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ORIGINAL ARTICLE - FUNCTIONAL NEUROSURGERY - PAIN

Flat-shaped posterior cranial fossa was associated with poor outcomes of microvascular decompression for primary hemifacial spasm

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Abstract

Background Numerous factors have been investigated on affecting the outcomes of primary hemifacial spasm (HFS) after microvascular decompression (MVD). It is well established that anatomical differences of the posterior cranial fossa (PCF) plays an important role in the occurrence of HFS. However, it is still not clear whether morphological characteristics of PCF affect the surgical outcomes of HFS after MVD. Our study aims to investigate the prognostic factors for surgical outcomes of MVD for primary HFS, with a particular focus on the morphological characteristics of PCF.

Methods Between January 2014 and November 2017, a total of 152 HFS patients who underwent MVD treatment in our department were included in this study. The clinical data were retrospectively reviewed. The outcomes of MVD were classified into success and failure groups according to the short- and long-term postoperative responses. Particularly, we established an ellipsoid model for PCF. The related length (Y), width (X) and height (Z) of the PCF were measured and the volume of PCF was calculated employing a formula of $\frac{\pi}{6}XYZ$. The relationship between PCF volume and surgical outcomes was statistically analysed.

Results The severity of neurovascular compression (NVC) ($p = 0.010$), type of NVC ($p = 0.001$) and lateral spread response (LSR) ($p < 0.0001$) significantly influenced the long-term surgical outcomes of MVD for primary HFS. In particular, for the first time, we demonstrated that a flat-shaped PCF was associated with poor long-term outcome and postoperative recurrence.

Conclusions Our current study suggests that mild NVC, small vessel compression, intraoperative LSR persistence and flat-shaped PCF are independent factors predicting poor prognosis of MVD for primary HFS.

Keywords Hemifacial spasm (HFS) · Microvascular decompression (MVD) · Posterior cranial fossa (PCF) · Lateral spread response (LSR) · Outcome · Recurrence and delayed cure

Abbreviations

AICA	Anterior inferior cerebellar artery
BA	Basilar artery
CPA	Cerebellopontine angle
HFS	Hemifacial spasm
LSR	Lateral spread response
MRI	Magnetic resonance imaging
MVD	Microvascular decompression
NVC	Neurovascular compression
PCF	Posterior cranial fossa
PICA	Posterior inferior cerebellar artery
REZ	Root exit zone
TN	Trigeminal neuralgia
VA	Vertebral artery

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Introduction

Hemifacial spasm (HFS) is a common neuromuscular movement disorder that manifests as brief or persistent involuntary contractions from multiple muscles innervated by the seventh cranial nerve [7, 19]. HFS can be divided into primary and secondary HFS according to the definite aetiology [7]. Neurovascular compression (NVC) of the root exit zone (REZ) of the facial nerve is considered the common cause of primary HFS [7].

Microvascular decompression (MVD) is a highly recommended treatment for HFS caused by NVC [16, 17]. In recent decades, MVD has achieved very good curative effects reported in approximately 95% of patients. However, the postoperative course can be variable. Most of the patients become immediately spasm-free after MVD, and some patients who exhibit residual HFS after MVD have got delayed cure within several months or even years [22, 24]. Recurrent HFS after MVD has also been increasingly reported during prolonged follow-up [1]. To date, numerous factors [1, 14, 15] have been stated as prognostic factors for the outcomes of HFS after MVD. The anatomical study of the posterior cranial fossa (PCF) has revealed a relationship with the occurrence of primary HFS [2, 3, 5, 20]. Moreover, the limited volume of the PCF shows a high risk of early postoperative complications after MVD and is significantly associated with poor short-term curative effects [3]. Nevertheless, multiple parameters of the PCF, such as the width, length and depth of the PCF, have not been fully investigated in terms of their relationship with the curative effect of MVD on primary HFS.

Our study aimed to investigate the prognostic factors of the surgical outcomes of MVD for primary HFS, with a particular focus on the morphological characteristics of PCF.

Materials and methods

Patient data and study design

Between January 2014 and November 2017, there were 171 patients who underwent MVD for primary HFS in Tongji Hospital, Wuhan, China. The diagnosis of primary HFS was confirmed based on typical clinical manifestations and preoperative neuroimaging examinations. The exclusion criteria were as follows: (1) other forms of facial movement disorders, such as facial tics and facial dystonia; (2) symptomatic HFS secondary to PCF mass lesions, aneurysms, Chiari malformations, hydrocephalus, etc.; and (3) patients with a history of craniotomy, gamma-knife therapy and other nerve block treatments. As a result, we finally included 152 patients (88.9%) in our study.

The clinical data regarding sex, age, affected side, spasm duration (period from onset to first hospitalization), follow-up duration (period from the date of surgery to January 2019), complications and short-term and long-term outcomes were retrospectively reviewed. All subjects were preoperatively applied to high-resolution T1-BRAVO and 3D FIESTA scanning on a 3-T magnetic resonance imaging (MRI) scanner (GE 750 Discovery, USA) using a 32-channel commercial head coil. The parameters for T1-BRAVO were field of view (FOV) = 22 × 22 cm, slice thickness = 1 mm and matrix = 256 × 256. The parameters for 3D FIESTA were FOV = 18 × 18 cm, slice thickness = 0.8 mm and matrix = 312 × 312. This study was approved by local ethical authorities (file number TJ-C20190387) in accordance with the Helsinki criteria. Written informed consent was obtained from each individual.

PCF morphometry

The anatomic study of the PCF was performed by using the methods described by Hamasaki et al. [5] and Fukuoka et al. [4]. The PCF was assumed to be approximately ellipsoid in shape (Fig. 1a). The length (Y), width (X) and height (Z) of PCF were measured based on reconstructed coronal and sagittal T1-BRAVO images and the volume of the PCF was calculated by a formula of $\frac{\pi}{6}XYZ$ (Fig. 1a, lower panel). The height (Z) was defined as the distance from the top of the straight sinus to the foramen magnum along the superior-inferior axis (Z axis), the length (Y) was defined as the distance from the posterior clinoid process to the confluence of sinuses along the anterior-posterior axis (Y axis) and the width (X) was defined as the distance between the bilateral transverse-sigmoid sinus junctions along the right-left axis (X axis). To further investigate the PCF morphological features in three dimensions, the ratios of X to Y (X/Y), X to Z (X/Z) and Y to Z (Y/Z) were also respectively explored.

Operation procedure and intraoperative findings

The patients were placed in a lateral prone or sitting position, and a retrosigmoid suboccipital approach followed by keyhole craniotomy was performed for a subsequent MVD procedure. After adequate cerebrospinal fluid drainage, the cerebellum was gently retracted to expose the cerebellopontine angle region. The entire facial nerve tract was carefully inspected to determine NVC location. The offending vessels and the severity of NVC were documented. Then, a Teflon sponge was inserted between the facial nerve and offending vessels. Intraoperative electrophysiological monitoring, including brainstem auditory-evoked potential and facial electromyographic monitoring, was routinely employed in each patient. The achievement of adequate decompression was subjectively determined by the fact that the offending vessel was sufficiently removed from the facial nerve and was objectively evaluated by the fact that the lateral spread response (LSR) disappeared or was significantly attenuated. In our present study, the offending vessels were divided into two groups: (i) large vessels: the main trunk and primary branches of the vertebral artery (VA) and basilar artery (BA), including the anterior

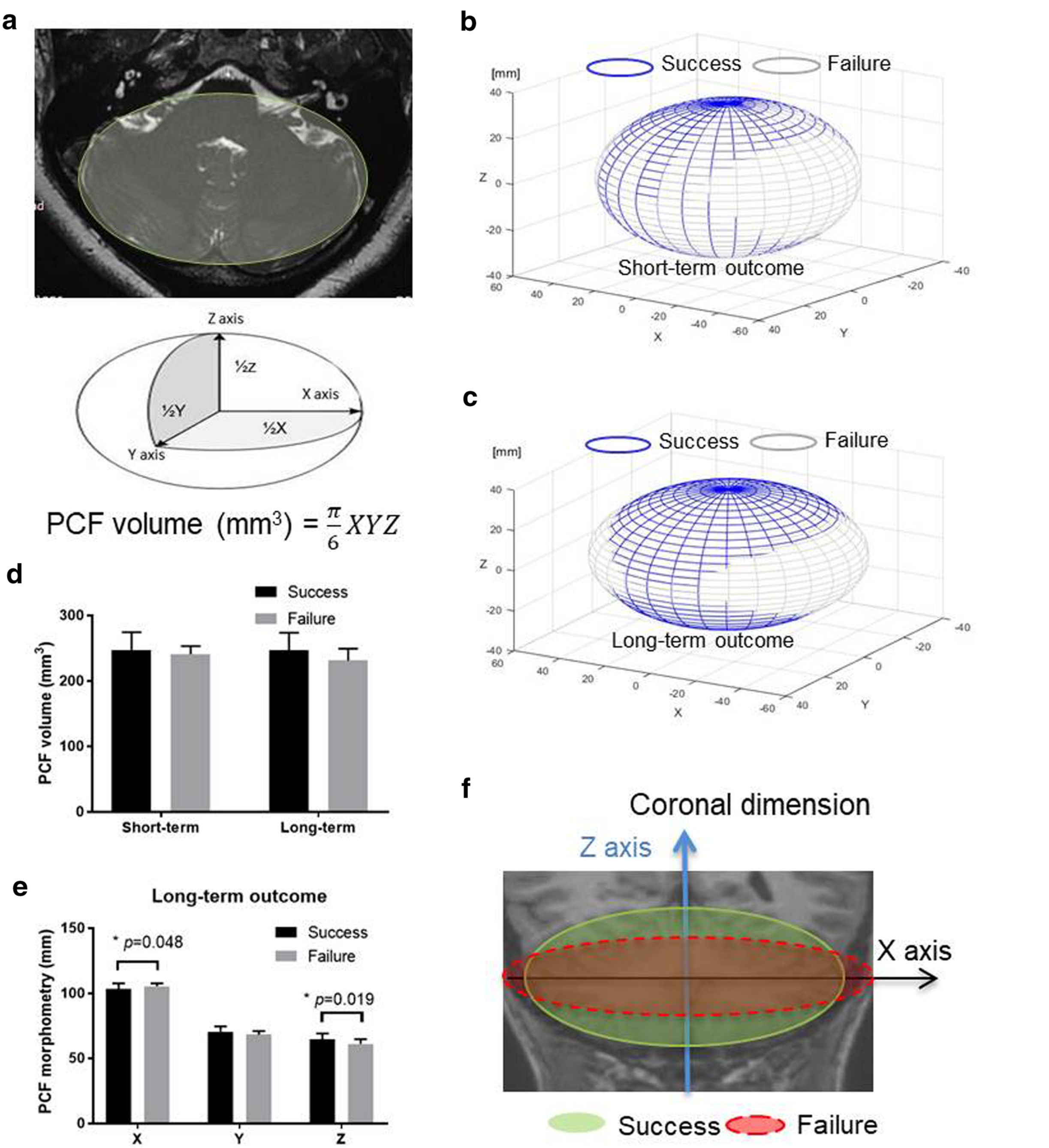

Fig. 1 Study of posterior cranial fossa (PCF) morphometry and microvascular decompression (MVD) outcomes. **a** The methods used for the quantitative study of PCF morphometry. An ellipsoid model was developed to approximately simulate the configuration of the PCF (upper panel). The *X*, *Y* and *Z* values of the PCF were measured by using the methods described above. The volume of the PCF was calculated by using the formula $\frac{\pi}{6}XYZ$ (lower). **b**, **c** The PCF ellipsoid modes of the success and failure groups were drawn and merged using MATLAB software, and short-term outcome (**b**) and long-term outcome (**c**) are shown. The volume of the PCF tended to be larger in the success group (blue ellipsoid in **b** and **c**) of both short- and long-term outcomes than in the failure group (grey ellipsoid in **b** and **c**). **d** The quantitative analysis of PCF volumes. The differences between the success and failure groups in both MVD outcomes were not significant. **e** The quantitative study of PCF parameters. In the success group of the long-term outcome, the value *X* was demonstrated to be remarkably smaller, and the value *Z* was larger than that in the failure group (X: $*p = 0.048 < 0.05$; Z: $*p = 0.019 < 0.01$). **f** Coronal two-dimensional modes showed the differences of *X* and *Z* values. As shown in the coronal dimension, *X* was shorter and *Z* was longer in the success group (green ellipse) than in the failure group (red ellipse), indicating a more flat-shaped configuration in the failure group

inferior cerebellar artery (AICA) and posterior inferior cerebellar artery (PICA); (ii) small vessels: secondary and tertiary branches of VA and BA. The severity of NVC was classified into 4 grades described by Fukuoka's study [4]: grade 0:

undefined NVC; grade 1: mild NVC, the vessels contacted the nerve without any visible indentation on the nerve; grade 2: moderate NVC, displacement or distortion of the nerve; and grade 3: severe NVC, marked indentation on the nerve.

Outcome evaluation and follow-up

All patients were followed up in the outpatient department, and information was obtained from patients during their visits or via telephone interviews. The postoperative complications were recorded within 1 month after MVD. The curative effect was determined as success (spasm-free and almost spasm relief) or failure (partial spasm relief and persistent spasm) and was categorized as short-term (1 week postoperatively) and long-term (more than 1 year during follow-up). During follow-up, the spasm aggravated in success patients (short-term) postoperatively was defined as recurrence of HFS, and the residual spasm (short-term) after MVD that had spasm relief or spasm-free in failure patients was regarded as delayed cure of HFS.

Statistical analysis

All statistical analyses were performed by using IBM SPSS statistics 23.0 software. Continuous data are described as mean ± standard deviation and were analysed by the Student t test (for parametric data) or the Mann-Whitney U test (for non-parametric data). For categorized data, the two independent sample tests were used to compare the differences. $p < 0.05$ was considered statistically significant.

Results

The clinical information of 152 primary HFS patients are summarized in Table 1. Our series included 56 men and 96 women with a mean age of 47.7 ± 9.0 years (range 25–67 years). The mean duration of symptoms was 48.6 ± 42.0 months (range 2–240 months). HFS was identified at the left side for 83 (54.6%) cases, and at the right side for 69 (45.4%) cases. In total, 113 (74.3%) patients were operated in lateral prone position and 39 (25.7%) in sitting position. Seventeen (11.2%) cases were identified to be with small vessel compression and 135 (88.8%) cases with large vessel compression, including 119 (78.3%) cases with AICA or PICA compression and 16 (10.5%) with VA or BA compression. The severity of NVC was classified as grade 0 in 17 (11.2%) cases, grade 1 in 35 (23.0%) cases, grade 2 in 46 (30.3%) cases and grade 4 in 54 (35.5%) cases.

The mean follow-up duration was 24.0 ± 8.3 months (range 13–38 months). In total, 137 of 152 (90.1%) patients were identified to be successful cases due to complete relief of spasm at 1-week postoperative evaluation (short-term outcome), and 15 (9.9%) patients were classified into the failure group due to residual HFS (Table 1). The long-term outcome was evaluated at the final follow-up and described as follows: 143 (94.1%) patients were classified into the success group and 9 (5.9%) patients into the failure group (Table 1). Six cases experienced recurrence after hospitalization (0.7–1.8 years), and 12 cases had a delayed cure. Nine (5.9%) patients had postoperative complications, including permanent hearing loss ($N = 1$, 0.7%), partial hearing loss ($N = 3$, 2.0%), temporary facial paralysis ($N = 2$, 1.3%), CSF leakage ($N = 2$, 1.3%) and incision infection ($N = 1$, 0.7%). There was no dead case in our series (Table 1). Patient age, sex, symptom duration and affected side were not correlated with surgical outcomes (Table 2). Patients with large vessel compression showed a significantly better long-term outcome than those with small vessel compression ($p = 0.001$); however, there was no statistical difference regarding the short-term outcome between these two groups ($p = 0.255$) (Table 2). The severity of NVC was positively correlated with a better short-term ($p = 0.041$) and long-term ($p = 0.010$) outcomes (Table 2). Moreover, small vessel compression in NVC was associated with postoperative recurrence ($p = 0.002$) but not with postoperative delayed cure ($p = 0.531$) (Table 3). In addition, higher NVC severity was also associated with postoperative recurrence ($p = 0.015$) but not with delayed cure ($p = 0.077$) (Table 3). The intraoperative monitoring revealed that 137 (90.1%) patients showed LSR disappearance and 15 (9.9%) cases showed LSR attenuation. The statistical analysis demonstrated that LSR disappearance was positively correlated with both better short-term and long-term outcomes ($p = 0.001$ and $p < 0.0001$, respectively) (Table 2). Moreover, the LSR disappearance was associated with a lower risk of recurrence ($p = 0.0008$); however, it was not correlated with postoperative delayed cure ($p = 0.067$) (Table 3). We further explore the relationship between flat-shaped posterior cranial fossa and intraoperative LSR. The results showed that smaller height (Z), axial dimension (X/Y), coronal dimension (X/Z) and PCF volume were negative predictors for intraoperative LSR ($p = 0.002$, $p = 0.022$, $p < 0.001$ and $p = 0.045$, respectively) (Table 4).

As shown in Tables 2 and 3, PCF morphometry was performed and correlated to surgical outcomes. As a result, the values of X, X/Y and X/Z in the long-term success group were remarkably smaller and the value of Z was significantly larger than those in the failure group (X: $p = 0.048$; Z: $p = 0.019$; X/Y: $p = 0.005$ and X/Z: $p = 0.005$) (Table 2 and Fig. 1e). However, no statistical differences were established regarding these four variables in the short-term success or failure groups (Table 2). Moreover, the values of Y and Y/Z showed no significant differences between the success and failure groups with respect to both the short-term and long-term outcomes. By using MATLAB software, a series of PCF ellipsoid modes were established and shown in Fig. 1. The volume of the PCF

Table 1 Clinical data and outcomes of MVD in 152 primary HFS patients

Variables	Number (%)
Number of patients	*n* = 152
Sex	
Male	56 (36.8%)
Female	96 (63.2%)
Age (years)	47.7 ± 9.0 (range 25–67)
Side	
Left	83 (54.6%)
Right	69 (45.4%)
Spasm duration (months)	48.6 ± 42.0 (range 2–240)
Follow-up period (months)	24.0 ± 8.3 (range 13–38)
Operative position	
Lateral prone position	113 (74.3%)
Sitting position	39 (25.7%)
Offending vessel within NVC	
Small vessels	17 (11.2%)
Anterior and posterior inferior cerebellar artery	119 (78.3%)
Vertebral artery/basilar artery	16 (10.5%)
Severity of NVC	
Grade 0: undefined of NVC	17 (11.2%)
Grade 1: mild NVC	35 (23.0%)
Grade 2: moderate NVC	46 (30.3%)
Grade 3: severe NVC	54 (35.5%)
Intraoperative LSR	
Disappearance	137 (90.1%)
Attenuation	15 (9.9%)
Short-term curative effect	
Spasm-free	133 (87.5%)
Almost spasm relief	4 (2.6%)
Partial spasm relief	4 (2.6%)
Persistent spasm	11 (7.2%)
Success (spasm-free and almost spasm relief)	137 (90.1%)
Failure (partial spasm relief and persistent spasm)	15 (9.9%)
Long-term curative effect	
Spasm-free	132 (86.8%)
Almost spasm relief	11 (7.2%)
Partial spasm relief	1 (0.7%)
Persistent spasm	8 (5.3%)
Success (spasm-free and almost spasm relief)	143 (94.1%)
Failure (partial spasm relief and persistent spasm)	9 (5.9%)

MVD microvascular decompression, *HFS* hemifacial spasm, *NVC* neurovascular compression, *LSR* lateral spread response

tended to be larger in the success group (blue ellipsoid in Fig. 1b and c) than that in the failure group (grey ellipsoid in Fig. 1b and c) regarding both short-term and long-term outcome groups than in the failure group (grey ellipsoid in Fig. 1b and c); nevertheless, no significant differences were elucidated in our data (Fig. 1d). Additionally, a PCF ellipsoid model was developed and is shown in Fig. 1f, demonstrating that the configuration of the PCF in the success group was larger along the superior-inferior axis and smaller along the left-right axis and the anterior-posterior axis. Furthermore, we found that postoperative recurrence was positively correlated with a larger X/Y ($p = 0.040$) and X/Z ($p = 0.034$) values (Table 3).

Table 2 The relationship between patient variables and outcomes of MVD

Variables	Short-term		p value	Long-term		p value
	Success	Failure		Success	Failure	
Number of patients	n = 137	n = 15		n = 143	n = 9	
Sex			0.767			0.627
Male	51 (37.2%)	5 (33.3%)		52 (36.4%)	4 (44.4%)	
Female	86 (62.8%)	10 (66.7%)		91 (63.6%)	5 (55.6%)	
Age (years)	47.4 ± 9.0	50.1 ± 9.1	0.253	47.4 ± 9.0	52.8 ± 9.0	0.134
Spasm duration (months)	50.5 ± 43.5	31.3 ± 17.2	0.185	50.1 ± 42.6	24.9 ± 21.4	0.054
Side			0.323			0.151
Left	73 (53.3%)	10 (66.7%)		76 (53.1%)	7 (77.8%)	
Right	64 (46.7%)	5 (33.3%)		67 (46.9%)	2 (22.2%)	
NVC			0.255			0.001**
Small vessels	14 (10.2%)	3 (20.0%)		13 (9.1%)	4 (44.4%)	
Large vessels	123 (89.8%)	12 (80.0%)		130 (90.9%)	5 (55.6%)	
Severity of NVC			0.041*			0.010*
Grade 0	14 (10.2%)	3 (20.0%)		13 (9.1%)	4 (44.4%)	
Grade 1	30 (21.9%)	5 (33.3%)		34 (23.8%)	1 (11.1%)	
Grade 2	41 (29.9%)	5 (33.3%)		42 (29.4%)	4 (44.4%)	
Grade 3	52 (38.0%)	2 (13.3%)		54 (37.8%)	0 (0.0)	
Intraoperative LSR			0.001**			< 0.0001***
Disappearance	128 (93.4%)	9 (60.0%)		135 (94.4%)	2 (22.2%)	
Attenuation	9 (6.6%)	6 (40.0%)		8 (5.6%)	7 (77.8%)	
PCF morphometry						
Width (X, mm)	103.4 ± 4.3	103.9 ± 4.4	0.389	103.3 ± 4.4	105.6 ± 2.1	0.048*
Length (Y, mm)	70.4 ± 3.9	70.7 ± 3.5	0.589	70.6 ± 3.9	68.2 ± 2.7	0.076
Height (Z, mm)	64.6 ± 4.6	62.6 ± 2.6	0.117	64.6 ± 4.5	61.2 ± 3.5	0.019*
Axial dimension (X/Y)	1.47 ± 0.10	1.47 ± 0.09	0.933	1.47 ± 0.10	1.54 ± 0.05	0.005**
Coronal dimension (X/Z)	1.61 ± 0.13	1.66 ± 0.13	0.080	1.61 ± 0.13	1.73 ± 0.09	0.005**
Sagittal dimension (Y/Z)	1.09 ± 0.08	1.13 ± 0.08	0.192	1.10 ± 0.08	1.11 ± 0.07	0.250
Volume (mm^3)	246.7 ± 27.6	240.6 ± 12.4	0.417	247.0 ± 26.7	231.3 ± 17.7	0.069

MVD microvascular decompression, *NVC* neurovascular compression, *PCF* posterior cranial fossa, *LSR* lateral spread response

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Discussion

Primary HFS is a common neurovascular disorder that mostly occurs in elderly [21], female [13] and Asian patients [5, 16]. The general consensus is that the pathophysiological cause of primary HFS is NVC in the REZ of the facial nerve due to the achievement of more than 95% success following MVD surgery. Numerous prognostic factors have been identified in MVD for HFS in recent decades. Our present study elucidated that type of offending vessels, severity of NVC and intraoperative LSR influenced MVD short- and long-term outcomes.

Increasing data have revealed that HFS in patients caused by large vessel compression might have a better curative effect compared with those caused by small vessel compression [11, 25]. Furthermore, various offending vessels in HFS show no significant difference in terms of the relationship with outcome after MVD surgery [8, 26]. Our results were in accordance with previous reports. Surprisingly, a significant difference was found between the two groups regarding the long-term outcome but not the short-term outcome, suggesting that HFS caused by small vessel compression shows a predominant tendency to obtain spasm recurrence [11]. We suspect that small vessels running among the facial nerve tracts, together with a thickened arachnoid, might be the major culprit for HFS. Accordingly, both the small vessels and the thickened arachnoid should be completely isolated from the whole length of the facial nerve. Otherwise, the arachnoid adhesion between the facial nerve and the surrounding structures might result in a new NVC and postoperative recurrence. Additionally, numerous studies have suggested that NVC severity is an independent prognostic factor for MVD in HFS patients [12, 14, 15]. In the present study, we also established that higher NVC severity was associated with better surgical

Table 3 The analysis of affecting factors for HFS delayed cure and recurrence

Variables	Delayed cure	Non-delayed cure	*p* value	Recurrence	Non-recurrence	*p* value
Number of patients	*n* = 12	*n* = 140		*n* = 6	*n* = 146	
NVC						
Small/Large vessels	2/10	15/125	0.531	3/3	14/132	0.002**
Intraoperative LSR						
Attenuation/disappearance	3/9	12/128	0.067	4/2	11/135	0.0008***
Severity of NVC						
Grade 0/1/2/3	2/5/3/2	15/30/43/52	0.077	3/1/2/0	14/34/44/54	0.015*
PCF morphometry						
Width (*X*, mm)	103.3 ± 4.6	103.5 ± 4.3	0.876	105.2 ± 2.1	103.4 ± 4.4	0.320
Length (*Y*, mm)	71.1 ± 3.8	70.4 ± 3.9	0.498	67.8 ± 3.3	70.5 ± 3.9	0.093
Height (*Z*, mm)	63.0 ± 2.8	64.6 ± 4.6	0.234	61.3 ± 4.4	64.6 ± 4.5	0.082
Axial dimension (*X*/*Y*)	1.5 ± 0.1	1.5 ± 0.1	0.495	1.6 ± 0.1	1.5 ± 0.1	0.040*
Coronal dimension (*X*/*Z*)	1.6 ± 0.1	1.6 ± 0.1	0.358	1.7 ± 0.1	1.6 ± 0.1	0.034*
Sagittal dimension (*Y*/*Z*)	1.1 ± 0.1	1.1 ± 0.1	0.103	1.1 ± 0.1	1.1 ± 0.1	0.694
Volume (mm^3)	241.8 ± 13.1	246.5 ± 27.3	0.562	229.1 ± 21.3	246.8 ± 26.5	0.110

HFS hemifacial spasm, *NVC* neurovascular compression, *PCF* posterior cranial fossa, *LSR* lateral spread response

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

outcomes. There is obvious controversy regarding the effect of LSR abolition in predicting surgical outcomes [6, 10, 23]. Several studies have demonstrated the positive effect of LSR abolition in predicting surgical outcomes of MVD [6, 23]. It has been suggested that patients with intraoperative LSR disappearance have better outcomes than those with only LSR attenuation [18]. In our study, intraoperative LSR disappearance was a positive prognostic factor for both short- and long-term outcomes, which was in accordance with the published reports.

To date, several quantitative studies of PCF morphometry, either performed by computer tomography or on MRI, have indicated that the small size [20] and the crowdedness [3, 9, 13] of the PCF, as well as the narrowness of the cistern space in cerebellopontine angle (CPA) [9] and the small volume of cerebrospinal fluid in CPA cistern [2, 3, 20], might be associated with the prevalence of HFS in the population. Most recently, Hamasaki et al. [5] revealed a possible underlying mechanism that the flatness of the PCF might result in deviation of the basilar artery and tortuosity of branch vessels such as the AICA and PICA, which in turn led to the development of NVC of the facial nerve in HFS patients. However, the correlation between PCF morphological features and MVD outcome in primary HFS remains unknown. To date, limited reports have indicated that PCF crowdedness negatively influences the outcome of MVD surgery [3]. To consider the validity of these clinical facts for HFS, we assumed that PCF morphometry influenced the MVD outcome for HFS. Although our current study found that the PCF volume seemed to be larger in HFS patients with good outcomes, this difference was not statistically significant. In particular, for the first time, we reported that the flat-shaped PCF configuration

Table 4 The relationship between PCF morphometry and intraoperative LSR

Variables	LSR disappearance (*n* = 137)	LSR attenuation (*n* = 15)	*p* value
PCF morphometry			
Width (*X*, mm)	103.3 ± 4.6	105.5 ± 1.7	0.059
Length (*Y*, mm)	70.6 ± 3.9	69.2 ± 3.4	0.186
Height (*Z*, mm)	64.8 ± 4.5	61.0 ± 2.4	0.002**
Axial dimension (*X*/*Y*)	1.5 ± 0.1	1.5 ± 0.1	0.022*
Coronal dimension (*X*/*Z*)	1.6 ± 0.1	1.7 ± 0.1	< 0.001***
Sagittal dimension (*Y*/*Z*)	1.1 ± 0.1	1.1 ± 0.1	0.057
Volume (mm^3)	247.5 ± 27.1	233.1 ± 15.7	0.045*

PCF posterior cranial fossa, *LSR* lateral spread response

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

(shorter along the superior-inferior axis and longer along the left-right axis) was correlated with poor long-term outcome but not short-term outcome. We further investigated the relationship between flat-shaped PCF and postoperative recurrence as well as spasm delayed cure. It was demonstrated that a flat-shaped PCF influenced the spasm recurrence but did not delay the curative effect, which in turn suggested that the flatness of the PCF was a poor prognostic factor for MVD in HFS. We also explored the relationship between flat-shaped PCF and LSR, the latter of which was identified to be a prognostic factor for MVD in HFS. The results revealed that flat-shaped PCF might be a negative predictor for intraoperative LSR disappearance. We believe that the limited PCF space would attenuate the loose effect of NVC by CSF drainage and subsequent decompression. Thus, a larger craniectomy should be performed for cases with flat-shaped PCF to get space for vessels and nerves.

In our study, we modified a PCF ellipsoid model to quantify the parameters of PCF morphometry. All the parameters of PCF morphometry were directly measured on high-resolution MRI images by two independent neuroradiologists. We identified several useful prognostic factors of MVD for primary HFS. However, there are limitations in this study. First, the number of patients studied was small. Second, our follow-up was performed mainly by telephone interview and lasted for at least 1 year, and we cannot distinguish the subjective evaluation of different patients on the effect of spasm. However, the time periods of follow-up were not standardized. Selection bias thus cannot be excluded. To overcome these shortcomings, further studies with longer follow-up durations and more extensive data are needed.

Conclusion

Except for the identification of mild NVC, small vessel compression and intraoperative LSR persistence as negative prognostic factors of long-term MVD outcome for primary HFS, our current study demonstrated for the first time that flat-shaped PCF may be related to poor long-term outcome after MVD for primary HFS. A flat-shaped PCF increased the opportunity for HFS recurrence in patients.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the Medical Ethics Committee of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology (file number TJ-C20190387) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For retrospective study, formal consent is not required.

Informed consent Informed consent was obtained from all individual participants included in the study.

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