Preoperative visualization of neurovascular contact with 3D-FIESTA combined with 3D-TOF MRA to guide microvascular decompression surgery planning

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Preoperative visualization of neurovascular contact with 3D-FIESTA combined with 3D-TOF MRA to guide microvascular decompression surgery planning

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ABSTRACT
Background: Neurovascular compression syndromes including trigeminal neuralgia (TN) and hemifacial spasm (HFS) are caused by neurovascular conflicts at the root entry zone of the corresponding cranial nerves in the posterior fossa. Microvascular decompression (MVD) is the best choice for the treatment of TN and HFS. An accurate delineation of the responsible vessel could decrease the rate of possible operative complications such as nerve paresis.

Methods: In this study, three-dimensional fast imaging employing steady-state acquisition (3D-FIESTA) and three-dimensional time-of-flight magnetic resonance angiography (3D-TOF MRA) were performed on 113 patients with TN or HFS. The imaging data were compared to the intraoperative findings and the accuracy of the data was calculated among the different responsible blood vessels and disease types. The accuracy of the data among different genders, disease durations, disease sides, and disease types was also calculated to identify the target patients for the preoperative diagnostic approach with 3D-FIESTA combined with 3D-TOF MRA.

Results: The accuracy of detection with the imaging was above 75% in cases with single-vessel compression. Among these, the accuracy of the preoperative imaging result was the highest when the lesions were in the superior cerebellar artery (SCA; 91.1%). In cases of multiple-vessel compression, however, the coincidence between the preoperative and intraoperative results was only 30.0%. In most of the cases of TN, the responsible blood vessels were in the SCA, and the accuracy in the SCA reached 94.9%. In HFS patients, the responsible blood vessels were in the anterior inferior cerebellar artery (AICA) and posterior inferior cerebellar artery (PICA), and the accuracy was 86.8% and 90.0%, respectively. The differences in the accuracy of the data among different genders, disease durations, disease sides, and disease types were not statistically significant.

Conclusion: This study verified the clinical instructional value of 3D-FIESTA combined with 3D-TOF MRA in MVD, and showed that this preoperative examination is reliable for all genders, disease durations, disease sides, and disease types.
1 Introduction

Neurovascular compression syndromes are caused by pathological neurovascular conflicts at the root entry zone (REZ) of the corresponding cranial nerves in the posterior fossa [1, 2]. Trigeminal neuralgia (TN; compression of cranial nerve V) and hemifacial spasm (HFS; compression of cranial nerve VII) are the most commonly diagnosed neurovascular compression syndromes. TN has an annual incidence of about 12.6 per 100,000. Patients with TN suffer from sharp, paroxysmal, unilateral, and electric shock-like pain in the branches of the trigeminal nerve, accompanied by innocuous triggers [3, 4]. HFS is a movement disorder of the seventh cranial nerve which is characterized by brief or persistent intermittent twitching of the muscles innervated by the facial nerve. HFS has an annual incidence of 7.4 per 100,000 in men and 14.5 per 100,000 in women, and patients suffer from poor quality of life due to social embarrassment [5].

Since the introduction of microvascular compression “short circuit theory” in 1976, microvascular decompression (MVD) has gradually become the best choice for the treatment of TN and HFS. The clinical application of magnetic resonance (MR) scanning technology, especially three-dimensional fast imaging employing steady-state acquisition (3D-FIESTA) and three-dimensional time-of-flight MR angiography (3D-TOF MRA), provides an observable basis for the diagnosis and surgical treatment of TN and HFS by identifying the offending vessel.

In spite of the different symptoms, the etiologies of TN and HFS are similar. They are a result of aberrant blood vessels at the REZ that cause axonal loss or demyelination in the compressed cranial nerve root, and therefore induce neurological disorders. In patients with neurovascular compression syndromes, the outcome after MVD is highly correlated with the presence and severity of the compression. Although the exact etiologies of primary TN and HFS are still debatable, microvascular compression is thought to be crucially involved in most cases. Accurately identifying the responsible vessel preoperatively helps neurosurgeons to effectively perform MVD and reduces the risks associated with surgery.

In this study, to illustrate the clinical instructional value of 3D-TOF MRA combined with 3D-FIESTA in the determination of the responsible vessels, we performed 3D-TOF MRA and 3D-FIESTA on 113 patients with TN or HFS, and analyzed the accuracy of the preoperative detection and intraoperative results.

3 Materials and methods

2.1 Participants

Patients with secondary lesions caused by tumors in the cerebellopontine angle region (CPA), severe underlying diseases, or no responsible vessels detected by 3D-FIESTA and 3D-TOF MRA, were excluded from the study. A total of 122 patients with trigeminal neuralgia or facial spasm were admitted to the neurosurgery department of Henan Zhoukou Central Hospital from 2014 to 2016. Among them, 9 cases (4 cases of TN, 5 cases of HFS) were excluded from the study due to no responsible blood vessels being identified in a preoperative magnetic resonance imaging (MRI) examination. Finally, 113 patients with neurovascular compression syndromes (53 cases of trigeminal MVD, 60 cases of facial nerve MVD) were enrolled in this study. All patients have signed informed consent. Of these, 49 cases were male and 64 were female patients. The average age was 54.1 ± 11.2 years old, the course of disease was from 1 month to 20 years, and the average disease duration was 5.2 ± 5.2 years. 63 cases were on the right side, 50 cases were on the left
side, and there was no case on both sides. All of the participants had stopped the administration of carbamazepine because it was an ineffective treatment.

2.2 Magnetic resonance imaging

A HDx 3.0 T magnetic resonance scanner (Signa; GE Medical Systems, Milwaukee, WI, USA) was used to perform all the MRI before the operation. After a conventional axial T1WI and T2WI scanning, the trigeminal nerve or facial nerve of the CPA cisternal segment was scanned. The sequence scanning parameters of 3D-FIESTA and 3D-TOF MRA were as follows. T1WI: repetition time (TR) 2150 m, echo time (TE) 15 ms, thickness 6.0 mm; T2WI TR 2400 m, TE 122.1 ms, thickness 6.0 mm, 3D-TOF MRA: TR 13.0 ms, TE 3.4 ms, flip angle (FA) 15°, field of view (FOV) 180 mm × 180 mm, matrices 512 × 512, thickness 1.0 mm. 3D-FIESTA: TR 4.9 ms, TE 1.8 ms, FA 60°, FOV 160 mm × 160 mm, matrices 512 × 512, thickness 1.0 mm.

2.3 Image analysis

3D reconstruction of the collected images was performed on the workstation. The relationship between the cerebral nerves and the responsible vessels on the affected side was confirmed by the axial, coronal, and sagittal images. The images were independently reviewed by two neuroradiologists and one neurosurgeon.

2.4 Surgery

All the patients underwent a suboccipital retrosigmoid sinus approach. In brief, the skin was cut, the bone flap was removed, the dura was suspended and cut, and the cerebrospinal fluid was slowly released. The CPA area was fully exposed and probed to identify the position of the trigeminal nerve, facial nerve, and posterior cranial nerve, vein, and artery. The arachnoid around the nerve was fully loosened, and the REZ area was exposed. The responsible blood vessels that caused the neurological symptoms were identified and separated into Teflon cotton.

2.5 Evaluation indicator

The specificity of the 3D-FIESTA combined with 3D-TOF MRA sequence was evaluated by comparing its agreement with the surgical findings. The accuracy of the preoperative 3D-FIESTA combined with 3D-TOF MRA sequence scan results and the intraoperative observations was calculated. The correlation of specificity with genders, disease durations, disease sides, and disease types were also evaluated.

2.6 Statistical analysis

Statistical analyses were conducted with SPSS (version 20.0). The measurement data were shown as mean ± standard deviation, a χ² test was conducted to compare the accuracy, and a Pearson correlation analysis was used in the single-factor analysis. All of the statistical tests were two-sided, and P < 0.05 was considered to be statistically significant.

3 Results

3.1 Preoperative 3D-FIESTA combined with 3D-TOF MRA accurately identified the offending vessels in TN and HFS patients

In the 3D-FIESTA images, the cranial nerves and blood vessels are dark [Fig. 1(A)]. In the 3D-TOF MRA images, the arteries are bright, while the nerves are equisignal [Fig. 1(B)]. Multiplanar reformatted (MPR) images can observe the relationship between blood vessels and nerves from many angles [Fig. 1(C)–(F)]. In all of the 113 cases, the presence of vascular compression was detected preoperatively and verified intraoperatively. As shown in Table 1, in cases with single-vessel compression, the accuracy
of detection was above 75% in all of the regions. Among these, the accuracy of the preoperative imaging results was the highest when the lesions were in the superior cerebellar artery (SCA; 91.1%), followed by lesions in the anterior inferior cerebellar artery (AICA; 77.8%). In cases of multiple-vessel compression, the coincidence between the preoperative and intraoperative results was 30.0%, which was much lower than that of single-vessel compression.

To illustrate the instructional value of the preoperative 3D-FIESTA combined with 3D-TOF MRA in cases of TN and HFS, respectively, we further analyzed the clinical data of the different patient groups. As shown in Table 2, in most of the cases of TN, the responsible blood vessels were in the SCA. The coincidence between preoperative and intraoperative results in the SCA reached 94.9%, indicating that the preoperative imaging with 3D-FIESTA combined with 3D-TOF MRA successfully identified almost all of the common cases in TN patients. In HFS patients, however, the lesions were detected mainly in the AICA and PICA. Although the coincidence rates in

Table 1 Accuracy of the preoperative and intraoperative results among different responsible vascular vessels.

| Responsible vessels | Preoperative (using MRI) | Coincidence with intraoperative | Accuracy |
|---------------------|--------------------------|---------------------------------|----------|
| SCA                 | 49                       | 41                              | 91.1%    |
| AICA                | 45                       | 35                              | 77.8%    |
| PICA                | 13                       | 10                              | 76.9%    |
| Multiple vessels    | 10                       | 3                               | 30.0%    |

SCA, superior cerebellar artery; AICA, anterior inferior cerebellar artery; PICA, posterior inferior cerebellar artery; MRI, magnetic resonance imaging.

Fig. 1 MRI of a patient with trigeminal neuralgia caused by an artery. (A) and (B) Axial images show the relationship between the trigeminal nerve and vessel in 3D-FIESTA and 3D-TOF MRA (a1, b1: trigeminal nerve; a2, b2: AICA). (C) to (F) MPR images show the relationship between the trigeminal nerve and vessel (c1, d1, e1, f1: trigeminal nerve; c2, d2, e2, f2: AICA).
cases of HFS were relatively lower than that in TN, the results of 3D-FIESTA combined with 3D-TOF MRA in common cases of HFS were also fairly reliable (86.8% in the AICA and 90.0% in the PICA).

3.2 Gender, disease duration, disease side, and disease type had no influence on the accuracy of identification

To clarify the target patients for the preoperative diagnostic approach with 3D-FIESTA combined with 3D-TOF MRA, we compared the coincidence rates in patients of different genders, disease durations, disease sides, and disease types. As shown in Tables 3 and 4, although not completely common, the differences in the accuracy among these cases were not statistically significant ($P > 0.05$). This indicates that the preoperative 3D-FIESTA combined with 3D-TOF MRA could identify the vascular compression in most patients with neurovascular compression syndromes, especially patients with TN or HFS, regardless of their gender, disease duration, disease side, or disease type.

**Table 2** Accuracy between the preoperative and intraoperative results among different responsible blood vessels in TN and HFS.

| Disease | Preoperative (using MRI) | Coincidence with intraoperative | Accuracy |
|---------|--------------------------|--------------------------------|----------|
|         | a b c d                   | a b c d                        | a b c d |
| TN      | 39 7 3 4                 | 37 2 1 1                      | 94.9%   |
|         |                          |                                | 28.6%   |
|         |                          |                                | 33.3%   |
|         |                          |                                | 25.0%   |
| HFS     | 6 38 10 6                | 6 4 33 9                      | 66.7%   |
|         |                          |                                | 86.8%   |
|         |                          |                                | 90.0%   |
|         |                          |                                | 33.3%   |

TN, trigeminal neuralgia; HFS, hemifacial spasm. a, CA; b, AICA; c, PICA; d, Multiple vessels.

**Table 3** Accuracy between the preoperative and intraoperative results among different genders, disease durations, disease sides, and disease types.

| Group        | Preoperative (using MRI) | Coincidence with intraoperative | Accuracy | $\chi^2$ Test $P$ value |
|--------------|--------------------------|--------------------------------|----------|------------------------|
| Gender       |                          |                                |          |                        |
| Male         | 49                       | 37                             | 75.5%    | 0.305                  |
| Female       | 64                       | 52                             | 81.2%    |                        |
| Disease side |                          |                                |          |                        |
| Left         | 50                       | 39                             | 78.0%    | 0.520                  |
| Right        | 63                       | 50                             | 79.0%    |                        |
| Disease duration |              |                                |          |                        |
| $\leq$ 1 year| 15                       | 12                             | 80.0%    | 0.602                  |
| $>$ 1 year   | 98                       | 77                             | 78.6%    |                        |
| Disease Type |                          |                                |          |                        |
| TN           | 53                       | 41                             | 77.4%    | 0.454                  |
| HFS          | 68                       | 48                             | 80.0%    |                        |

**Table 4** Correlation of the accuracy with gender, disease duration, disease side, and disease type.

| Factor      | Correlation coefficient | Variance | $P$ value |
|-------------|-------------------------|----------|-----------|
| Gender      | 0.656                   | 0.458    | 0.152     |
| Disease     | 0.269                   | 0.461    | 0.560     |
| Disease side| 0.041                   | 0.04     | 0.307     |
| Disease duration | 0.057        | 0.454    | 0.901     |
| Disease type |                       |          |           |

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4 Discussion

MVD is one of the main treatments for neurovascular compression syndromes, but studies have shown no responsible vessel discovery during MVD surgery in some patients. Therefore, preoperative identification of neurovascular compression (NVC) has an impact on the determination of the appropriate treatment for TN or FHS. In this study, we retrospectively reviewed the notes of 113 cases of TN or HFS, and confirmed the clinical value of a preoperative 3D-FIESTA combined with 3D-TOF MRA in MVD.

The REZ is the junction between the central and peripheral nerve segments of the cranial nerves, where the cells responsible for myelination transit from the oligodendroglia cells in the central nerve to the Schwann cells in the peripheral nerve. The cranial nerves in the REZ are highly susceptible to injury because they are only protected by an arachnoid membrane and lack epineurium [6]. In patients with TN, the overlying blood vessels cause demyelination changes in the nerve root at the regions of compression, and produce abnormal impulses, which result in pain-focused lesions in the brainstem and cerebrum [7]. Physiologically, the myelin sheath inhibits ephaptic transmission. In cases of HFS, however, local compression induced demyelination in the facial nerve results in facial hyperactivity [8–10]. Although a detailed pathogenesis of these cranial nerve hyperactive disorders is still debatable, MVD surgeries have been successfully performed to alleviate TN and HFS.

An accurate delineation of the responsible vessel may decrease the rate of possible operative complications such as nerve paresis. A detailed preoperative anatomic evaluation using MR imaging is now widely used for precise assessment of neurovascular relationships [11].

A study shows the overall reliability of MRI to predict the existence of an NVC. The prediction value is excellent for high grades of compression. Some apparent low-grade compressions evident on MRI may be revealed as false positives upon surgical exploration [12]. Since conventional MRI has failed to evaluate a quite a number of patients with neurovascular compression, high-resolution MRI has gradually been applied. Recently, high-field MRI (3.0 T or higher) has become one of the main methods used to evaluate the relationship between vessels and cranial nerves [13]. 3.0 T MRI offers increased diagnostic sensitivity and specificity due to its higher signal noise ratio, and improvements at 3.0 T have already been established for several MRA sequences and 3D-T2WI [14].

In this study, 3D-TOF MRA and 3D-FIESTA were used to provide preoperative visualization of neurovascular contact in MVD. MRA is used to observe vascular lumens. 3D-TOF MRA enhanced the images of the blood flow by increasing the contrast of the blood flow and static organization. Basi-parallel anatomical scanning with 3D-FIESTA supplements the images of 3D-TOF MRA by depicting the outside of the vessels even if there is no blood flow, and shows the images of the vertebrobasilar and nerve systems which are surrounded by cerebrospinal fluid [15, 16]. We can trace the origin of the responsible vessel via the 3D-TOF sequence. Some vessels do not make contact with the nerves in the 3D-TOF sequence, but may clearly show contact with the nerves in the 3D-FIESTA sequence. Therefore, it is more accurate to determine whether the blood vessel contacts the nerve with 3D-FIESTA. A section thickness of 1.0 mm was used in the 3.0 T MRI because some of the compressing vessels have a diameter of 2.0 mm [17]. We found that 3D-FIESTA combined with 3D-TOF MRA effectively identified the region of compression in most of the cases. However, in
the cases where multiple vessels were involved, the coincidence rate in preoperative identification was much lower. The reason may be that the diameter of some blood vessels was too small to be detected, or the veins displayed on the sequence were not enough to reflect the overall situation.

3D-TOF MRA and 3D-FIESTA sequences at 3T were used to evaluate the neurovascular relationship in patients with TN or FHS. Studies have shown that the combination of two imaging techniques identified surgically-verified contacts between trigeminal nerves and vessels in 35 of 36 symptomatic nerves, and there were no false-positive results [16]. 3D-TOF can show the arterial pressure on the facial nerve, the positive rates and the overall accuracy were 92.63% and 93.68%, respectively [18]. As for the accuracy of finding the responsible blood vessels in patients with TN or HFS with a preoperative examination, previous studies mostly focused on TN or HFS alone, or described the overall accuracy of both using other MRI techniques. Few studies have distinguished and compared the two groups of TN and HFS patients, and then assessed the accuracy using 3D-FIESTA and 3D-TOF MRA. Some scholars used 3D-TOF and MIP reconstruction images to determine the source of the responsible blood vessels. They found that the consistency between preoperative imaging and intraoperative diagnosis (i.e., the accuracy) was 80.85%. However, it reduced to 50% for cases that involved multiple vessels [18].

In this study, the 3D-FIESTA and 3D-TOF MRA scans found that the accuracy of the responsible vessels including the SCA, AICA, PICA, and multiple vessels were 91.1%, 77.8%, 76.9%, and 30.0%, respectively, which was consistent with previous studies [16]. Why was the accuracy of the results for multiple responsible vessels low? The reason may first be attributed to the variation of the anatomical relationship between blood vessels and the trigeminal nerve or facial nerve. Second, on 3D-TOF MRA, there are some vessels that have a small diameter and a tortuous blood flow direction; the signal intensity is not high, and they look like nerves. Third, the displacement of nerves, blood vessels, brain tissue and the release of cerebrospinal fluid after a craniotomy may alter the neighboring relationships and lead to misjudgments. In addition, it may be because the number of patients is small, and not enough to accurately reflect the overall situation. Among the patients included in this study, the responsible blood vessel was not found during the operation as a venous blood vessel. The reason for the analysis may be that the veins on the TOF MRA sequence are not visible, and the simple 3D-FIESTA sequence is difficult to judge. Also, cases where no responsible blood vessel was found with preoperative MRI examination were not included in this study. In addition, we found that in TN patients, the main responsible vessels were in the SCA, followed by the AICA, which was consistent with previous research [19]. However, the diagnostic ability of trigeminal neuralgia with the AICA or PICA was very low at 28.6% and 33.3%, respectively. This may be because the anatomy of the vessels is complex and prone to variation, and some vessels have a small diameter and tortuous blood flow direction, which leads to misjudging the vessel that is responsible. In HFS patients, however, the main responsible vessels were in the AICA or PICA. It was noteworthy that the vertebral artery was never found to be the responsible vessel during a preoperative examination, but 2 cases where this was the case were identified during surgery. We also found that the accuracy of the preoperative examination had no correlation with gender, disease duration, disease side, or disease type, and therefore confirmed the possibility of the general applicability of 3D-TOF MRA combined with 3D-FIESTA before MVD.
In conclusion, this study verified the clinical instructional value of 3D-FIESTA combined with 3D-TOF MRA in MVD, and showed that this preoperative examination is reliable in all genders, disease durations, disease sides, and disease types.

Conflict of interests

The authors declare no conflict of interests.

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