The Value of Three-Dimensional Brain Volume Combined with Time-of-Flight MRA in Microvascular Decompression

Jun Li^a Ying Wang^b Zhigang Lian^a Rongyao Liu^a Zhanhua Liang^b
Chunli Song^b Qingwei Song^c Zhenqing Wei^a

^aDepartment of Neurosurgery, First Affiliated Hospital of Dalian Medical University, Dalian, PR China;

^bDepartment of Neurology, First Affiliated Hospital of Dalian Medical University, Dalian, PR China;

^cDepartment of Radiology, First Affiliated Hospital of Dalian Medical University, Dalian, PR China

Keywords

Microvascular decompression · Magnetic resonance · Three-dimensional brain volume · Three-dimensional time of flight

Abstract

Objectives: To explore the guidance value of preoperative 3-dimensional brain volume (3D-BRAVO) and 3-dimensional time-of-flight (3D-TOF) MRA scanning for microvascular decompression. **Methods:** One hundred thirteen patients treated with microvascular decompression from February 2016 to February 2018 in the First Affiliated Hospital of Dalian Medical University were retrospectively analyzed. All patients received 3D-BRAVO combined with 3D-TOF MRA sequence reconstruction before the operation. The anatomical relationship of neurovascular tissues was analyzed and compared with the results of intraoperative exploration. **Results:** The results of MVD showed that the number of positive cases was 108 (95.6%) on the diseased side. 3D-BRAVO combined with 3D-TOF sequence reconstruction resulted in 106 positive cases (93.8%), with a 98.1% positive coincidence rate and a 13.2% false positive rate ($p < 0.05$). 3D-BRAVO-TOF sequence reconstruction of trigeminal neuralgia showed a

positive coincidence in 78 cases (92.8%) and for hemifacial spasm a positive coincidence was found in 27 cases (93.1%).

Conclusion: 3D-BRAVO combined with 3D-TOF sequence reconstruction before microvascular decompression can fully evaluate the morphology, location, and anatomical relationship of lesions, which is of guidance value for clinical diagnosis and treatment.

© 2019 S. Karger AG, Basel

Introduction

Microvascular decompression is an effective minimally invasive treatment for primary trigeminal neuralgia (TN) and hemifacial spasm (HFS) which allows patients to achieve long-term symptomatic relief with a low recurrence rate [1, 2]. The preoperative comprehensive evaluation of the responsible vessels determines the success or failure of the operation, which is of great significance to the operation effect. With the innovation and application

Zhenqing Wei
Department of Neurosurgery, First Affiliated Hospital of Dalian Medical University
222 Zhong Shan Rd.
Dalian 116011 (PR China)
E-Mail weizhqd@126.com

Qingwei Song
Department of Radiology, First Affiliated Hospital of Dalian Medical University
222 Zhong Shan Rd.
Dalian 116011 (PR China)
E-Mail songqw1964@163.com

Table 1. Surgical findings in 113 patients with MVD compared with 3D-BRAVO/TOF and 3D-T2/TOF/T1

Compression	MVD findings	3D-BRAVO/TOF			3D-T2/TOF/T1		
		SS		AS	SS		AS
		positive	negative		positive	negative	
Yes	108	106 (98.1)	2 (1.9)	9 (7.9)	104 (96.2)	4 (3.8)	7 (6.4)
No	5	5 (100)	0	104 (92.1)	4 (80)	1 (20)	104 (93.6)

Values are presented as numbers or numbers (%). SS, symptomatic side; AS, asymptomatic side.

Table 2. Surgical findings in 84 TN and HFS patients with MVD compared with 3D-BRAVO/TOF

Compression	MVD (TN)	TN			MVD (HFS)	HFS		
		SS (TN)		AS (TN)		SS (HFS)		AS (HFS)
		positive	negative			positive	negative	
Yes	80	78 (97.5)	1	7 (8.3)	28	27 (96.4)	1	2 (6.8)
No	4	4 (100)	0	77	1	1 (100)	0	27

Values are presented as numbers or numbers (%). SS, symptomatic side; AS, asymptomatic side.

of brain MRI hardware and software technology [3, 4], the problem that the relationship between blood vessels and neuroimaging in the cerebellopontine angle region is difficult to clearly display in the past is solved [5–8]. In this study, we retrospectively analyzed 113 patients who underwent microvascular decompression in the First Affiliated Hospital of Dalian Medical University from February 2016 to February 2018. All of the patients underwent MRI 3D-BRAVO combined with 3D-TOF (3D-BRAVO/TOF) sequence multiplanar reconstruction and 3D T2 high-resolution in combination with 3D TOF-MRA and 3D T1-gadolinium (3D-T2/TOF/T1) before the operation. The results were compared with intraoperative exploration results, and the prognosis was analyzed and reported as follows.

Materials and Methods

Patients

One hundred thirteen patients were analyzed retrospectively, including 84 patients with TN and 29 patients with HFS, and the average age was 60.5 years. There were 33 cases of right TN and 51 cases of left TN, i.e., there was a higher incidence on the left side than on the right side. Moreover, there were 10 cases of HFS on the right side and 19 cases on the left side. This study was approved by the institutional review board, and informed consent was obtained from all of the patients.

Methods

The cerebellopontine angle nerve was scanned by MRI before the operation, including 3D-BRAVO, a 3D-TOF sequence, 3D T2 (high-resolution), and 3D T1-gadolinium. Patients with a history of any prior surgery involving the trigeminal nerve and facial nerve were excluded. Prior to this study, all of the recruited patients signed an informed consent form. The blind method recommended by Yoshino was used to read the MRI scans; the blood vessels on the diseased side pressed the nerve to create deformation or indentation, and 2 or more planes showed that the nerve vessel contact was “positive.” No touch relationship between the nerve and blood vessels was found to be “negative” at more than 2 azimuthal levels. The positive relationship between nondiseased-side blood vessels and the nerve is a “false positive.” Results were compared with the intraoperative exploration of responsible vessels, and the prognosis of the patients was also observed.

Equipment

A GE Signa HDx 3.0T magnetic resonance scanner (USA) was used. The 3D-BRAVO parameters were: TE: 3.0 ms, TR: 8.0 ms, echo train: 1 ms, and T1 reversal angle: 12°. The 3D-TOF sequence parameters were: TE: 2.8 ms, TR: 19 ms, and echo train: 1 ms. The fast imaging employment state acquisition (FIESTA) sequence parameters were: TE: 1.8~2.2 ms, TR: 4.7~5.2 ms, and echo train: 1 ms. GE 4.6 Workstation and General Registration BW software were used for sequence image fusion. The T1-weighted images had: a field of view of 230–230 mm, a matrix of 256, and a sectional thickness of 3 mm with a 1-mm intersection gap. The T2 images had: a field of view of 230 × 230 mm, a matrix of 512, and a 34-mm slab thickness.

Fig. 1. 3D-BRAVO combined with 3D-TOF sequence reconstruction and intraoperative exploration. **a** The arrows indicate the SCA responsible for compression of the right trigeminal nerve. **b** The arrows indicate the SCA responsible for compression of the left trigeminal nerve.

Operative Technique and Effect

The operation was performed via a suboccipital-retrosigmoid approach, and the CPA area was fully exposed under a bone window of 2×2 cm. During the operation, the surgeon carefully identified the compressed nerves and the responsible vessels and put a Teflon pad between them with no looseness compared to preoperative MRI image data. The field image data were collected during the whole operation. Criteria for efficacy were: cure (asymptomatic), markedly effective (symptom relief more than 90%), effective (at least 50% symptom relief); and invalid (below 50% symptom relief).

Results

After 3D-BRAVO combined with 3D-TOF sequence reconstruction, the 3D images of the trigeminal/facial nerve of the cerebellopontine angle region and periph-

eral blood vessels could be observed directly from different angles, and the anatomical relationship between blood vessels and the nerve position could be analyzed. Among the 113 patients, the results of 3D-BRAVO combined with 3D-TOF sequence reconstruction demonstrated that the number of patients with nerves compressed by diseased-side vessels was 106 (positive rate: 93.8%) and for the asymptomatic side the number was 9 (false positive rate: 7.9%), with 98.1% (106/108) sensitivity and 100% (5/5) specificity. Moreover, the results of 3D-T2 high-resolution in combination with 3D TOF-MRA and 3D T1 sequence reconstruction showed that the number of patients with nerves compressed by diseased-side vessels was 104 (positive rate: 92.0%) and for the asymptomatic side the number was 7 (false positive rate: 6.1%), with 96.2% (104/108) sensitivity and 80%

Fig. 2. 3D-BRAVO combined with 3D-TOF sequence reconstruction and intraoperative exploration. The arrows indicate the AICA responsible for compression of the left facial nerve (FN).

(4/5) specificity. The results of intraoperative exploration showed a positive result in 108 (95.6%) patients and a negative result in 5 (4.4%) (Table 1). Among 84 TN patients, the results of 3D-BRAVO/TOF sequence reconstruction showed that the number of patients with nerves compressed by symptomatic-side vessels was 78 (positive rate: 92.8%) and for the asymptomatic side the number was 7 (false positive rate: 8.3%), with 97.5% (78/80) sensitivity. In addition, among 29 HFS patients, the positive result rate was 92.8% (27/29) and the false-positive rate was 6.8% (2/29), with 96.4% (27/28) sensitivity (Table 2). In these responsible vessels, 54 cases (47.8%) involved the superior cerebellar artery (SCA) (Fig. 1a), 37 cases (32.7%) involved the anterior inferior cerebellar artery (AICA) (Fig. 2), 6 cases (5.3%) involved the posterior inferior cerebellar artery, 8 cases (7.1%) involved the basal artery, 3 cases (2.7%) involved venous compression, and 5 cases (4.4%) involved combined compression (Fig. 3).

Postoperative efficacy results showed that 101 cases (89.4%) were cured, in 107 cases (94.7%) the procedure was markedly effective, in 112 cases (99.1%) it was effective, and in 1 case (0.9%) it was invalid. Postoperative complications i.e., intracranial infection, occurred in 6 (5.3%) patients aged 70 years or older; no other complications occurred.

Discussion/Conclusion

The most common cause of TN and HFS is vascular compression in the CPA region. During microvascular decompression, it was found that the vessels responsible

for compression of the trigeminal nerve were the SCA, the AICA, the posterior inferior cerebellar artery, the verte-brobasilar artery, the bridging vein, and other minor arteries [9], while the vessels responsible for compression of the facial nerve were the inferior cerebellar artery, the internal auditory artery, the SCA, the vertebral artery, and the pontine perforator artery [10]. The results of this study are consistent with previous literature. Many researches have proven that MRI sequences can assist neurosurgeons in predicting the anatomical space structure of nerve vessels prior to the surgery and to develop a surgical plan, increasing the probability of the surgeon finding the responsible vessels and of a successful MVD operation, and it even reduces postoperative complications because of the short operation time and the small side injury [11–14]. A study by Leal et al. [7] showed that 3D-T2/TOF/T1 images before MVD coincided with the surgical findings. The 3D-T2/TOF/T1 sequence reconstruction in this study showed that the number of patients with nerves compressed by diseased-side vessels was 104 (positive rate: 92.0%) and for the asymptomatic side the number was 7 (false-positive rate: 6.1%), with 96.2% (104/108) sensitivity and 80% (4/5) specificity. However, the results of the 3D-BRAVO/TOF sequence demonstrated that the number of patients with nerves compressed by diseased-side vessels was 106 (positive rate: 93.8%) and for the asymptomatic side the number was 9 (false-positive rate: 7.9%), with 98.1% (106/108) sensitivity and 100% (5/5) specificity, indicating that 3D-BRAVO/TOF sequence reconstruction before MVD also had a certain clinical value.

There are few recent reports on 3D-BRAVO combined with 3D-TOF sequence reconstruction technology. In

Fig. 3. 3D-BRAVO combined with 3D-TOF sequence reconstruction and combined compression. The black arrows indicate the small artery (A) responsible for compression of the right trigeminal nerve (T). The white arrows indicate the small vein (V) responsible for compression of the right trigeminal nerve.

this study, among 84 TN patients, the results of 3D-BRAVO/TOF sequence reconstruction showed that the number of patients with nerves compressed by symptomatic-side vessels was 78 (positive rate: 92.8%) and for the asymptomatic side the number was 7 (false-positive rate: 8.3%), with 97.5% (78/80) sensitivity; among 29 HFS patients, the positive rate was 92.8% (27/29) and the false positive rate was 6.8% (2/29), with 96.4% (27/28) sensitivity. Thus, regardless of whether TN or HFS is present, 3D-BRAVO/TOF sequence reconstruction before MVD in the study is in a good agreement with the results of intraoperative exploration. Use of a 3D-BRAVO sequence for the display of neural tissue (including gray matter, etc.) has an absolute advantage; it is clearer and more detailed than other MRI sequences, and the blood vessels will be significantly enhanced [15]. In addition, the 3D-TOF sequence is irreplaceable in vascular imaging, especially of microarteriovenous tissues, and it can be clearly displayed by GD-DTPA in T1WI-weighted images [16, 17]. Therefore, 3D-BRAVO combined with 3D-TOF sequence reconstruction in showing the anatomical relationship between nerve tissue and microarteriovenous tissue has a high significance.

The most common cause of TN and HFS is vascular compression in the CPA region, so microvascular decompression is an effective treatment, but there are still some patients without significant vascular compression [9, 18, 19]. Therefore, a preoperative correct evaluation of the anatomical relationship between the nerve and the compressed blood vessels is a key factor in the decision of whether to perform microvascular decompression or not.

At present, 3D-FIESTA combined with 3D-TOF sequence reconstruction is commonly used to determine the vascular compression before the operation, and it has some guidance value for determination of the origin, course, and anatomical relationship of the responsible vessels with the rapid development of high-resolution 3D imaging and fusion platform [20, 21]. However, it could not fully guide the clinician's treatment. The causes were analyzed as follows: first, the peripheral nerve vessels were complicated and could not be identified; second, MRI resolutions of medium and low field strength are low; and third, the 3D-FIESTA sequence overlapped with the tiny responsible vessels of adjacent nerves because of sensitivity to fat and water. In addition, some studies have shown that structural neuroimaging evidence could support peripheral theories of TN etiology and pathophysiology and structural MRI methods offer a valuable means to noninvasively examine the trigeminal system [11, 22]. In this study, 3D-BRAVO combined with 3D-TOF sequence reconstruction had a high coincidence rate with intraoperative exploration. The reasons included: first, the compression relationship of the CPA nerve and adjacent vessels could be evaluated objectively and accurately, including complex minute arteriovenous tissue (Fig. 1b, 3); second, the 3D images could be reconstructed in any orientation and displayed clearly and delicately; third, 3D vascular imaging and parenchyma imaging were taken into account simultaneously; and fourth, overlapping of microvascular signals with tissue signals such as cerebrospinal fluid and fat having an influence on the judgment of the anatomical relationship was avoided.

Previous studies have shown that the responsible vessels were not found in some patients with trigeminal and HFS, and microvascular decompression was not effective for all such patients, with symptoms even recurring [23]. So, we must accurately assess the anatomic relationship between the symptomatic lateral nerves and their surrounding vascular tissue and fully understand the patients' history before performing microvascular decompression, especially combined with clinical practice, and then predict the postoperative effect. 3D-BRAVO sequence technology can be used to analyze the brain structure comprehensively and accurately, and it has been increasingly applied in the study of living brain histomorphology [24]. In addition, a 3D-BRAVO sequence could be performed to analyze brain gray and white matter lesions and corresponding anatomical structure differences [25, 26]. Among patients with TN, Li et al. [27] found that the volume of the right insula, the right prefrontal lobe, the bilateral anterior cerebellum, and the right putamen increased with the BRAVO sequence [27]. These results reveal that not all TN can be explained by compression of the responsible vessels. Therefore, 3D-BRAVO combined with 3D-TOF sequence reconstruction is very useful in the diagnosis and treatment of patients with nonresponsible vascular compression TN.

In conclusion, the reconstruction of different special MRI sequences assists neurosurgeons in predicting the anatomical space structure of nerve vessels prior to surgery and to develop a surgical plan, increasing the probability of the surgeon finding the responsible vessels and of a successful MVD operation; it even reduces postoperative complications because of the short operation time and small side injury. 3D-BRAVO combined with 3D-TOF sequence reconstruction technology can improve

the clarity and recognition of neurovascular tissue, just like the economic and rapid 3D printing technology, which can be used to understand the size, morphology, location, and anatomical relationship of the lesion in detail. At the same time, it is helpful for the diagnosis and treatment of atypical TN. With the development of MRI and software postprocessing techniques, we believe that preoperative assessment will be fully consistent with intraoperative findings.

Statement of Ethics

All of the procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments.

Disclosure Statement

The authors have no conflict of interests to declare.

Funding Sources

No funding was received for this study.

Author Contributions

Z.W., J.L., and Q.S. conceived and designed this study. C.S. and Z.L. operated the electrophysiological monitor. Q.S. and Y.W. provided material and collected the clinical data. J.L. and Y.W. analyzed the data. J.L. was involved in writing this paper. All of the authors gave their final approval for submission of this paper for publication.

References

- 1 Wu M, Fu X, Ji Y, Ding W, Deng D, Wang Y, et al. Microvascular decompression for classical trigeminal neuralgia caused by venous compression: novel anatomical classifications and surgical strategy. *World Neurosurg.* 2018;113:707–13.
- 2 Sindou M, Howeydi T, Acevedo G. Anatomical observations during microvascular decompression for idiopathic trigeminal neuralgia (with correlations between topography of pain and site of the neurovascular conflict). Prospective study in a series of 579 patients. *Acta Neurochir (Wien).* 2002 Jan;144(1):1–12.
- 3 Oster J, Clifford GD. Acquisition of electrocardiogram signals during magnetic resonance imaging. *Physiol Meas.* 2017 Jun;38(7):R119–42.
- 4 Thompson PM, Sowell ER, Gogtay N, Giedd JN, Vidal CN, Hayashi KM, et al. Structural MRI and brain development. *Int Rev Neurobiol.* 2005;67:285–323.
- 5 Ruiz-Juretschke F, Gonzalez-Quarante LH, Garcia-Leal R, Martinez de Vega V. *Neurovascular relations of the trigeminal nerve in asymptomatic individuals studied with high-resolution three-dimensional magnetic resonance imaging.* Anat Rec (Hoboken). 2019 Apr;302(4):639–45.
- 6 Leal PR. Fraction of anisotropy and apparent diffusion coefficient as diagnostic tools in trigeminal neuralgia. *Acta Neurochir (Wien).* 2019 Feb. <https://doi.org/10.1007/s00701-019-03852-1>.
- 7 Leal PR, Hermier M, Froment JC, Souza MA, Cristino-Filho G, Sindou M. Preoperative demonstration of the neurovascular compression characteristics with special emphasis on the degree of compression, using high-resolution magnetic resonance imaging: a prospective study, with comparison to surgical findings, in 100 consecutive patients who underwent microvascular decompression for trigeminal neuralgia. *Acta Neurochir (Wien).* 2010 May;152(5):817–25.

- 8 Leal PR, Froment JC, Sindou M. [Predictive value of MRI for detecting and characterizing vascular compression in cranial nerve hyperactivity syndromes (trigeminal and facial nerves)]. *Neurochirurgie*. 2009 Apr;55(2): 174–80.
- 9 Patel SK, Liu JK. Overview and History of Trigeminal Neuralgia. *Neurosurg Clin N Am*. 2016 Jul;27(3):265–76.
- 10 Ghali MG, Srinivasan VM, Viswanathan A. Microvascular Decompression for Hemifacial Spasm. *Int Ophthalmol Clin*. 2018;58(1): 111–21.
- 11 DeSouza DD, Hodaie M, Davis KD. Structural magnetic resonance imaging can identify trigeminal system abnormalities in classical trigeminal neuralgia. *Front Neuroanat*. 2016 Oct;10:95.
- 12 DeSouza DD, Hodaie M, Davis KD. Diffusion imaging in trigeminal neuralgia reveals abnormal trigeminal nerve and brain white matter. *Pain*. 2014 Sep;155(9):1905–6.
- 13 Hodaie M, Coello AF. Advances in the management of trigeminal neuralgia. *J Neurosurg Sci*. 2013 Mar;57(1):13–21.
- 14 Hitchon PW, Zanaty M, Moritani T, Uc E, Pieper CL, He W, et al. Microvascular decompression and MRI findings in trigeminal neuralgia and hemifacial spasm: a single center experience. *Clin Neurol Neurosurg*. 2015 Dec;139:216–20.
- 15 Davis KD, Moayedi M: Central mechanisms of pain revealed through functional and structural MRI. *J Neuroimmune Pharmacol*. 2013; 8:518–34.
- 16 Binyamin TR, Dahlin BC, Waldau B: Comparison of 3D TOF MR angiographic accuracy in predicting Raymond grade of flow-diverted versus coiled intracranial aneurysms. *J Clin Neurosci*. 2017;42:182–5.
- 17 Lin Z, Guo Z, Qiu L, Yang W, Lin M: The applied research of MRI with ASSET-EPI-FLAIR combined with 3D TOF MRA sequences in the assessment of patients with acute cerebral infarction. *Acta Radiol*. 2016; 57:1515–23.
- 18 Chen GQ, Wang XS, Wang L, Zheng JP: Arterial compression of nerve is the primary cause of trigeminal neuralgia. *Neurol Sci*. 2014;35: 61–6.
- 19 Campero A, Herreros IC, Barrenechea I, Andjel G, Ajler P, Rhoton A. [Microvascular decompression in hemifacial spasm: 13 cases report and review of the literature]. *Surg Neurol Int*. 2016 Apr;7(9 Suppl 8):S201–7.
- 20 Docampo J, Gonzalez N, Muñoz A, Bravo F, Sarroca D, Morales C. Neurovascular study of the trigeminal nerve at 3t MRI. *Neuroradiol J*. 2015 Feb;28(1):28–35.
- 21 Wu GQ, Wang L, Yin WN, Liu XM, Li CF, Wu GH. [Guiding values of facial nerve 3D-TOF-MRA and 3D-FIESTA scan for primary hemifacial spasm operation]. *Zhonghua Yi Xue Za Zhi*. 2013 Dec;93(45):3614–6.
- 22 Leal PR, Roch JA, Hermier M, Souza MA, Cristino-Filho G, Sindou M. Structural abnormalities of the trigeminal root revealed by diffusion tensor imaging in patients with trigeminal neuralgia caused by neurovascular compression: a prospective, double-blind, controlled study. *Pain*. 2011 Oct;152(10): 2357–64.
- 23 Leidinger A, Munoz-Hernandez F, Molet-Teixido J: Absence of neurovascular conflict during microvascular decompression while treating essential trigeminal neuralgia. How to proceed? Systematic review of literature. *Neurocirugia (Astur)*. 2018;29(3):131–7.
- 24 Kashou NH, Smith MA, Roberts CJ. Ameliorating slice gaps in multislice magnetic resonance images: an interpolation scheme. *Int J CARS*. 2015 Jan;10(1):19–33.
- 25 Obermann M, Rodriguez-Raecke R, Naegel S, Holle D, Mueller D, Yoon MS, et al. Gray matter volume reduction reflects chronic pain in trigeminal neuralgia. *Neuroimage*. 2013 Jul; 74:352–8.
- 26 Rodriguez-Raecke R, Niemeier A, Ihle K, Ruether W, May A. Brain gray matter decrease in chronic pain is the consequence and not the cause of pain. *J Neurosci*. 2009 Nov; 29(44):13746–50.
- 27 Li QY, Zhang SX, Heng PA, Liu ZJ, Lin ZF, Tan LW, Xie YM: Segmentation and three-dimension reconstruction of Chinese digitized human cerebrum. *Comput Med Imaging Graph*. 2006;30:89–94.