

Discussion

After measuring CBF using laser-Doppler flowmetry, Miller et al[9] reported that normal mucosa in humans does not contribute significantly to the laser-Doppler output. Nakashima et al[10] reported that removal of the middle ear mucosa under the probe tip lowered the laser-Doppler output to 50% - 80%. In the present study, removal of the middle ear mucosa lowered the laser-Doppler output to 33% of the average of its previous level. This large reduction in output may suggest a disturbance of CBF in ears receiving cochlear implants.

Since we opened the bony wall using a drill, blood flow in the bony wall or blood flow in the perilymphatic lateral membrane adjacent to the drilled part may be disturbed by the mechanical or thermal effect of the drilling. However, we consider that the laser-Doppler output measured when the tip of the probe was inserted into the perilymphatic space reflected CBF without the mechanical or thermal effect of the drilling because the output reflected blood flow in the area illuminated by the laser light through the transparent perilymph, where it is distant to the drilled part. In measuring blood flow where it is not transparent, blood flow in the portion within about 1 mm from the tip of the probe can be measured using this laser probe.

In this study, we did not observe bleeding when the bony wall was opened (from Fig. 2b to Fig. 2e). This is contrast to the fact that bleeding always occurs when the bony wall is opened in normal guinea pigs. Actually, in guinea pigs using the same probe, we confirmed that the laser-Doppler output measured when the middle ear mucosa was intact was not different significantly from that measured when the probe tip was inserted into the perilymph. In a case with a narrow internal auditory canal, reduction of CBF was anticipated because the inner ear artery runs through the internal auditory canal. However, the laser-Doppler output in this case was not significantly different from those in the other cases. These findings may also suggest disturbance of CBF in patients who receive cochlear implants.

Fibrous or bony occlusion of the perilymphatic space, which occasionally makes cochlear implantation difficult, may be associated with impairment of CBF. Perlman et al[19] described that experimental obstruction of the labyrinthine artery was rapidly followed by severe degenerative changes and ossification in the cochlea. Human temporal bones following surgical removal of acoustic tumor or sudden sensorineural hearing impairment also revealed that cochlear ossification suggested vascular etiology of hearing loss.[20] Cochlear ossification is a common occurrence in postmeningitic deaf patients.[21,22] However, whether or not the postmeningitic cochlear ossification is associated with the disturbance of CBF is not clear at present.

Because laser-Doppler flowmetry provides only relative values, it is difficult to compare results across patients. However, laser-Doppler flowmetry is superior for examining relative changes due to various stimuli. It has been shown that direct electrical stimulation of the cochlea elevates CBF.[1,9,23] As electrical stimulation to the cochlea has been recently applied to observe neural responsiveness during a cochlear implant procedure, as neural response telemetry (NRT), we believe that observation of the laser-Doppler response to such electrical stimulation may provide further information about CBF.

In conclusion, laser-Doppler flowmetry is both safe and useful for measuring blood flow in the ears during cochlear implantation procedures. The measurement may be useful to investigate etiology of sensorineural hearing loss, the relationship between ossification and disturbance of blood flow and so on.

References

1. Miller JM, Ren TY, Nuttall AL. Studies of inner ear blood flow in animals and human beings. Otolaryngol Head Neck Surg 1995;112:101-3.

2. Nakashima T. Autoregulation of cochlear blood flow; a review. Nagoya J Med Sci 1999;62:1-9.

3. Prazma J, Carrasco VN, Garrett CG, Pillsbury HC. Measurement of cochlear blood flow: intravital fluorescence microscopy. Hear Res 1989;42:229-36.

4. Axelsson A, Nuttall AL, Miller JM. Observations of cochlear microcirculation using intravital microscopy. Acta Otolaryngol 1990;109:263-70.

5. Suga F. Neural control of cochlear blood flow. Acta Otolaryngol 1976;81:26-35.

6. Sillman JS, LaRouere MJ, Nuttall AL, Lawrence M, Miller JM. Recent advances in cochlear blood flow measurements. Ann Otol Rhinol Laryngol 1988;97:1-8.

7. Angelborg C, Hillerdal M, Hultcrantz E, Larsen HC. The microsphere method for studies of inner ear blood flow. ORL 1988;50:355-62.

8. Nakashima T, Suzuki T, Morisaki H, Yanagita N. Blood flow in the cochlea, vestibular apparatus and facial nerve. Acta Otolaryngol 1991;111:738-42.

9. Miller JM, Bredberg G, Grenman R, Suonpaa J, Lindstrom B, Didier A. Measurement of human cochlear blood flow. Ann Otol Rhinol Laryngol

1991;100:44-53.

10. Nakashima T, Suzuki T, Morisaki H, Yanagita N. Measurement of cochlear blood flow in sudden deafness. Laryngoscope 1992;102:1308-10.

11. Miller JM, Laurikainen EA, Grenman RA, Suonpaa J, Bredberg G. Epinephrine-induced changes in human cochlear blood flow. Am J Otol 1994;15:299-05.

12. Degoute CS, Preckel MP, Dubreuil C, Banssillon V, Duclaux R. Sympathetic nerve regulation of cochlear blood flow during increases in blood pressure in humans. Eur J Appl Physiol & Occupational Physiol 1997;75:326-32.

13. Tono T, Ueki Y, Nagata N, Haruta A, Komune S. Effects of trimetaphan-induced deliberate hypotension on human cochlear blood flow. Acta Otolaryngol 1998;Suppl 539:40-3.

14. Preckel MP, Ferber-Viart C, Leftheriotis G, Dubreuil C, Duclaux R, Saumet JL, Banssillon V, Granry JC. Autoregulation of human inner ear blood flow during middle ear surgery with propofol or isoflurane anesthesia during controlled hypotension. Anesth Analg 1998;87:1002-8.

15. Yamamoto J, Nakashima T, Yanagita N. The effect of CO2 and apnea on cochlear and middle ear blood flow in guinea pigs. Nippon Jibiinkoka Gakkai Kaiho 1997;100:36-44.

16. Scheibe F, Haupt N, Berndt H, Magnus S, Weymar P. Laser-light transmission and laser Doppler blood flow measurements on human, rat, and

guinea pig cochlea. Eur Arch Otorhinolaryngol 1990;247:20-3.

17. Laurikainen E, Kanninen P, Aho H, Saukko P. The anatomy of the human promontory for laser Doppler flowmetry. Eur Arch Otorhinolaryngol 1997;254:264-8.

18. Suzuki T, Iwagaki T, Hibi T, Nakashima T. Effects of the anterior inferior cerebellar artery occlusion on cochlear blood flow: a comparison between laser-Doppler and microsphere methods. ARO abstract 2000.

19. Perlman H, Kimura R, Fernandez C. Experiments on temporary obstruction of the internal auditory artery. Laryngoscope 1959;69:591-12.

20. Belal A Jr. Pathology of vascular sensorineural hearing impairment. Laryngoscope 1980;90:1831-9.

21. Axon PR, Temple RH, Saeed SR, Ramsden RT. Cochlear ossification after meningitis. Am J Otol 1998;19:724-9.

22. Young NM, Highes CA, Byrd SE, Darling C. Postmeningitic ossification in pediatric cochlear implantation. Otolaryngol Head Neck Surg 2000;122:183-8.

23. Laurikainen EA, Costa O, Miller JM, Nuttall AL, Ren TY, Masta R, Quirk WS, Robinson PJ. Neuronal regulation of cochlear blood flow in the guinea pig. J Physiol 1994;480:563-73.

Figure Legends

Fig.1. CT of a case with bilateral narrow internal auditory canals.

Fig. 2. Blood flow measurements in the ears of patients receiving cochlear implants.

a; The tip of the probe is on the mucous membrane of the promontory.

b; The mucous membrane of the promontory was removed.

c; Half of the bony wall was drilled.

d; The bony wall was drilled until the the mucous membrane surrounding the perilymph.

e; The bony wall was opened, with the tip of the probe inserted into the perilymphatic space.

Fig. 3. An example of recording (case 1 1 in Table). Laser-Doppler output measured at the positions in Fig. 2a-e. Each recording was shown from placement to removai of the probe.

LASER-DOPPLER OUTPUT FROM THE EARS RECEIVING COCHLEAR IMPLANTS

	Age Gender	Hearing loss	output at a	output at b	output at c	output at d	output at e
1	16F	hereditary	5.3	2.9	4.0	1.9	2.7
2	3F	Waardenburg synd.	44.8	4.0	2.3	0.0	5.0
3	45F	IPSNHL	4.2	1.4	2.4	0.0	1.1
4	2F	congenital	27.8	1.3	NM	2.2	4.6
5	3M	narrow IAC	3.8	2.5	0.4	1.8	1.4
6	3M	congenital	2.2	NM	1.0	0.2	0.7
7	55M	IPSNHL	1.0	0.6	NM	NM	0.4
8	3M	congenital	5.9	3.0	1.1	NM	2.7
9	2M	congenital	22.8	2.1	2.2	NM	2.5
10	26F	IPSNHL	6.8	NM	1.5	NM	4.0
11	2M	congenital	4.5	1.2	1.3	0.6	0.8
12	53M	sudden deafness	15.6	1.9	NM	7.0	2.3

Outputs at a, b, c, d and e represent those measured at positions shown in Fig. 2a-e, respectively. Gender F; female, M; male. Hearing loss, IPSNHL; idiopathic progressive sensorineural hearing loss, narrow IAC; narrow internal auditory canal. NM; not measured.

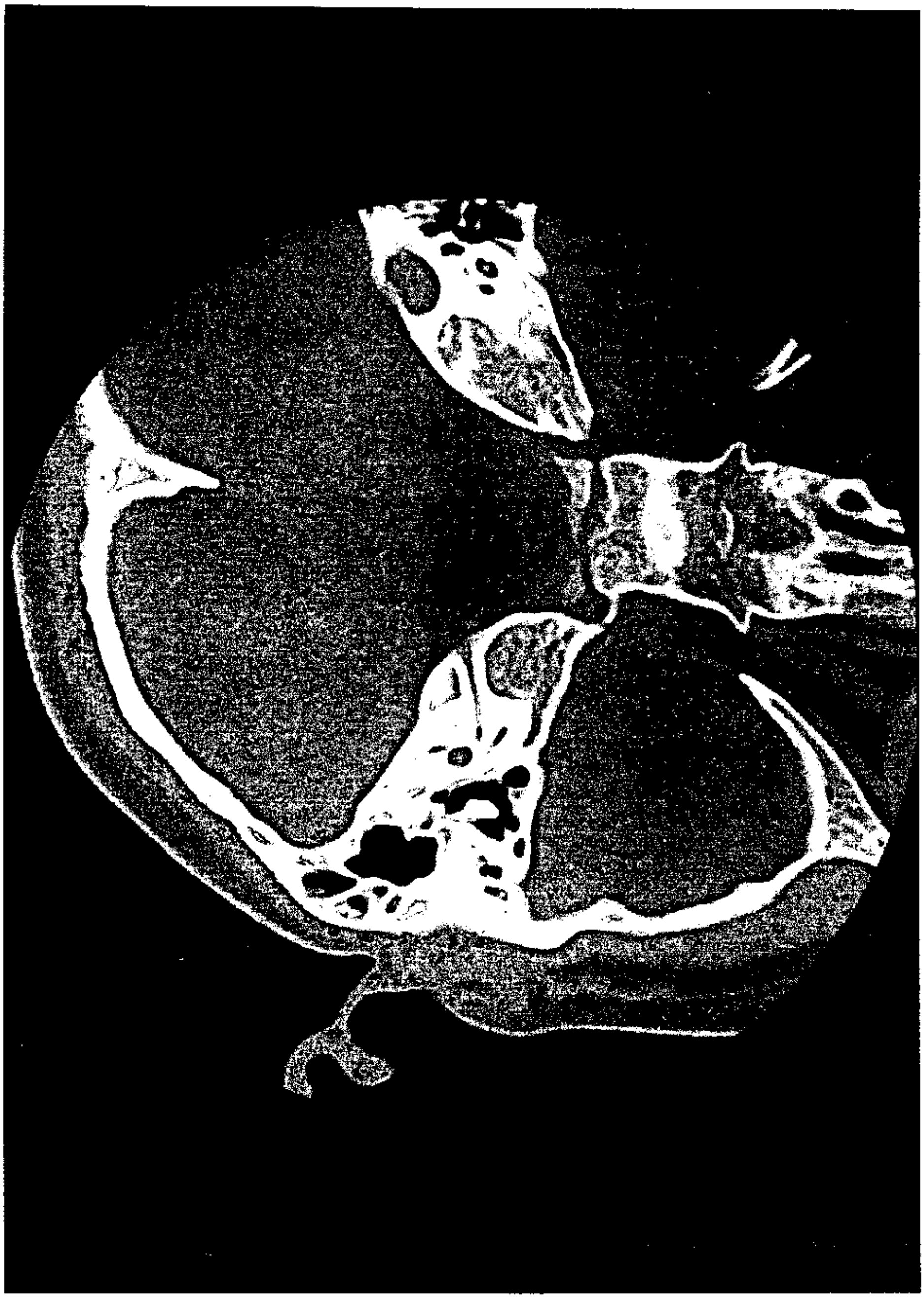

Fig.1

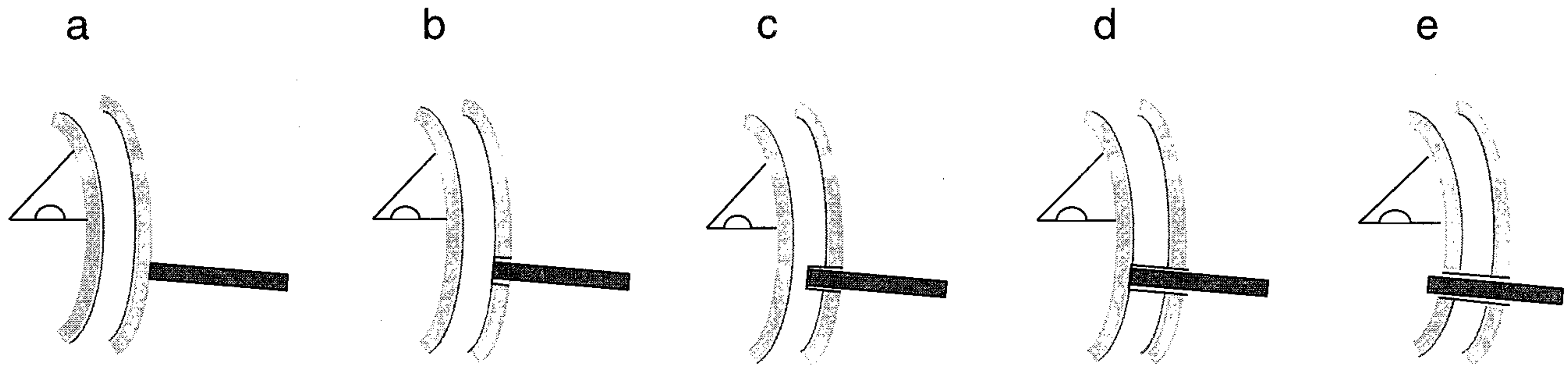

Fig.2

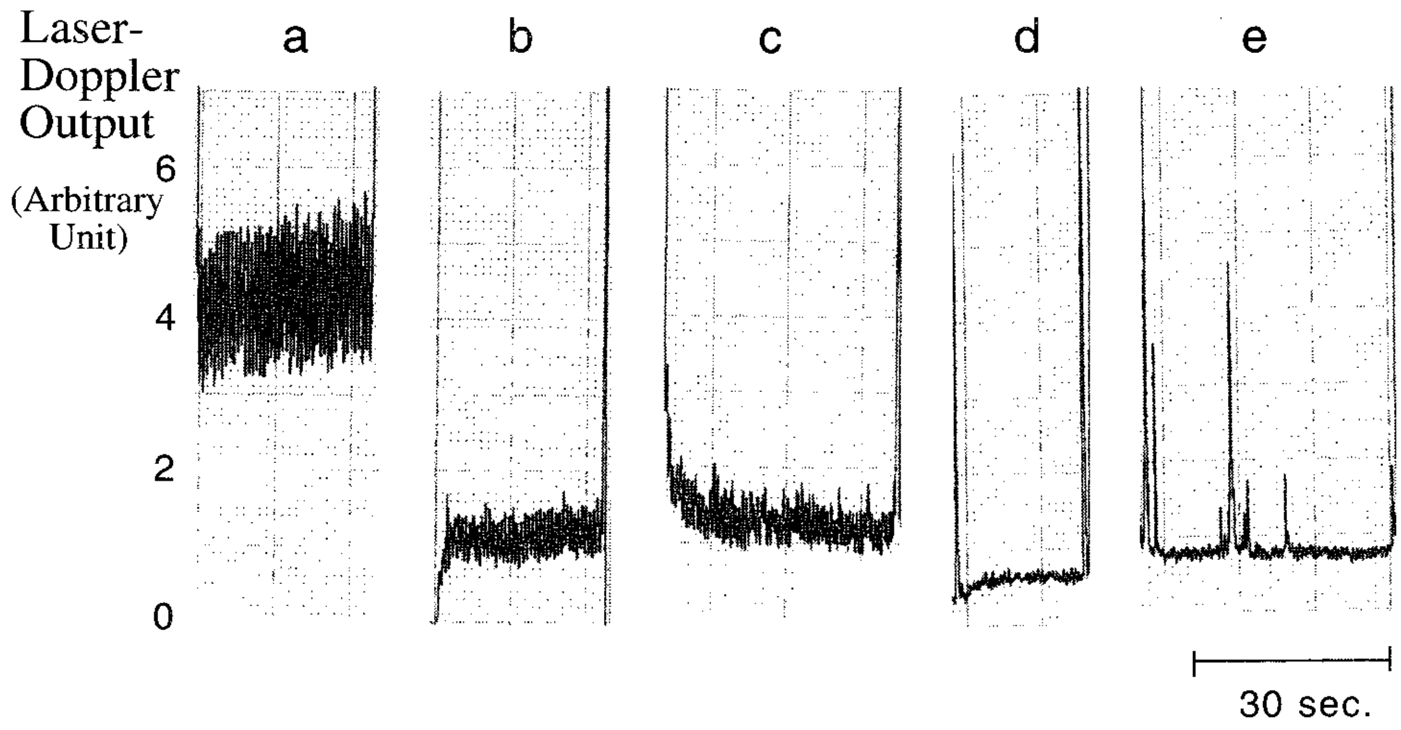

Fig.3

研究成果の刊行に関する一覧表

氏　名	題　名	雑　誌　名	年
Nakashima T, Hattori T Sone M Sato E Tominaga M	Blood flow measurements in the ears of patients receiving cochlear implants	Ann Otol Rhinol Laryngol	in press