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ORIGINAL
RESEARCH

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Severity Analysis of Neurovascular Contact in Patients with Trigeminal Neuralgia: Assessment with the Inner View of the 3D MR Cisternogram and Angiogram Fusion Imaging

BACKGROUND AND PURPOSE: Neurovascular contact (NVC) of the trigeminal nerve is not only detected at the affected trigeminal nerve in patients with trigeminal neuralgia (TN) but is also observed at the asymptomatic nerves on the side contralateral to the TN as well as in normal nerves in control subjects. The frequency and severity of the NVC among the affected, contralateral, and normal trigeminal nerves were analyzed by 3D MR cisternogram and angiogram fusion imaging in relation to the cause of TN.

MATERIALS AND METHODS: The inner view of the fusion MR imaging projected from inside the trigeminal nerve was used. The severity of the NVC was classified as none, simple, moderate, or severe, according to the nerve circumference in contact with the vessel. The NVC was analyzed in the affected nerves ($n = 66$) and the contralateral nerves ($n = 66$). Forty patients underwent microvascular decompression surgery, and 26 were treated medically. The NVC at the normal trigeminal nerves ($n = 78$) was studied in 39 control subjects without symptoms of TN.

RESULTS: The NVC in the affected trigeminal nerve was observed more frequently and much more severely than that at the contralateral and normal trigeminal nerves in controls ($P < .01$). Additionally, the NVC in the surgical patients was more severe than that in the medically treated patients ($P < .01$).

CONCLUSIONS: Severity analysis of the NVC with the inner view of the fusion MR imaging may provide useful information in the diagnosis of TN and can be a helpful adjunct in treatment planning for patients with TN.

Typical trigeminal neuralgia (TN) is characterized by a paroxysmal electric shocklike lancinating facial pain, and most instances are caused by neurovascular contact (NVC) at the root entry zone of the trigeminal nerve.^{1,2} Recent advances in MR imaging have provided us with fine volumetric data regarding the anatomic elements composing the NVC.³⁻¹² NVC is often detected on the affected side of TN (affected trigeminal nerve), though it is not infrequently observed in the asymptomatic nerve contralateral to the affected side (contralateral trigeminal nerve), as well as in the normal trigeminal nerve in a control subject without TN (normal trigeminal nerve).^{3,4,6} The significance of the MR imaging findings of the NVC has not been established, and it remains unclear whether the NVC is symptomatic and linked to cause TN or asymptomatic and observed incidentally.

We have developed a fusion imaging technique for 3D MR cisternography and angiography by compositing a 3D MR cisternogram and a coregistered 3D MR angiogram in a single 3D image.^{8,9} We have then applied this method to the direct visualization of NVC in patients with TN.⁹ In this study, we have newly reconstructed the inner view of the NVC; the 3D anatomic relationship between the offending vessel and the tri-

geminal nerve at the NVC was visualized from inside the rootlet of the trigeminal nerve at the brain stem and/or within the trigeminal nerve in the ambient cistern and projected posteroanteriorly along the course of the nerve axis toward the orifice of the Meckel cave. With the inner view of the fusion MR imaging, the severity of the NVC was morphologically classified as none, simple, moderate, or severe. The frequency and severity of the NVC among affected, contralateral, and normal trigeminal nerves were statistically analyzed. The usefulness of the severity analysis of the fusion MR imaging findings on the NVC in the diagnosis and treatment planning in patients with TN is discussed herein.

Materials and Methods

Patient Population and Clinical Data

A total of 66 patients (44 women, 22 men; age range, 34–87 years; mean, 63.9 years) with TN were included (Table 1). All patients were imaged by means of MR cisternography and MR angiography, and the NVC at the root entry zone of the trigeminal nerve was assessed in the affected nerves ($n = 66$) and contralateral nerves ($n = 66$). Forty patients underwent microvascular decompression (MVD) surgery via the retrosigmoid approach, and the remaining 26 patients were treated medically. For the control subjects, the NVC at the normal trigeminal nerves ($n = 78$) was studied in 39 subjects without symptoms of TN, who were examined for supratentorial lesions such as pituitary adenomas and unruptured small cerebral aneurysms.

Imaging Procedure

Imaging was performed with MR imaging scanners (either Signa Excite EchoSpeed 1.5T or Signa HiSpeed 1T; GE Healthcare, Milwaukee, Wis). MR cisternography was performed by using a T2-weighted 3D

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Table 1: Study population of neurovascular contact in patients with TN and healthy control subjects

Descriptor	TN	Healthy Controls
No. of Subjects	66	39
Age (yr) (mean $\pm$ SD)	63.9 $\pm$ 13.4	66.4 $\pm$ 12.6
Sex, % female (No.)	44 (67)	24 (62)
Symptom side (% right)	34 (52)	

Note:—TN indicates trigeminal neuralgia.

fast spin-echo sequence with the following parameters: TR/ TE, 4000/160 ms; NEX, 1; echo-train length, 128; bandwidth, 41.67–15.63 KHz; matrix, 256 $\times$ 256; section thickness, 0.6 mm; section interval, 0.6 mm; FOV, 16 cm; and total imaging time, 768–803 seconds. A total of 96 continuous axial source images were acquired. With the same scanning baseline, we performed MR angiography by using a 3D time-of-flight spoiled gradient-recalled sequence: TR/TE, 25–35/4.0–2.6 ms; NEX, 2; flip angle, 20°; matrix, 192 $\times$ 128; section thickness, 1.2 mm; section interval, 0.6 mm; FOV, 16 cm; without magnetization transfer contrast; zero-fill interpolation processing, 2 times; 120 sections in total (2 slabs); overlap of 8 sections; and total imaging time, 468–529 seconds. A total of 104 continuous axial source images were obtained.

Image Processing

Technical aspects of the 3D MR cisternogram and angiogram fusion imaging have been described previously.^{8,9} Briefly, volumetric data of MR cisternography and MR angiography were transferred to a workstation (Zio M900 or Ziostation; Ziosoft, Tokyo, Japan). The perspective views of the 3D MR cisternogram and 3D MR angiogram were independently reconstructed and then fused by compositing a 3D MR cisternogram and a coregistered 3D MR angiogram in a single 3D image. The overall time required to reconstruct the fusion image was 45–50 seconds per image after completion of MR imaging.

Similarity Study of the NVC between the Preoperative MR Images and Intraoperative Findings

In the 40 patients undergoing the MVD surgery, the anatomic relationship of the NVC, including the offending vessels, sites, and directions, was preoperatively analyzed by the fusion MR imaging. The offending vessels, sites, and directions of the NVC were observed from various perspectives within the ambient cistern. The virtual image of the preoperative simulation was compared with the intraoperative findings. The similarity of the NVC was assessed by the operative neurosurgeons with the surgical findings recorded on digital videotapes.

Severity Analysis of the MR Imaging Findings on the NVC with the Inner View of the 3D MR Cisternogram and Angiogram Fusion Imaging

With the inner view of the fusion MR imaging, the 3D anatomic relationship between the offending vessel and the trigeminal nerve at the NVC was projected along the axis of the trigeminal nerve running in the ambient cistern, from the rootlet of the nerve at the brain stem toward the orifice of the Meckel cave. The assessment of the severity of the NVC was based on the morphologic contact between the outer walls of the offending vessel and the trigeminal nerve. According to the extent of the nerve circumference in contact with the vessel, the severity of the NVC was determined and classified into 4 groups: severe, NVC with the vessel contacting the trigeminal nerve covering

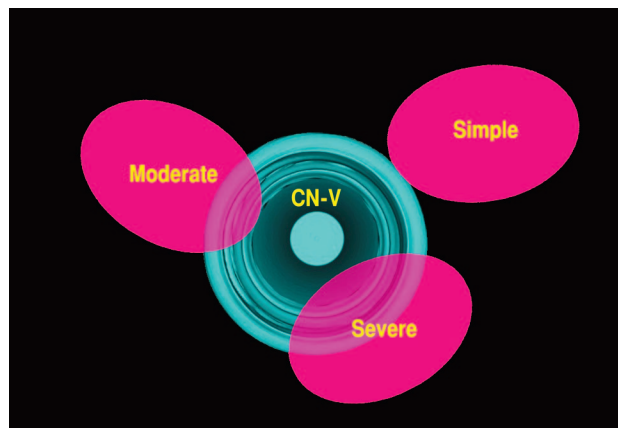


Fig 1. Schematic illustration of the severity analysis of the NVC. Severity of the NVC was determined by the extent of the nerve circumference in contact with the vessel and classified into 4 groups: severe, NVC with the vessel contacting the trigeminal nerve covering >20% of the nerve circumference; moderate, with <20% contact; simple, with slight touch; and none. CN-V indicates trigeminal nerve.

>20% of the nerve circumference; moderate, with <20% contact; simple, with slight touch; and none. A schematic illustration of the severity analysis of the NVC is shown in Fig 1. In cases showing multiple offending vessels and various sites in contact with the NVC, the severity was determined by the most severe degree of the NVC. The frequency and severity of the NVC among the affected, contralateral, and normal trigeminal nerves were statistically analyzed by using χ^2 and Mann-Whitney *U* tests, respectively. In addition, the severity of the NVC in 66 patients with TN was statistically analyzed between the surgical patients ($n = 40$) and those undergoing medical treatment ($n = 26$) by using the Mann-Whitney *U* test.

Results

In all cases, the 3D MR cisternogram depicted the fine anatomic elements composing the NVC at the root entry zone of the trigeminal nerve. The entire course of the trigeminal nerve was shown from the rootlet at the brain stem toward the orifice of the Meckel cave. The offending vessels were identified by tracing the arteries to the origin at the basilar and vertebral arteries and the tributaries of the superior petrosal vein to a larger vein and the superior petrosal sinus. Additionally, by using the fusion imaging of the 3D MR cisternogram and angiogram, we could discriminate the vascular components depicted on the 3D MR cisternogram from other anatomic structures, including the nerves, vessels, and parenchyma around the root entry zone of the trigeminal nerve by referencing the overlapped 3D MR angiogram through the boundary of the vascular structures shown as a series of clear rings.

Similarity Study of the NVC between the Preoperative MR Imaging and Intraoperative Findings

NVC was detected in 37 of the 40 patients (93%) undergoing MVD surgery on the basis of the preoperative surgical simulation images and surgery. The intraoperative findings disclosed a close similarity to the simulation in the anatomic relationship of the NVC. In the remaining 3 patients, the NVC was not observed in either the preoperative simulation images or the intraoperative findings. Consequently, in the 40 surgical patients, the preoperative MR images showed 100% correlation with the surgical findings regarding the presence or ab-

Table 2: Severity analysis of MR imaging findings on the neurovascular contact in the affected, contralateral, and normal trigeminal nerves

Nerve Category (No.)	Affected* ¹		Contralateral* ²	Normal* ³
Treatment (No.)	MVD (40)* ⁴	Medical (26)* ⁵	None (66)	None (78)
None, No. (%)	3 (8)	7 (27)	43 (65)	54 (69)
Simple, No. (%)	4 (10)	7 (27)	19 (29)	18 (23)
Moderate, No. (%)	13 (33)	7 (27)	4 (6)	6 (8)
Severe, No. (%)	20 (50)	5 (19)	0 (0)	0 (0)
NVC on image, No. (%)	56 (85)		23 (35)	24 (31)

Note:—NVC indicates neurovascular contact; MVD, microvascular decompression; *¹, affected trigeminal nerves in the symptomatic sides of the TN; *², contralateral trigeminal nerves on the sides contralateral to the symptomatic TN; *³, normal trigeminal nerves in the control subjects; MVD*⁴, microvascular decompression surgery; Medical *⁵, medical control.

sence of the NVC. Direct depiction and severity analysis of the NVC with the fusion imaging before the operation could provide useful information in surgical planning. Additionally, the correlation of the NVC between the 3D image sets and the intraoperative views as well as reviewing videotapes afterward confirmed the success of the MVD surgery.

Severity Analysis of the NVC with an Inner View of Fusion MR imaging

With the inner view of the 3D MR cisternogram and angiogram fusion imaging, the severity of the NVC was assessed in the affected and contralateral trigeminal nerves in patients with TN and in normal trigeminal nerves in the control subjects (Table 2). Differences in the age and sex distribution between patients with TN and healthy control subjects were not statistically significant ($P = .91$, χ^2 test). At the affected trigeminal nerves ($n = 66$), the NVC was detected in 56/68 patients (85%), and the severity of the NVC was none in 10 (15%), simple in 11 (17%), moderate in 20 (30%), and severe in 25 (38%). In the 40 surgical patients, NVC at the affected nerves was found in 37/40 patients (93%), and the severity of the NVC was none in 3 (8%), simple in 4 (10%), moderate in 13 (33%), and severe in 20 (50%). In medically treated patients ($n = 26$), NVC was detected in 19/26 patients (73%), and the degree of the NVC was none in 7 (27%), simple in 7 (27%), moderate in 7 (27%), and severe in 5 (19%). At the contralateral trigeminal nerves ($n = 66$), NVC was found in 23/66 patients (35%), and the degree of the NVC was none in 43 (65%), simple in 19 (29%), moderate in 4 (6%), and severe in none (0%). At the normal trigeminal nerves ($n = 78$) in 39 control subjects, NVC was detected in 24/78 patients (31%), and the degree of the NVC was none in 54 (69%), simple in 18 (23%), moderate in 6 (8%), and severe in none (0%).

Statistical analysis revealed that the affected trigeminal nerves in patients with TN showed the NVC more frequently and much more severely compared with that observed in the contralateral and normal trigeminal nerves ($P < .01$, χ^2 test; $P < .01$, Mann-Whitney U test, respectively). The frequency and severity of the NVC between the asymptomatic and normal trigeminal nerves were not different significantly ($P = 0.77$, χ^2 test; $P = .84$, Mann-Whitney U test, respectively). In addition, the degree of the NVC in the surgical patients with MVD was more severe than that in patients with medical treatment ($P < .01$, Mann-Whitney U test).

Illustrative Case

Severe NVC at the Affected Trigeminal Nerve. A 53-year-old woman underwent MVD surgery because of medically refractory left TN (territory of the mandibular branch) for 13

years and aggravation for the past 3 months. The minimum intensity projection (MinIP) image of the source MR cisternogram (Fig 2A), superoinferior projection, showed the 2 vessels crossing over the left trigeminal nerve in different directions. The preoperative simulation images of the 3D MR cisternogram and angiogram fusion imaging (Fig 2D, -E), projected left posterolaterally (the view-position box at the right corner and indicated by a red curved arrow in Fig 2A), depict the anatomic relationship of the NVC. The left transverse pontine vein, in the course from the medial aspect of the pons toward the superior petrosal sinus, compressed the left trigeminal nerve from the superomedial direction. The trunk of the left superior cerebellar artery (SCA), just before branching off the rostral and caudal tributaries, strongly pushed that vein. The preoperative simulation image disclosed that the offending vessels compressing the trigeminal nerve consisted of the transverse pontine vein directly and the trunk of the SCA indirectly.

The NVC was located at the mid-one-third portion of the intracisternal course of the nerve. An illustrative sketch of the simulation image is shown in Fig 2F. In the operative photograph before decompression of the NVC at MVD surgery (Fig 2B), the affected nerve is shown to be severely compressed by the offending vein directly and the artery indirectly and to be bent inferolaterally with an indentation. Intraoperative findings of the NVC were in agreement with the preoperative MR imaging findings of the simulation images (Fig 2D–F). After surgical decompression (Fig 2C), the NVC was resolved clearly by displacement of the complex of the offending vein and artery anterosuperiorly, and the affected trigeminal nerve restored the normal running course and pulsation. The patient recovered from TN immediately after surgery. The inner view of the fusion MR imaging (Fig 2G, -H), projected posteroanteriorly along the nerve axis, viewed from inside the rootlet of the nerve at the brain stem (the view-position box at the right corner and indicated by a yellow arrowhead in Fig 2A), depicted the 3D anatomic relationship of the NVC. The contour of the trigeminal nerve was in contact with the complex of the transverse pontine vein and the trunk of the SCA and was compressed and deformed from the superomedial direction. The circumference of trigeminal nerve was disrupted $>40\%$, and the severity of the NVC was assessed as severe. An illustrative sketch of the inner view is shown in Fig 2I.

Discussion

The TN frequently has posed a diagnostic dilemma due to the lack of a reference standard to detect the fine anatomic relationship of the offending vessel with the trigeminal nerve compressing the NVC.^{1,2} With recent advances in MR imaging and

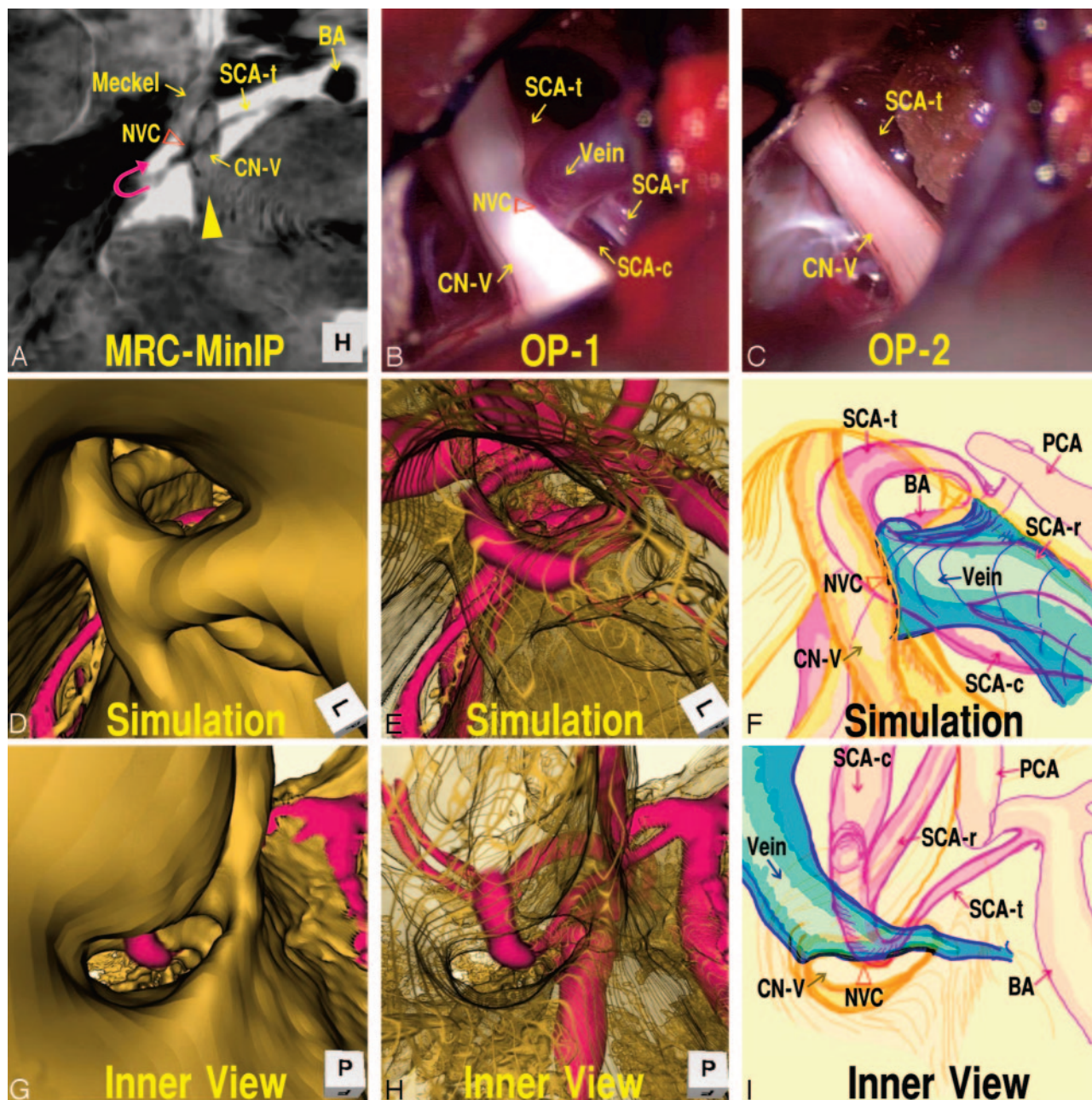


Fig 2. Severe NVC at the affected trigeminal nerve. *A*, MinIP image of the source MR cisternogram (MRC). *B*, Operative photograph (OP-1) before decompression of the NVC at MVD surgery. *C*, Operative photograph (OP-2) after surgical decompression. *D* and *E*, Preoperative simulation images of the 3D MR cisternogram and angiogram fusion imaging, projected left posterolaterally (the view-position box at the right corner and indicated by a red curved arrow in *A*). The offending transverse pontine vein compresses the trigeminal nerve directly and the trunk of the SCA indirectly. *F*, Illustrative sketch of the simulation images. *G* and *H*, Inner views of the fusion MR imaging, projected posteroanteriorly along the nerve axis, viewed from inside the rootlet of the nerve at the brain stem (the view-position box at the right corner and indicated by a yellow arrowhead in *A*), showing the 3D anatomic relationship of the NVC. The contour of the trigeminal nerve is severely compressed by the complex of the transverse pontine vein and the trunk of the SCA. *I*, Illustrative sketch of the inner view. CN-V indicates the trigeminal nerve; SCA-r, rostral branch of the superior cerebellar artery; SCA-c, caudal branch of the superior cerebellar artery; SCA-t, trunk of the superior cerebellar artery; PCA, posterior cerebral artery; BA, basilar artery.

image-reconstruction techniques, the existence of the NVC at the root entry zone of the affected trigeminal nerve in patients with TN is often detected, or at least suspected, with an incidence between 77%–100%.^{3–12} Symptomatic NVC is often found at the affected trigeminal nerve, but asymptomatic NVC is also detected at the contralateral and normal trigeminal nerves.^{3,4,6} Regarding the MR imaging findings of the NVC, it remains to be clarified whether the NVC by an artery or a vein at the trigeminal nerve root entry zone causes TN.

With the use of MR imaging in patients with TN, Anderson et al⁶ have reported detecting NVC in 42/48 patients (88%) at the affected trigeminal nerve; simple contact was found in 21 (44%) and moderate/severe contact in 21 (44%). In contrast, NVC was observed at the contralateral trigeminal nerve in 34/48 patients (71%), including simple contact in 26 (54%) and moderate/severe contact in 8 (17%). Majoie et al⁴ studied 13 patients with TN and 50 control subjects without symptoms of TN; severe NVC was detected in 10/13 (77%) at the

affected trigeminal nerves and in 8/113 (7%) at the contralateral and normal ones. Additionally, Erbay et al⁷ analyzed nerve atrophy in 31 cases of severe TN; the mean diameter and cross-sectional area of the affected trigeminal nerves were significantly smaller than the asymptomatic nerves on the contralateral sides. The above results indicate that innocent juxtaposition of the trigeminal nerve and vessels is infrequently found with MR imaging, but a trend toward greater compression severity of the NVC is more frequently found at the affected trigeminal nerve than at the contralateral and normal trigeminal nerves.

The severity of the NVC may relate to the degree of nerve compression produced by the offending vessels, and severe NVC may result in morphologic changes, including distortion, indentation, and atrophy of the trigeminal nerve.^{1,2,6,9,10,12} Axial source or multiplanar reconstruction images have been used to evaluate the severity of the NVC; however, the exact site of the NVC is unclear due to the difficulties in finding an imaging plane perfectly perpendicular to the course of the nerve in 2D fashion.³⁻⁷ We have developed the fusion imaging technique to depict the NVC by 3D image reconstruction^{8,9} and have applied it in patients with neurovascular compression syndrome, including those with hemifacial spasms, glossopharyngeal neuralgia, and TN. In the present study, we have newly reconstructed the inner view of fusion MR imaging to assess the fine morphologic change in the affected trigeminal nerve just at the site of the NVC; the anatomic relationship of the NVC is projected along the nerve axis from the rootlet toward the orifice of the Meckel cave. Because the NVC can be depicted directly from inside the affected trigeminal nerve, without interruption caused by the offending vessels compressing from outside, the inner view may be useful to standardize the assessment of the severity of the NVC in 3D fashion.

Our results indicate that the NVC was observed more frequently in the affected trigeminal nerves (85%, $P < .01$, χ^2 test) than in the contralateral and normal trigeminal nerves. Because the innocent juxtaposition of the trigeminal nerve and vessels was found in 31%–35% of patients, the presence of NVC itself did not appear to be the cause of TN. The severity of the NVC at the affected trigeminal nerve showed more severe compression than that at the contralateral and normal trigeminal nerves ($P < .01$, Mann-Whitney U test). Accordingly, when moderate-to-severe NVC was observed at the affected trigeminal nerve in patients with TN, the NVC may be a cause of TN. Although a simple NVC may not be sufficient to explain the cause of TN, any degree of NVC in the affected trigeminal nerve may cause TN.^{1-5,9} Additionally, the NVC in the patients who underwent surgery for TN was more severe than that in patients with medical treatment ($P < .01$, Mann-Whitney U test). Prediction of the severity of the NVC with an inner view of the fusion MR imaging does not mean that MVD surgery is necessary, but it may provide useful information in selecting patients who are insufficiently responsive to medical treatment and most likely to benefit from MVD surgery. Because a few patients with TN may not exhibit any evidence of

the offending vessels in either preoperative MR imaging or intraoperative findings but may show a morphologic change due to adhesive arachnoiditis of the affected trigeminal nerve,^{2,9,11,13} MR imaging findings of NVC alone do not necessarily establish it as a cause of TN.

Conclusions

Prediction and depiction of the severity of the NVC with the inner view of the fusion MR imaging may be useful in differentiating symptomatic from innocent NVC and can be a helpful adjunct in patient selection for treatment planning. For neurosurgeons, the actual visualization and prediction of the severity of the NVC with 3D image sets in patients with TN can provide not only valuable preoperative assessment for the success of MVD surgery but also postoperative educational comprehension by reviewing the operative videotapes. Due to the limited understanding of the pathophysiology of TN, more work is required to validate the imaging technique and to clarify the significance of MR imaging findings regarding the severity analysis of the NVC in patients with TN.

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