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Microvascular Decompression for Tinnitus: Surgical Indication with Median Nerve Stimulation

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Abstract Microvascular decompression for tinnitus by neurovascular compression can improve tinnitus; however, surgical indications remain controversial. We report the results of an analysis of the symptoms of surgical patients who were categorized on the basis of modulation by the median nerve. We also analyzed changes in tinnitus intensity using the pitch-match loudness method in 35 patients with tinnitus. Three significant ($P < 0.001$) changes were observed with increases in the intensity on the median nerve: no change (N-type), suppression (S-type), and excitation (E-type). We evaluated 16 patients (16 sides) who underwent preoperative modulation tests and 10 patients (10 sides) who did not (F-type). Four patients who had S- or N-type tinnitus intensity (25%) had tinnitus-free sides; all had experienced tinnitus for 6 years or less and an improvement in tinnitus was observed in 8/16 sides (50%). Good results (the complete resolution of tinnitus or improvements in tinnitus without high-pitched tinnitus) were observed in 6/7 sides (86%) in S-type patients. More patients in the S-type group had good outcomes following median nerve stimulation than those in the other groups. We conclude that patients with S-type tinnitus for 6 years or less are good candidates for surgery and may show good indications.

Key words: eighth cranial nerve, median nerve stimulation, tinnitus, cochleovestibular neurovascular compression syndrome, microvascular decompression

Introduction

Some forms of tinnitus are intractable and cause sleep disturbances and intellectual function impairments. Numerous studies have examined the underlying pathological basis of tinnitus. Jannetta et al.[1,2] demonstrated that tinnitus attributable to cochleovestibular neurovascular compression syndrome (CNVC) could be relieved or improved by microvascular decompression (MVD). We previously reported that tinnitus with high- or low-pitched components or a combination of both is a characteristic of CNVC.[3] However, it is difficult to select patients who may have good surgical outcomes through surgery. Møller et al.[4] showed that median nerve stimulation can modulate tinnitus, which indicates a role for the extralemniscal auditory pathway.

We investigated changes in chronic tinnitus intensity in response to median nerve stimulation in patients with tinnitus attributable to CNVC, idiopathic tinnitus, midbrain infarction, or acoustic neuroma. Our results indicate that tinnitus can be modulated by median nerve stimulation and we discussed the surgical indications for tinnitus attributable to CNVC.

Materials and Methods

The study population was selected from 35 patients (40 sides) with tinnitus, who provided their complete medical histories and underwent physical examinations, routine neurological and otological examinations, and modulation tests using our modification of a previously reported method.[4] Otological examinations included the auditory brainstem response (ABR) test and constructive interference in steady state (CISS) magnetic resonance (MR) imaging. Some patients with idiopathic tinnitus appeared to have neurovascular contact on CISS MR imaging; however, the results of ABR ruled out CNVC. Surgery was performed on 16 patients who had undergone preoperative modulation tests (age range, 34-73 years; 6 women and 10 men) and on 10 patients (age range, 36-67 years; 5 women and 5 men) who did not (F-type). These patients were included in a consecutive series before the introduction of this test (Table 1). The process for the diagnosis of CNVC was included in the probable group from the examination and the definite group underwent surgery (Table 2).

Tinnitus modulation test by the median nerve

Patients underwent the modulation test while seated in a sound-insulated room. We used a Nicolet Viking IV stimulator (Nicolet Co., Madison, WI, USA) to deliver rectangular 0.2-ms electrical impulses through an electromyographic circular pad on the forearm to stimulate the median nerve. The stimulus rate was 1.0 Hz/s. Stimuli were applied in 1-mA steps, from 0 to- 10 mA. Patients who complained of forearm discomfort with an increase in the stimulus intensity were tested at a maximum of 9 mA. Several assessments were made at each step to ensure the response reliability of the response. The change in tinnitus intensity was assessed using the pitch-match loudness balance method with an audiometer (Type AA78; RION, Tokyo, Japan). Sounds were delivered to the ipsilateral ear in patients with normal to moderately decreased hearing and to the contralateral ear in patients with severe hearing loss. The change in tinnitus intensity on the affected side was evaluated by the stimulation of both the ipsilateral-and contralateral median nerves.

Table 1 Types of tinnitus modulation in 45 patients (50 sides)

Type (*n*)	Disease (n)	Surgical patient of CNVC (*n*)
S (14)	CNVC (14)	7
N (17)	Idiopathic tinnitus (8), CNVC (5), infarction (2), and acoustic neuroma (2)	2
E (9)	CNVC (9)	7
F* (10)	CNVC (10)	10

n, number of sides; CNVC, cochleovestibular neurovascular compression syndrome; * Patients who did not undergo the preoperative modulation test were considered to be F-type.

Table 2 CNVC and the diagnostic process*

Probable	Patients 11 (Sides 12); Men 7, Women 4 Age range, 35-72 years (mean, 61.1) Duration of tinnitus, 0.9-20 years (mean, 5.8)
Definite (Surgical)	Patients 25 (Sides 26); Men 15, Women 10 Age range, 30-73 years (mean, 48.3) Duration of tinnitus, 0.4-22 years (mean, 4.1)

CNVC, cochleovestibular neurovascular compression syndrome

The demographic characteristics and clinical features of notable patients are shown in Table 3. Case 1 (Suppression: S-type) had left-ear tinnitus (70 dBSL at 125 Hz) for 0.7 years with intermittent vertigo. The patient's ABR test showed a low amplitude and double-peaked left II wave. The results showed S-type modulation (suppression in intensity) by the left median nerve and no modulation (N-type) by the right median nerve (Fig. 1-A). The operative view is shown (Fig. 1-B). At the 1-month and 5-year postoperative follow-ups, the patient was completely relieved of tinnitus and vertigo, and ABR tests revealed that the waveform had normalized. Case 2 (N-type) had left-ear tinnitus (90 dBSL at 6000 Hz) for 1.3 years with left hemifacial spasm. The ABR test showed a low amplitude and waveform change in the left II wave. The test results showed no modulation (<5 dB) by the stimulation of either median nerves (Fig. 2-A). The operative view is shown (Fig. 2-B). At the 1-month and 5-year postoperative follow-ups, the patient was completely relieved of tinnitus and hemifacial spasm. ABR tests showed that the waveform had normalized. Case 3 (Excitation: E-type) had right-ear tinnitus (85-97 dBSL at 8000 Hz) for 22 years with hearing loss and left-ear tinnitus. The ABR test showed a low amplitude and double-peaked right II wave with an I-III interpeak latency delay. The right ear exhibited E-type modulation (excitation in intensity) at the initial testing and again 3 months later (Fig. 3-A). The operative view is shown (Fig. 3-B). One month after surgery, the postoperative to preoperative tinnitus intensity ratio was 0.6. At the 5-year postoperative follow-up, the patient had low-pitched right-ear tinnitus (72 dBSL), and the ABR had not normalized.

Results

Thirty-five patients (40 sides) with tinnitus underwent the modulation test (Table 1 and Fig. 4). Twenty-eight sides had CNVC, and MVD was performed in 16 patients. One E-type patient with recurrent tinnitus was operated on after the first MVD for F-type tinnitus. Another E-type patient with right-ear tinnitus was operated on after left-ear MVD for F-type tinnitus. Eight sides in 8 patients had idiopathic tinnitus (2 women, 6 men; age range, 35-75 years); one 64-year-old man with bilateral tinnitus had midbrain and thalamic infarctions; and 2 patients (1 woman and 1 man; 27 and 52 years old, respectively) had acoustic neuromas. The post-median nerve stimulation modulations in each patient were averaged to yield an individual mean response-type, with the value before stimulation set to zero (Fig. 4). Tinnitus showed the following 3 types of modulation

Table 3 CNVC, cochleovestibular neurovascular compression syndrome

Case No.	Age/Sex	Symptom	Tinnitus duration (years)	Type * Surgical finding	Outcome At 1 month	Outcome After 5 years
1	47/F	Left-ear tinnitus (70 dBSL at 125 Hz) and vertigo	0.7	S **	Ratio: 0	Free of tinnitus and vertigo, normal hearing, normalized ABR
2	73/M	Left-ear tinnitus (90 dBSL at 6000Hz) and HFS	1.3	N ***	Ratio: 0	Free of tinnitus and HFS, normal hearing, normalized ABR
3	65/F	Right-ear tinnitus (85-97 dBSL at 8000Hz) and left-ear tinnitus	22	E ****	Ratio: 0.6	Bilateral tinnitus, ABR: not normalized

Type*, type of modulation test: S, Suppression-type response; N, No modulation; E, Excitation-type response; **Fig.1-B; *** Fig.2-B; **** Fig.3-B; Ratio, postoperative to preoperative tinnitus intensity ratio; HFS, hemifacial spasm

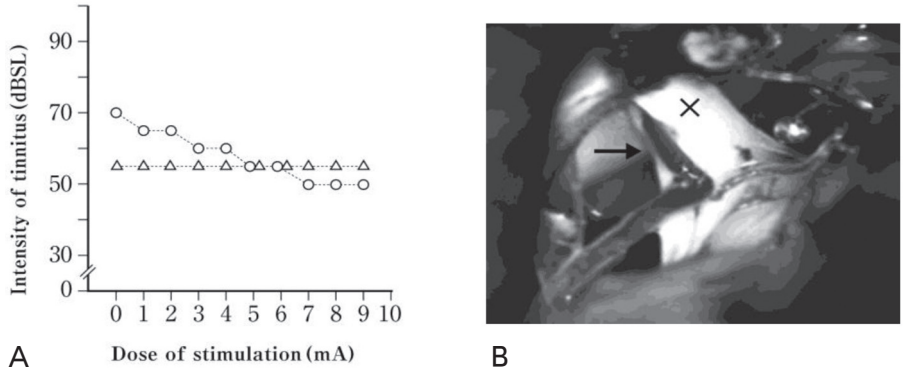

Fig. 1 A: Test results showing an S-type tinnitus response (125 Hz) in the left side (from 70 to 50 dBSL) with increasing stimulation intensity of the left median nerve (*circles*) and an N-type response with right median nerve stimulation (*triangles*). B: Operative view showing the anterior inferior cerebellar artery (AICA) (*arrow*) passing inside the VII-VIII nerves and compressing the VIII nerve (*cross mark*).

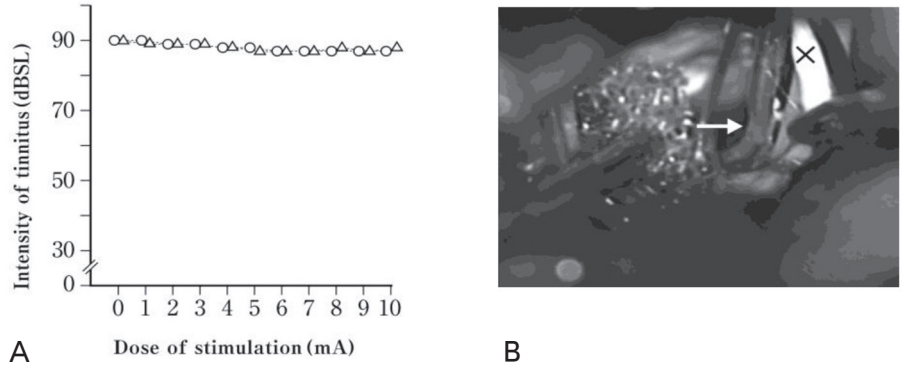

Fig. 2 A: Test results showing an N-type response of tinnitus (6000 Hz) from the left median nerve (*circles*) and right median nerve (*triangles*). B: Operative view showing the AICA (*arrow*) compressing the VIII nerve (*cross mark*).

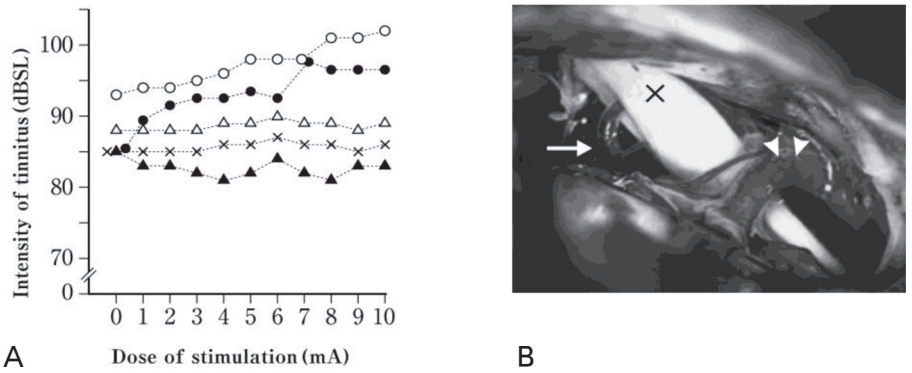

Fig. 3 A: Right-ear tinnitus (8000 Hz) with an E-type response following right median nerve stimulation (*open circles*), and a similar response from the right median nerve when the test was repeated 3 months later (*closed circles*). An N-type response from the left median nerve at the initial test (open triangles) and after 3 months (*cross marks*), and an N-type response of left-ear tinnitus (6000 Hz) from the left median nerve (*closed triangles*) were observed. B: Operative view showing the AICA (*arrowheads*) and small AICA (arrow) compressing the VIII nerve (*cross mark*).

in response to increasing intensity: (1) N-type (a change of less than 5 dBSL in tinnitus intensity with an increasing stimulation intensity from 0 to 9-10 mA, as tolerated), (2) E-type (an increase in tinnitus intensity of 5 dBSL or more in response to increasing intensity), or (3) an S-type (a decrease in tinnitus intensity of 5 dBSL or more in response to increasing intensity). All patients were grouped solely on the basis of these 3 modulation types (Fig. 4). The types of tinnitus and characteristics of CNVC are shown in Table 4.

Follow-up assessment

The tests were repeated during the follow-up period. Eight sides in 7 patients were studied repeatedly over 3-12 months, and no change in the classification type was observed. In 11 sides of the 16 patients who underwent surgery, tinnitus was preoperatively classified as S- or E-type. After surgery, 9 sides (82%) showed a postoperative change to the N-type.

Results of the modulation test and statistical analysis

Changes in tinnitus intensity (dB) during electrical stimulation of the median nerve from 0- to 9 mA on 40 sides and from 0 to 10 mA on 35 sides were recorded and are shown in Fig. 4. The dBSL value of tinnitus before the stimulation was set to zero on the Y-axis. The values ranged from 26 to 92.5 dBSL in the N-type group (mean = 71.5), from 33 to 86 dBSL in the S-type group (mean = 66.7), and from 49.5 to 93 dBSL in the E-type group (mean = 69.2). To compare the values of the 3 groups, the homogeneity of variance from 0 to 9 mA was assessed with an analysis of variance (ANOVA). The results showed a significant difference between the no-significant difference group for 17 sides, the significant negative difference group (a 5 dB or more decrease) in 14 sides, and the significant positive difference group in 9 sides (a 5 dB or more increase) ($P < 0.001$). Furthermore, Student's t tests revealed significant differences among the N-, S-, and E-types for each paired dose of stimulation from 2 to 9 mA ($P < 0.05$) (Fig. 4).

Surgical results with respect to the modulation type

The changes observed at the 1-month follow-up after surgery were as follows:
(1) Preoperative/postoperative tinnitus rates in the group with tinnitus for a short duration of less than 3 years (n=16) were 0-1.1 in the 5 S-type patients, 0.2-0.8 in the 3 E-type patients, 0 in the N-type patient, and 0-1.3 in the 7 F-type patients.

Table 4 Types of tinnitus and the characteristics of CNVC

Type*	Age/Sex	Tinnitus duration (yr)	High-low pitch of tinnitus	Tinnitus intensity	Hearing-loss	Symptoms except for tinnitus
S	44～69 yr mean: 60.0 yr M(4) / F(9)	0.5～10.0 yr mean: 3.3 yr	high (4) low (9)	over (2) under (11)	severe (6) normal～moderate (7)	vertigo (7) HFS (1)
E	35～75 yr mean: 56.1 yr M(8) / F(1)	0.5～15.0 yr mean: 7.4 yr	high (6) low (3)	over (5) under (4)	severe (3) normal～moderate (6)	vertigo (5)
N	51～73 yr mean: 63.0 yr M(5) / F(1)	2.0～13.0 yr mean: 7.0 yr	high (5) low (1)	over (5) under (1)	severe (5) normal～moderate (1)	vertigo (3) HFS (1)

Type*, type of modulation test: S, Suppression-type response; N, No modulation; E, Excitation-type response; M: male, F: female; high-pitch of tinnitus; 6000≤～≤8000 Hz, low-pitch of tinnitus; < 6000Hz, strength of tinnitus intensity; over= 60≤～≤100 dBSL; under= <60 dBSL, severity of hearing loss; severe = ≥25dB, *n*, number of sides; yr, years; HFS, hemifacial spasm

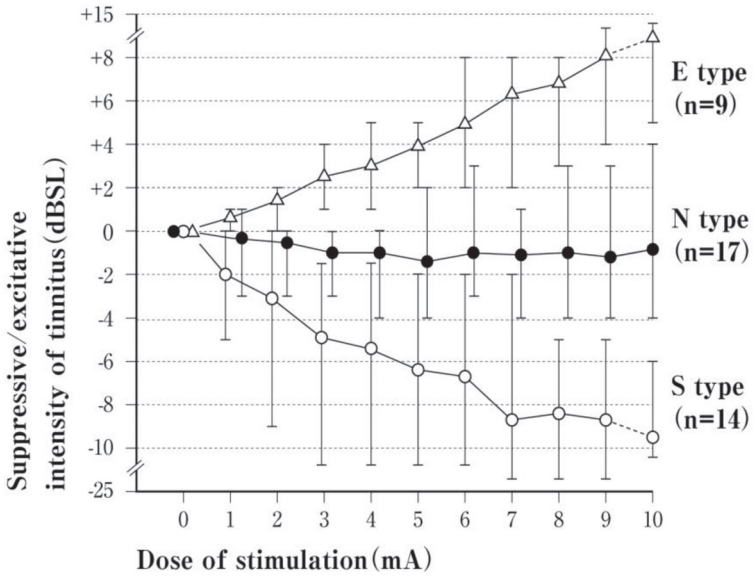

Fig. 4 Changes in tinnitus intensity and statistical analysis results.

Changes in tinnitus intensity (dB) during median nerve electrical stimulation from 0 to 9 mA on 40 sides and from 0 to 10 mA on 35 sides were recorded. The stimulation dose (mA) was plotted on the X-axis and the suppressive/excitative intensity of tinnitus (dBSL) was plotted on the Y-axis. The dB value of tinnitus before the stimulation was set to 0 on the Y-axis. Changes ranged from 26 to 92.5 dBSL in the N-type group (mean = 71.7), from 33 to 86 dBSL in the S-type group (mean = 66.7), and from 49.5 to 93 dBSL in the E-type group (mean = 69.2). Here, error bars mean the extent of actual value changes against the dBSL value before the stimulation. Indications of the range of changes in the tinnitus intensity (dB) were as follows: open triangles, closed circles, and open circles, corresponding to the mean values of tinnitus for the N-, S-, and E-type responses, respectively. The homogeneity of variance from 0 to 9 mA for the 3 groups was assessed using ANOVA, and a significant difference among the N-, S-, and E-types was observed ($P < 0.001$). Furthermore, the Student's t test indicated a significant difference among the N-, S-, and E-types with respect to each paired dose of stimulation from 2 to 9 mA ($P < 0.05$).

(2) In the group with tinnitus for 3-6 years (n=5), preoperative/postoperative tinnitus rates were 0-0.4 in the 2 S-type patients, 0.7 in the E-type patient, 0.5 in the N-type patient, and 0.6 in the F-type patient.
(3) In the group with tinnitus for more than 6 years (n=5), preoperative/postoperative tinnitus rates were 0.6-0.8 in the 3 E-type patients and 0.6-1.5 in the 2 F-type patients.

The results in patients with tinnitus for a short duration were more significant than those for patients with a longer duration of tinnitus (Mann-Whitney U test; $P < 0.001$) (Fig. 5).

The results at the 5-year follow-up were as follows:
(1) In the group with tinnitus for less than 3 years, the complete resolution of tinnitus (31%) was observed in 2 S-type patients, 1 N-type patient, and 2 F-type patients. Moreover, improvements (50%) were observed in 3 S-type patients, 1 E-type patient, and 4 F-type patients, but no changes (19%) were noted in 2 E-type patients and 1 F-type patient. Improvements without high-pitched tinnitus are shown in Fig.6.
(2) In the group with tinnitus for 3-6 years, the complete resolution of tinnitus (20%) was observed in 1 S-type patient. Improvements (60%) were observed in 1 S-type patient, 1 E-type patient, and 1 F-type patient. Unfortunately, a poor outcome (20%) was noted in 1 N-type patient; the individual with hemifacial spasm had severe postoperative hearing

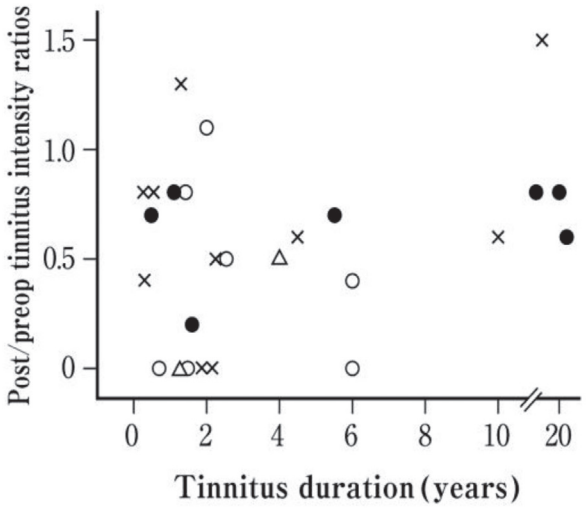

Fig. 5 One-month follow-up results. Postoperative to preoperative tinnitus intensity ratios are shown along with each type of tinnitus (N, S, E, and F) and tinnitus duration (years). Open circles, closed circles, open triangles, and cross marks correspond to the ratios of the S-, E-, N-, and F-type responses, respectively.

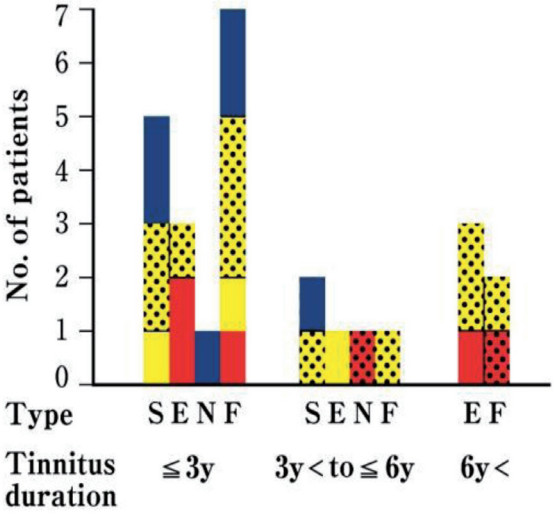

Fig. 6 Five-year follow-up results. Patients who showed complete resolution of tinnitus (*blue*), improvements (*yellow*), and no changes (*red*) are indicated, along with the tinnitus duration, within 3 years, 3-6 years, and over 6 years, respectively. The dotted yellow bars indicate patients who improved without high-pitched tinnitus (>4000 Hz), and the dotted red bars indicate those with worse results.

loss. Worse results were seen in 2 patients. (3) In the group with tinnitus for more than 6 years, improvements (60%) were observed in 2 E-type patients and 1 F-type patient (60%), and no or poor changes (40%) were noted in 1 E-type patient and 1 F-type patient (Fig. 6).

When the surgical results of 16 women and 10 men were evaluated after 5 years, 4 women and 2 men were completely tinnitus-free. With respect to surgical complications, none of the patients showed new postoperative neurological deficits, but 2 patients (7%) experienced marked changes in their hearing levels and severe hearing loss. In summary, the long-term follow-up showed good results (complete resolution or improvements without high-pitched tinnitus >4000 Hz) from 17 sides: 6/7 sides (86%) in S-type patients, 3/7 sides (43%) in E-type patients, 1/2 sides (50%) in N-type patients, and 7/10 sides (70%) in F-type patients. Conversely, good results in all sides were observed in 17/26 sides (65%). We also examined the relationship between a good result and surgical risk factors, including severe preoperative hearing loss of 25 dB or more and a compressing artery passing inside the VII-VIII nerves.3 In many S-type patients, neither hearing loss nor an artery passing inside the VII-VIII nerves precluded a good result.

Discussion

The following have been described as essential diagnostic bases of CNVC[1,2,3,8,9]: 1. Tinnitus is initially "mild" or "moderate" and "severe". It then occasionally fluctuates or progresses and combines with vertigo or hearing loss; however, the symptoms of some patients do not progress. 2. Severe tinnitus is combined with a marked interference on daily life including sleep. 3. Tinnitus associated with unilateral CNVC is not only unilateral, but also bilateral. 4. The typical findings of ABR initially are a low amplitude and waveform change in the II wave, followed by an I-III or 1-V interpeak latency delay. 5. We investigate vascular conflict in the eight cra-

nial nerve on MRI, and prefer CISS images. Among patients with tinnitus attributable to CNVC, the indications for surgery have been reported to be significant in patients with tinnitus for a short duration.[2,5,6] While we agree with this finding in principle, various factors[8,9] must be evaluated before a recommendation for surgery can be made. Møller et al.[4] showed that median nerve stimulation could modulate tinnitus. Here, we monitored 3 types of responses to tinnitus modulation. Møller et al. noted the possibility of a relationship between some types of tinnitus and the extralemniscal auditory pathway. However, other neural foci have been associated with the somatic modulation of tinnitus, and have been referred to as classical and nonclassical ascending auditory pathways, such as the thalamocortical system. The dorsal cochlear nucleus (DCN), inferior colliculus, and other structures in the brainstem are important for the activation of afferent central auditory nerves in the periphery.[7]

Clinical differences between S-, E-, and N-types are complex (Table 4). Differences in the mean levels of tinnitus duration were shorter in the S-type, and longer in the N-type and E-type, but these differences were not significant. As distressful factors, high pitch tinnitus and strong intensity tinnitus were combined in many patients in the N- and E- type groups. Postoperative changes have been described on some aspect. The 82% change from preoperative S- or E-type to N-type is very significant for the change in pathophysiology.

Tinnitus modulation by the median nerve and implications in experimental reports

Kanold et al.[10] reported the significance of the C2-3 and C7-8 cervical spinal nerves for understanding somatosensory modulation. When C1-8 nerves were electrically stimulated, response amplitudes were high in C2-3 and C7-8. In humans, C7 corresponds to the median nerve; therefore, this evidence supports the anatomical relationship between the median nerve and the DCN. Suppression could occur following slight damage to the cochlear second-order neurons rather than excitation in patients with severe damage due to vascular compression. However, this phenomenon is controversial because of the multiple functions of the DCN. Zhang et al.[11] performed an experimental study that examined the effects of somatosensory electrical stimulation on DCN activity with special temporal consideration and the strong clinical correlation of tinnitus. Moreover, they described that somatosensory electrical stimulation was induced in a slightly higher proportion and degree of suppressive, rather than excitatory, responses. However, these studies were based on animal models with short-term observation periods. Kaltenbach et al.[12] reported excitatory responses using tone exposure models with a long-term observation and suggested "inappropriate plastic changes". Although stimulation by tone exposure or acoustic trauma[13] with long-term observation has elements in common with stimulation by vascular compression of CNVC, CNVC pathology may involve various cochlear nerve functions. The "no response" is involved in idiopathic tinnitus, infarction, acoustic neuroma, and postoperative changes in CNVC. Experimental reports on the DCN may help us understand tinnitus modulation by the median nerve. Furthermore, the background of CNVC with the N-type response could be caused by the intermediate phase of focal nerve root demyelination; that is, tinnitus modulation by the median nerve may be involved in suppression or excitation responses in animal models[11,12,13].

Surgical indications for tinnitus attributable to CNVC

Our findings for CNVC indicate that differences between the 3 types of modulation are related to the duration of symptoms. The duration of tinnitus was significantly shorter in the S-type group than in the E-type group, and the surgical outcome in the former group was better than that in the latter. Four S- and N-type patients, but none of the E-type patients, experienced complete resolution. Although outcome grading[2,9] or the visual analog scale described by De Ridder et al.[14] may vary, we defined a good result as either the complete resolution of tinnitus or an improvement in tinnitus without high-pitched tinnitus. Patients commonly report significant relief with improvements in the

high-pitched component.

Next, we considered the surgical indications for tinnitus. One report described significant improvements in patients who had tinnitus for 4 years.[14] This study emphasized that decompression surgery did not influence tinnitus intensity in patients who had tinnitus for more than 4 years. Some reports[5,15] described significant improvements in a limited number of patients with tinnitus for longer durations, but the common clinical characteristics in these patients are undefined.

Thus, successful outcomes are expected in only a limited number of patients with prolonged tinnitus for more than 4 years if the patients are carefully selected for surgery. S-type presentation, ABR test results,[2,6] the size of the compressing artery on MRI,[9,16] and gender differences[2] should be considered during the selection of patients for surgery. S-type patients are expected to have favorable outcomes even if they have hearing loss or an artery passing inside the VII-VIII nerves.[3] Finally, the S-type response in the modulation test in patients with tinnitus for 6 years or less may contribute to a definite indication for surgery. However, an E-type response, even in patients with tinnitus for less than 3 years, may require the further evaluation of various factors before a recommendation for surgery can be made.

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Conflict of Interest

The authors state no conflict of interest.

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