·神经影像学·

面肌痉挛微血管减压术前基于3D Slicer三维重建技术的可视化研究

李保华 周忠海 孟凡刚 张树新

【摘要】 **目的** 对比术前3D Slicer三维重建技术判断面肌痉挛责任血管与微血管减压术中实际所见的一致性。**方法** 纳入2018年7月至2024年1月在山东省东阿县人民医院行微血管减压术的62例面肌痉挛患者,术前均行三维稳态进动快速成像(3D-FIESTA)和三维时间飞跃(3D-TOF)MRA检查,通过3D Slicer软件将3D-FIESTA和3D-TOF MRA图像配准并进行三维重建以明确责任血管,以术中实际所见为"金标准",对比术前三维重建与术中实际所见的一致性。**结果** 共62例患者中61例经术前三维重建明确责任血管,分别为小脑前下动脉47例、小脑后下动脉6例、椎动脉5例、椎动脉联合小脑前下动脉2例、小脑上动脉1例;59例与术中实际所见责任血管一致,1例术前三维重建考虑为椎动脉压迫,术中证实为椎动脉联合小脑前下动脉压迫,1例术前三维重建考虑为小脑前下动脉压迫,术中证实为小脑前下动脉联合迷路动脉压迫,1例未发现明显责任血管,术中证实为小动脉压迫。术前三维重建判断责任血管的准确率为95.16%(59/62),经一致性检验,与术中实际所见的一致性较高($\kappa = 0.886$, $P = 0.000$)。**结论** 面肌痉挛患者微血管减压术前通过三维重建技术明确责任血管具有很高的准确性,有助于制定手术方案,为术中责任血管的判断提供依据。

【关键词】 痉挛; 面部肌肉; 微血管减压术; 磁共振成像

Preoperative visualization of hemifacial spasm microvascular decompression based on 3D Slicer 3D reconstruction technology

LI Bao-hua[1], ZHOU Zhong-hai[1], MENG Fan-gang[2], ZHANG Shu-xin[1]

[1]*Department of Neurosurgery, Dong'e County People's Hospital of Shandong Province, Liaocheng 252201, Shandong, China*

[2]*Beijing Neurosurgical Institute; Department of Neurosurgery, Beijing Tiantan Hospital, Capital Medical University, Beijing 100070, China*

Corresponding author: ZHANG Shu-xin (Email: zhangshuxin1216@163.com)

【**Abstract**】 **Objective** To compare the agreement in judging the responsible vessels for hemifacial spasm (HFS) between the preoperative 3D Slicer 3D reconstruction and the actual intraoperative judgment of microvascular decompression (MVD). **Methods** A total of 62 patients with HFS who underwent MVD in Dong'e County People's Hospital of Shandong Province from July 2018 to January 2024 were included. 3D fast inflow with the steady state precession (3D-FIESTA) and 3D time-of-flight (3D-TOF) MRA were performed before surgery. 3D Slicer software was used to fuse 3D-FIESTA and 3D-TOF MRA images and 3D reconstruction to clarify the responsible vessels. The actual intraoperative judgment was taken as the "gold standard", and the agreement between preoperative 3D reconstruction and actual intraoperative judgment was compared. **Results** There were 61 cases whose responsible vessels were identified by preoperative 3D reconstruction, including anterior inferior cerebellar artery (AICA) in 47 cases, posterior inferior cerebellar artery (PICA) in 6 cases, vertebral artery (VA) in 5 cases, VA + AICA in 2 cases, and superior cerebellar artery (SCA) in one case. The 59 cases were consistent with actual intraoperative judgment. In one case, the preoperative 3D reconstruction was considered as VA compression, and the intraoperative evidence was VA + AICA compression; in one case, preoperative 3D reconstruction was AICA

doi:10.3969/j.issn.1672-6731.2024.10.010

作者单位:252201 聊城,山东省东阿县人民医院神经外科(李保华,周忠海,张树新);100070 首都医科大学附属北京天坛医院神经外科 北京市神经外科研究所(孟凡刚)

通讯作者:张树新,Email:zhangshuxin1216@163.com

compression, and the intraoperative evidence was AICA + labyrinthine artery compression; no significant responsible vessels were found in one case, and the intraoperative evidence was arteriole compression. The accuracy of preoperative 3D reconstruction was 95.16% (59/62). Agreement test showed a high consistency between preoperative 3D reconstruction and actual intraoperative judgment (κ = 0.886, P = 0.000). **Conclusions** It is very accurate to define the responsible vessels by 3D reconstruction before MVD in patients with HFS, which is helpful to make the surgical plan and provide the basis for the judgment of the responsible vessels during the operation.

【**Key words**】 Spasm; Facial muscles; Microvascular decompression surgery; Magnetic resonance imaging

Conflicts of interest: none declared

面肌痉挛(HFS)是单侧面部阵发性、不自主抽搐,总体患病率为(7～15)/10万,年平均年龄标准化发病率约为1.53%,女性1.94%、男性1.05%,其中男性平均年发病率最高是60～79岁年龄段、女性为≥80岁年龄段[1-2]。药物治疗效果欠佳,微血管减压术(MVD)是有效治疗手段,文献报道约90.8%患者术后1周内痊愈,96.1%术后2年痊愈[3]。微血管减压术创伤小、效果良好,术后并发症包括眩晕、颅内感染、耳鸣、听力减退、面瘫等,特别是术后迟发性面瘫发生率约6.86%[4]。术前明确神经血管关系(NVR)有助于手术方案的制定,为术中责任血管的判断提供依据,是手术成功的关键。近年随着三维重建技术的迅速发展,3.0T磁共振仿真内镜重建技术在面肌痉挛中的应用显示出较高的临床价值[5],融合图像的三维重建判断原发性三叉神经痛责任血管的准确性显著高于常规MRI检查[6]。本研究通过术前三维稳态进动快速成像(3D-FIESTA)和三维时间飞跃(3D-TOF)MRA图像配准后三维重建判断责任血管,对比其与术中实际所见责任血管的一致性,有助于制定手术方案,为术中责任血管的判断提供依据。

资料与方法

一、临床资料

1.纳入标准 (1)符合面肌痉挛的典型临床症状诊断标准,即单侧面部肌肉阵发性、节律性抽搐或强直。(2)均为单侧病变。(3)经标准药物治疗无效或无法耐受药物不良反应。(4)首次行微血管减压术。(5)术前均行MRI检查。(6)所有患者或其家属均对手术风险知情并签署知情同意书。

2.排除标准 (1)存在凝血功能异常、一般状况差等常规开颅手术禁忌证。(2)存在体内金属物、幽闭恐惧症等MRI检查禁忌证。(3)影像学数据或临床资料不完整。

3.一般资料 选择2018年7月至2024年1月在山东省东阿县人民医院神经外科住院治疗的面肌痉挛患者共62例,男性22例,女性40例;年龄32～76岁,平均(55.74±9.49)岁;病程1个月至20年,中位病程3.50(1.00,7.25)年;左侧面肌痉挛24例(38.71%),右侧38例(61.29%);所有患者均行微血管减压术,术前完成MRI检查并进行3D Slicer三维重建。

二、研究方法

1.MRI检查 所有患者术前均采用Ingenia 3.0T MRI扫描仪(荷兰Philips公司)行MRI检查,扫描序列为3D-TOF MRA和3D-FIESTA。(1)3D-TOF MRA:重复时间(TR)19 ms、回波时间(TE)3.45 ms,翻转角(FA)18°,扫描视野(FOV)200 mm×200 mm,矩阵400×267,激励次数(NEX)2次,层厚1.10 mm、层间距-0.55 mm,共240层,扫描时间约480 s,扫描范围覆盖全脑。(2)3D-FIESTA:重复时间6.10 ms、回波时间2.40 ms,翻转角45°,扫描视野180 mm×180 mm,矩阵308×307,扫描层厚为1 mm、层间距为-0.50 mm,共75层,时间约240 s,以前庭蜗神经为中心层面,包括全脑干和双侧小脑。

2.三维重建 3D-TOF MRA和3D-FIESTA图像以DICOM格式保存,经我院影像归档和通信系统(PACS)下载导入3D Slicer软件(https://www.slicer.org/),应用软件自带的General Registration(Elastix)模块对3D-TOF MRA和3D-FIESTA图像进行配准,使二者具备空间位置一致性;然后应用Editor模块提取3D-FIESTA序列中面神经、前庭蜗神经、脑干和小脑半球、小脑蚓部、小脑扁桃体结构信息,以及3D-TOF MRA中血管位置和走行信息;最后将具有

空间位置一致性的配准图像进行三维重建，调整观察角度，以备与术中实际进行对比。

3. 微血管减压术　患者侧卧位，以美国Mayfield公司生产的Mayfield手术头架固定头部，乳突根部位于最高点，静吸复合麻醉，采取乙状窦后入路，于耳后发际内做斜切口，长度约为8 cm，切开硬脑膜，探查面神经，充分显露面神经根部及面神经根出脑干区（REZ），判断责任血管，以术中所见神经血管关系为"金标准"，于显微镜下自后组脑神经尾端向头端锐性分离蛛网膜，显露血管与面神经位置关系，将Teflon棉垫入面神经根出脑干区与血管接触区域，解除压迫。36.5 ℃生理盐水彻底冲洗术野，确保无出血后严密缝合硬脑膜，逐层缝合切口。

4. 术后疗效观察　术后24 h判断手术疗效，痊愈，面肌痉挛症状完全消失；明显缓解，面肌痉挛症状基本消失，仅在情绪紧张激动时或特定面部动作时偶尔诱发面肌痉挛；部分缓解，面肌痉挛症状减轻，但仍较频繁发作；无效，面肌痉挛症状无变化，甚至加重。痊愈、明显缓解、部分缓解为有效，计算有效率[有效率（%）=（痊愈例数+明显缓解例数+部分缓解例数）/总例数×100%]。同时记录手术相关并发症，包括面瘫、小脑挫伤、听力减退、声音嘶哑、饮水呛咳、脑脊液漏等。

5. 统计分析方法　采用SPSS 25.0统计软件进行数据处理与分析。计数资料以相对数构成比（%）或率（%）表示，呈正态分布的计量资料以均数±标准差（$\bar{x} \pm s$）表示、非正态分布的计量资料以中位数和四分位数间距[$M(P_{25}, P_{75})$]表示。术前3D-TOF MRA与3D-FIESTA配准和三维重建判断责任血管与术中实际所见责任血管的一致性采用Kappa检验（$\kappa \geqslant 0.75$为一致性较高，$0.40 \leqslant \kappa < 0.75$为一致性中等，$\kappa < 0.40$为一致性较低）。以$P \leqslant 0.05$为差异具有统计学意义。

结　果

本组患者术后痊愈44例（70.97%），明显缓解10例（16.13%），部分缓解7例（11.29%），无效1例（1.61%），治疗有效率达98.39%（61/62）。术后并发面瘫5例（8.06%），予激素和扩血管药物治愈；小脑挫伤1例（1.61%），经脱水治疗后治愈。

术前经3D-TOF MRA与3D-FIESTA配准判断责任血管，60例发现责任血管，分别为小脑前下动脉（AICA）45例、小脑后下动脉（PICA）5例、椎动脉（VA）6例、椎动脉联合小脑前下动脉1例、小脑上动脉（SCA）3例，其中54例与术中实际所见责任血管一致；2例未发现明显责任血管，术中证实分别为小脑前下动脉和小动脉压迫。术前3D-TOF MRA与3D-FIESTA配准判断责任血管的准确率为87.10%（54/62）。经一致性检验发现，术前3D-TOF MRA与3D-FIESTA配准判断责任血管与术中实际所见责任血管的一致性中等（$\kappa = 0.711$，$P = 0.000$；表1）。术前经三维重建发现，神经血管压迫主要集中于面神经根出脑干区，61例发现责任血管，分别为小脑前下动脉47例、小脑后下动脉6例、椎动脉5例、椎动脉联合小脑前下动脉2例（图1）、小脑上动脉1例，其中59例与术中实际所见责任血管一致，1例术前三维重建考虑为椎动脉压迫，术中证实为椎动脉联合小脑前下动脉压迫（图2），1例术前三维重建考虑为小脑前下动脉压迫，术中证实为小脑前下动脉联合迷路动脉压迫，这两例患者术后均痊愈；1例术前三维重建未发现明显责任血管，术中证实为小动脉压迫。术前三维重建判断责任血管的准确率为95.16%（59/62）。经一致性检验发现，术前三维重建判断责任血管与术中实际所见责任血管的一致性较高（$\kappa = 0.886$，$P = 0.000$；表2）。

讨　论

面肌痉挛指单侧面部肌肉受同侧面神经支配而发生不自主抽搐或强直，分为原发性和继发性，原发性面肌痉挛系面神经血管压迫；继发性面肌痉挛可能由脑桥小脑角肿瘤、颅内动静脉畸形、颅内动脉瘤、神经肠源性囊肿等所继发。绝大多数为后颅窝面神经根出脑干区的血管压迫引起原发性面肌痉挛[7-8]，小脑前动脉（ACA）和小脑后动脉（PCA）是最常见的责任血管；其次是椎动脉，但是椎动脉作为单独责任血管者较少见，常联合其他动脉共同压迫，此时椎动脉多为次要责任血管；迷路动脉及其他小动脉也可引发面神经压迫症状[9-10]。面肌痉挛患者面神经运动核团兴奋性增高，诱发运动神经元之间突触短路，从而引起面部肌肉不自主抽搐或强直[11]。微血管减压术通过将责任血管推离面神经根出脑干区而达到治疗目的[12]，是目前最有效且广泛应用的治疗手段，而术前准确判断神经血管关系、最大程度避免术中盲目探查或探查不充分，是提高手术疗效和降低手术相关并发症的关键。

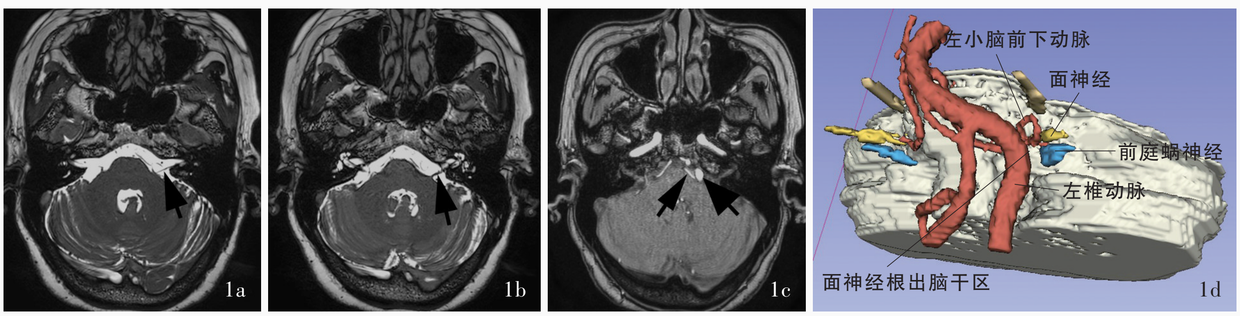
MRI技术的发展提高了神经血管压迫的检出

表1 术前3D-TOF MRA和3D-FIESTA配准图像与术中实际判断责任血管的一致性[例(%)]*

Table 1. Agreement of preoperative 3D-TOF MRA with 3D-FIESTA fusion image and actual intraoperative judgment of responsible vessels [case (%)]*

术中实际	3D-TOF MRA与3D-FIESTA配准						合计
	AICA	PICA	VA	VA + AICA	SCA	无	
AICA	43(69.35)	0(0.00)	0(0.00)	0(0.00)	2(3.23)	1(1.61)	46(74.19)
PICA	1(1.61)	5(8.06)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	6(9.68)
VA	0(0.00)	0(0.00)	4(6.45)	0(0.00)	0(0.00)	0(0.00)	4(6.45)
VA + AICA	0(0.00)	0(0.00)	2(3.23)	1(1.61)	0(0.00)	0(0.00)	3(4.84)
AICA + 迷路动脉	1(1.61)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	1(1.61)
SCA	0(0.00)	0(0.00)	0(0.00)	0(0.00)	1(1.61)	0(0.00)	1(1.61)
小动脉	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	1(1.61)	1(1.61)
合计	45(72.58)	5(8.06)	6(9.68)	1(1.61)	3(4.84)	2(3.23)	62(100.00)

*$\kappa = 0.711$, $P = 0.000$。3D-TOF, three-dimensional time-of-flight, 三维时间飞跃; 3D-FIESTA, three-dimensional fast inflow with the steady state precession, 三维稳态进动快速成像; AICA, anterior inferior cerebellar artery, 小脑前下动脉; PICA, posterior inferior cerebellar artery, 小脑后下动脉; VA, vertebral artery, 椎动脉; SCA, superior cerebellar artery, 小脑上动脉



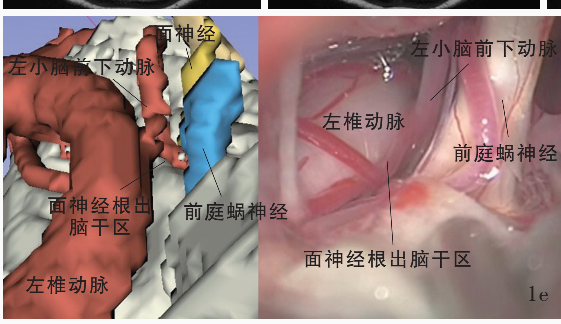
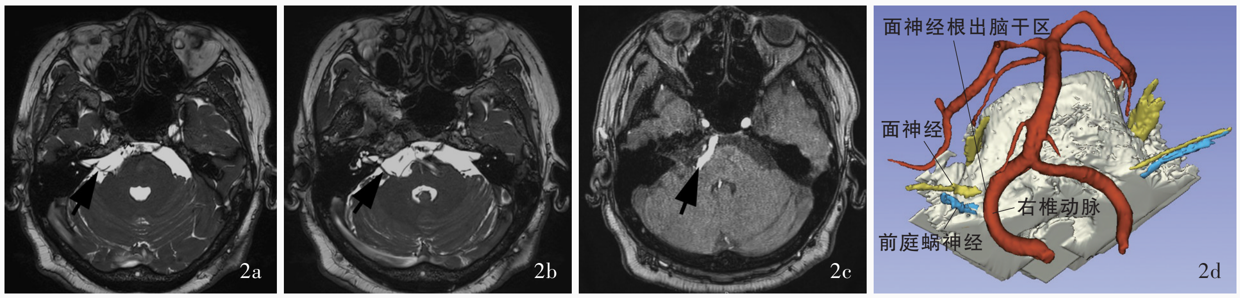


图1 女性患者，63岁，临床诊断为左侧面肌痉挛，行微血管减压术。术前MRI和术中所见 1a 术前横断面3D-FIESTA显示，面神经位于前庭蜗神经前上方，较细小(箭头所示) 1b 术前横断面3D-FIESTA显示，前庭蜗神经位于面神经后下方，较粗大(箭头所示) 1c 术前横断面3D-TOF MRA可见左椎动脉(粗箭头所示)和左小脑前下动脉(细箭头所示) 1d 经术前三维重建明确责任血管为左椎动脉联合左小脑前下动脉 1e 术中于显微镜下可见责任血管为左椎动脉联合左小脑前下动脉(左图为术前三维重建对比图)

Figure 1 A 63-year-old female patient with a clinical diagnosis of left HFS underwent MVD. Preoperative MRI and intraoperative findings Axial 3D-FIESTA showed the facial nerve was located in front and above the vestibulocochlear nerve and was smaller (arrow indicates, Panel 1a). Axial 3D-FIESTA showed the vestibulocochlear nerve was located behind and below the facial nerve and was larger (arrow indicates, Panel 1b). Axial 3D-TOF MRA showed the left VA (thick arrow indicates) and left AICA (thin arrow indicates, Panel 1c). Preoperative 3D reconstruction showed the responsible vessels were identified as the left VA + AICA (Panel 1d). During the operation, the responsible vessels under the microscope were the left VA + AICA (the left Figure was a comparison of preoperative 3D reconstruction, Panel 1e).

率，特别是判断面肌痉挛患者面神经根出脑干区责任血管的准确率，扫描序列为高分辨率3D-FIESTA、3D-TOF MRA和3D-T_1WI增强扫描，存在神经血管压迫时，这些技术对判断责任血管具有很高的准确性[13]。3D-FIESTA和3D-TOF MRA各有其优缺点，3D-FIESTA序列可以清晰显示脑脊液、神经血管结构，但扫描视野较小；3D-TOF MRA可以显示面神经周围基底动脉、椎动脉、小脑上动脉、小脑前下动脉等，但无法清晰显示前庭蜗神经结构[14-15]；而二者均无法直观显示神经血管的空间位置关系，因此均需构建三维空间模型。面神经-前庭蜗神经脑池段走行于桥延沟后外侧1/3，外侧与耳蜗相连续，多平面重建(MPR)序列上面神经与前庭蜗神经走行相一致，近端稍分开，再向外并行进入内耳道。术前于3D-FIESTA序列上标记出面神经和前庭蜗神经的解剖关系，面神经靠前，较细小，前庭蜗神经靠后，较粗大[16-17]。对多种图像、序列进行多模态融合重建，取长补短，可综合多种图像的优点，更直观显示解



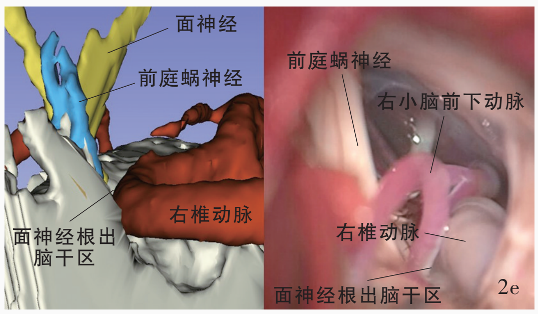


图2 女性患者，46岁，临床诊断为右侧面肌痉挛，行微血管减压术。术前MRI和术中所见 2a 术前横断面3D-FIESTA显示，面神经位于前庭蜗神经前方，较细小（箭头所示） 2b 术前横断面3D-FIESTA显示，前庭蜗神经位于面神经后方，较粗大（箭头所示） 2c 术前横断面3D-TOF MRA可见右椎动脉（箭头所示） 2d 术前经三维重建明确责任血管为右椎动脉 2e 术中于显微镜下可见责任血管为右椎动脉联合右小脑前下动脉（左图为术前三维重建对比图）

Figure 2 A 46-year-old female patient with a clinical diagnosis of right HFS underwent MVD. Preoperative MRI and intraoperative findings Axial 3D-FIESTA showed the facial nerve was located in front of the vestibulocochlear nerve and was smaller (arrow indicates, Panel 2a). Axial 3D-FIESTA showed the vestibulocochlear nerve was located behind the facial nerve and was larger (arrow indicates, Panel 2b). Axial 3D-TOF MRA showed the right VA (arrow indicates, Panel 2c). Preoperative 3D reconstruction showed the responsible vessel was identified as the right VA (Panel 2d). During the operation, the responsible vessels under the microscope were the right VA + AICA (the left Figure was a comparison of preoperative 3D reconstruction, Panel 2e).

表2 术前三维重建与术中实际所见责任血管的一致性[例(%)]*

Table 2. Agreement of preoperative 3D reconstruction and actual intraoperative judgment of responsible vessels [case (%)]*

术中实际	术前三维重建						合计
	AICA	PICA	VA	VA + AICA	SCA	无	
AICA	46(74.19)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	46(74.19)
PICA	0(0.00)	6(9.68)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	6(9.68)
VA	0(0.00)	0(0.00)	4(6.45)	0(0.00)	0(0.00)	0(0.00)	4(6.45)
VA + AICA	0(0.00)	0(0.00)	1(1.61)	2(3.23)	0(0.00)	0(0.00)	3(4.84)
AICA + 迷路动脉	1(1.61)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	1(1.61)
SCA	0(0.00)	0(0.00)	0(0.00)	0(0.00)	1(1.61)	0(0.00)	1(1.61)
小动脉	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	1(1.61)	1(1.61)
合计	47(75.81)	6(9.68)	5(8.06)	2(3.23)	1(1.61)	1(1.61)	62(100.00)

*$\kappa = 0.886$, $P = 0.000$。AICA, anterior inferior cerebellar artery，小脑前下动脉；PICA, posterior inferior cerebellar artery，小脑后下动脉；VA, vertebral artery，椎动脉；SCA, superior cerebellar artery，小脑上动脉

剖结构和血管位置、走行，并制定手术策略、模拟手术入路，达到精准手术的目的[18-19]。3D Slicer三维重建技术可以直观、多角度展示颅内病变及其周围解剖结构[20]，通过3D Slicer软件从3D-FIESTA图像中提取神经、脑干、小脑、静脉解剖，从3D-TOF MRA图像中提取动脉位置及走行，通过配准、融合、分割建立三维图像，显示出神经血管的三维空间关系，业已在原发性三叉神经痛微血管减压术中证实与术中实际所见相一致，实现术前可视化[21]。在本研究中，术前通过三维重建判断责任血管的准确率为95.16%（59/62）。

本研究通过术前3D-FIESTA与3D-TOF MRA融合三维重建以明确面肌痉挛的责任血管，与术中实际所见高度一致，面肌痉挛微血管减压术前通过三维重建技术明确责任血管具有很高的准确性，有助于制定手术方案，为术中判断责任血管提供依据。但是3D-TOF MRA无动脉壁信息，因此三维重建图像仍可造成血管与神经接触距离增大的假象，与仅3D-FIESTA与3D-TOF MRA配准图像相比，三维重建判断责任血管具有更高的准确性，但仍有不能反

应压迫程度的缺点;此外,本研究未发现静脉压迫等特殊病例,未来尚待大样本研究进一步验证。

利益冲突 无

参 考 文 献

[1] Nurminen P, Marjamaa J, Niemelä M, Sairanen T. Incidence and prevalence of hemifacial spasm in Finland's largest hospital district[J]. J Neurol Sci, 2023, 446:120587.

[2] Lu AY, Yeung JT, Gerrard JL, Michaelides EM, Sekula RF Jr, Bulsara KR. Hemifacial spasm and neurovascular compression [J]. ScientificWorldJournal, 2014:ID349319.

[3] Truong VT, Ngo MQ, Phan D, Le H, Tran Hoang NA. Results from 228 patients with hemifacial spasm undergoing microvascular decompression without intraoperative neuroelectrophysiology monitoring[J]. World Neurosurg, 2024, 185:e461-e466.

[4] Guan YH, Zheng G, Li G, Chen SJ. Delayed facial palsy after microvascular decompression for hemifacial spasm: multivariate Logistic regression analysis of influencing factors[J]. Zhongguo Xian Dai Shen Jing Ji Bing Za Zhi, 2020, 20:1099-1103.[管玉华, 郑刚, 李刚, 陈少军. 面肌痉挛微血管减压术后迟发性面瘫影响因素分析[J]. 中国现代神经疾病杂志, 2020, 20:1099-1103.]

[5] Chen LJ, Chen SX, Ma N, Xu L, Dai YQ. Research of 3.0 T MRI virtual endoscopy reconstruction in hemifacial spasm[J]. Ci Gong Zhen Cheng Xiang, 2014, 5:189-192.[陈利军, 陈士新, 马宁, 徐林, 代永庆. 3.0T MRI仿真内窥镜重建技术在面肌痉挛中的应用研究[J]. 磁共振成像, 2014, 5:189-192.]

[6] Jiao YB, Duan F, Yan ZY, Meng QH, Feng YG. The value of 3D-TOF-MRA and 3D-FIESTA fusion three-dimensional images in judgment of offending vessel in primary trigeminal neuralgia [J]. Zhonghua Shen Jing Wai Ke Za Zhi, 2019, 35:928-932.[焦迎斌, 段峰, 闫志勇, 孟庆海, 丰育功. 3D-TOF-MRA和3D-FIESTA三维融合图像在判断原发性三叉神经痛责任血管中的作用[J]. 中华神经外科杂志, 2019, 35:928-932.]

[7] Teton ZE, Blatt D, Holste K, Raslan AM, Burchiel KJ. Utilization of 3D imaging reconstructions and assessment of symptom-free survival after microvascular decompression of the facial nerve in hemifacial spasm[J]. J Neurosurg, 2019, 133:425-432.

[8] Park JS, Park K. Operative findings of over 5000 microvascular decompression surgeries for hemifacial spasm: our perspective and current updates[J]. Life (Basel), 2023, 13:1904.

[9] Hermier M. Imaging of hemifacial spasm[J]. Neurochirurgie, 2018, 64:117-123.

[10] Hao Y, Yu YB, Wang Q, Zhao YR, Zhang BJ, Aori GL, Zhang L. Microvascular decompression for treatment of hemifacial spasm[J]. Zhonghua Shen Jing Wai Ke Za Zhi, 2017, 33:887-891.[郝杨, 于炎冰, 王琦, 赵有让, 张保建, 敖日格勒, 张黎. 显微血管减压术治疗面肌痉挛[J]. 中华神经外科杂志, 2017, 33:887-891.]

[11] Yang DB, Zhou SJ, Wang ZM. Excitability of facial nerve motor nucleus in patients with hemifacial spasm[J]. Zhonghua Shen Jing Yi Xue Za Zhi, 2021, 20:617-620.[杨德宝, 周世军, 王之敏. 面肌痉挛患者面神经运动核团的兴奋性研究[J]. 中华神经医学杂志, 2021, 20:617-620.]

[12] Li DX, Niu CS. Pathogenesis and progress of surgical treatment of hemifacial spasm[J]. Zhonghua Shen Jing Yi Xue Za Zhi, 2018, 17:746-749.[李冬雪, 牛朝诗. 面肌痉挛的发病机制及治疗研究进展[J]. 中华神经医学杂志, 2018, 17:746-749.]

[13] Liang C, Yang L, Reichardt W, Zhang B, Li R. Different MRI-based methods for the diagnosis of neurovascular compression in trigeminal neuralgia or hemifacial spasm: a network meta-analysis[J]. J Clin Neurosci, 2023, 108:19-24.

[14] Guo TT, Zhang QM, Xu J, Miao CC. Application of the fusion imaging of 3D-TOF and 3D-FIESTA sequences in microvascular decompression for trigeminal neuralgia by 3.0T MR system[J]. Lin Chuang Fang She Xue Za Zhi, 2018, 37:387-391.[郭田田, 张秋妹, 徐建, 苗重昌. 3.0T MR 3D-TOF序列与3D-FIESTA序列融合图像在三叉神经微血管减压术术前评估中的应用价值[J]. 临床放射学杂志, 2018, 37:387-391.]

[15] Wu LQ, Wang JM, Wang L, Zhang SQ, Tian DF, Chen ZB, Chen QX. Application value of 3D-FIESTA combining 3D-TOF MRA in preoperative evaluation of microvascular decompression for cranial nerve[J]. Lin Chuang Wai Ke Za Zhi, 2013, 21:788-790.[吴立权, 王军民, 王龙, 张申起, 田道锋, 陈治标, 陈谦学. 三维稳态进动快速成像序列结合三维时间飞跃法血管造影在颅神经微血管减压术前的应用价值[J]. 临床外科杂志, 2013, 21:788-790.]

[16] Yang SH, Park H, Yoo DS, Joo W, Rhoton A. Microsurgical anatomy of the facial nerve[J]. Clin Anat, 2021, 34:90-102.

[17] Zhang WG, Zhang SX, Wu BH, Chen JH, Tan LW. Comparative study on sectional anatomy of the abducent nerve, facial nerve and vestibulocochlear nerve with MRI and plastination[J]. Zhongguo Lin Chuang Jie Pou Xue Za Zhi, 2002, 20:279-282.[张伟国, 张绍祥, 巫北海, 陈金华, 谭立文. Ⅵ~Ⅷ对脑神经生物塑化薄片断层解剖与MRI对照研究[J]. 中国临床解剖学杂志, 2002, 20:279-282.]

[18] Zhang LW. Application value of multimodal fusion technology in the era of precision neurosurgery[J]. Zhonghua Shen Jing Wai Ke Za Zhi, 2018, 34:325-326.[张力伟. 多模态融合技术在精准神经外科治疗时代的应用价值[J]. 中华神经外科杂志, 2018, 34:325-326.]

[19] Jian ZH, Chen P, Li Y, Liao CC, Yi XF, Zhan RG, Chen G. Surgical management of complex skull base tumor using preoperative multimodal image fusion technology [J]. J Craniofac Surg, 2024, 35:853-859.

[20] Ma LT, Zhang WW, Mei JM, Niu CS. Application of multi-modal image fusion three-dimensional reconstruction technology in operation of meningioma in the central area of the brain[J]. Zhongguo Xian Dai Shen Jing Ji Bing Za Zhi, 2022, 22:187-194.[马龙涛, 张伟文, 梅加明, 牛朝诗. 多模态影像融合三维重建技术在颅内中央区脑膜瘤手术中的应用[J]. 中国现代神经疾病杂志, 2022, 22:187-194.]

[21] Shono N, Kin T, Saito N. Preoperative 3D microvascular decompression simulation[J]. No Shinkei Geka, 2024, 52:163-176.

(收稿日期:2024-09-03)
(本文编辑:彭一帆)