·脑血管重建术·

顺血流搭桥术与逆血流搭桥术对烟雾病患者桥血管血流通畅性的对比分析

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【摘要】 **目的**　总结烟雾病患者大脑中动脉供血区血流方向，对比分析顺血流搭桥术与逆血流搭桥术对围手术期并发症和桥血管长期通畅性的影响。**方法**　纳入2010年6-12月在复旦大学附属华山医院行颞浅动脉-大脑中动脉搭桥术联合脑-硬膜-颞肌贴敷术和硬膜翻转术的50例烟雾病患者，术前均根据DSA判断大脑中动脉供血区血流方向，并根据桥血管血流方向分为顺血流组（与受体动脉血流方向一致，32例）和逆血流组（与受体动脉血流方向相反，18例）。吲哚菁绿荧光血管造影术（ICGA）观察术中血流对冲现象，记录围手术期短暂性神经功能障碍和术后30天缺血性卒中发生率；中期随访（平均为7.31个月）分别以DSA和Matsushima分级系统评价吻合口通畅性及桥血管供血范围；远期疗效（平均39.72个月）则以TCD显示的桥血管收缩期峰值流速（PSV）、舒张期末流速（EDV）和阻力指数（RI）等血流动力学特征为主要评价指标。**结果**　ICGA证实两组患者吻合口均保持通畅，但顺血流组血流对冲（$\chi^2=4.668$，$P=0.031$）和术后短暂性神经功能障碍（$\chi^2=6.630$，$P=0.010$）发生率均低于逆血流组，而术后30天缺血性卒中发生率组间差异无统计学意义（$\chi^2=0.177$，$P=0.674$）；中期随访时，吻合口仍保持通畅，两组桥血管供血范围差异亦无统计学意义（$\chi^2=0.613$，$P=0.434$）；长期随访时，顺血流组桥血管PSV（$t=3.599$，$P=0.001$）和EDV（$t=2.993$，$P=0.004$）高于逆血流组、RI低于逆血流组（$t=3.328$，$P=0.002$）。**结论**　顺血流搭桥术可以有效降低围手术期分水岭推移和术后短暂性神经功能障碍的风险，且远期疗效观察其桥血管血流速度更快、阻力指数更低。

【关键词】 脑底异常血管网病；　脑血管重建术；　大脑中动脉；　血流动力学；　手术中并发症；　手术后并发症

Analysis of middle cerebral artery blood flow in moyamoya disease and comparison of orthodromic and antidromic bypass

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【Abstract】 **Objective**　To analysis the middle cerebral artery (MCA) blood flow direction and compare the efficacy and safety of orthodromic and antidromic bypass. **Methods**　Fifty cases with moyamoya disease (MMD) surgical treated in Huashan Hospital of Fudan University from June to December 2010 were enrolled in the study. MCA blood flow direction was analysed according to DSA and classified into two types (antegrade flow and reversed flow). The surgical procedure was superficial temporal artery (STA)-MCA bypass, combined with encephalo-duro-myo-synangiosis (EDMS) and dural subvolution. For the bypass procedure, when blood flow in donor and recipient artery was in same direction, the case would be classified into orthodromic bypass group (orthodromic group, 32 cases), otherwise as antidromic bypass group (antidromic group, 18 cases). Blood flow interference phenomenon on cortex surface detected by intraoperative indocyanine green angiography (ICGA), postoperative transient neurological dysfunction (TND) and ischemic stroke in postoperative 30 d. DSA data and Matsushima grading system were used to evaluate anastomotic patency and bypass blood perfusion area in mid-term follow-up (mean 7.31 months).

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Hemodynamic parameters such as peak systolic velocity (PSV), end diastolic velocity (EDV) and resistant index (RI) demonstrated by transcranial Doppler (TCD) in long-term follow-up (mean 39.72 months) were all documented and used to compare the safety and efficacy between 2 groups. **Results** Patency of all stomas were confirmed by ICGA. The orthodromic group demonstrated a lower rate of blood flow interference (χ^2 = 4.668, P = 0.031) and TND (χ^2 = 6.630, P = 0.010) compared with antidromic group. The incidence of ischemic stroke had no difference between 2 groups (χ^2 = 0.177, P = 0.674). In mid-term follow-up, DSA confirmed the patency of all stomas, and no difference in bypass blood perfusion area between 2 groups (χ^2 = 0.613, P = 0.434). During long-term follow-up, syndromic group showed higher PSV (t = 3.599, P = 0.001) and EDV (t = 2.993, P = 0.004), and lower RI (t = 3.328, P = 0.002) compared with antidromic group. **Conclusions** Orthodromic bypass may reduce the risk of watershed shift and TND in perioperative period, increase blood flow velocity and decrease RI in the bypass vessel in long-term follow-up.

【Key words】 Moyamoya disease; Cerebral revascularization; Middle cerebral artery; Hemodynamics; Intraoperative complications; Postoperative complications

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Conflicts of interest: none declared

烟雾病(MMD)是一种病因不明的慢性闭塞性脑血管病,主要累及双侧颈内动脉(ICA)末端,以及大脑前动脉(ACA)和大脑中动脉(MCA)起始部,伴特征性"烟雾"状血管形成[1-3]。颞浅动脉-大脑中动脉(STA-MCA)搭桥术是治疗烟雾病的经典术式,其临床疗效已经验证[4-5]。但该术式供体动脉与受体动脉之间的血流竞争可导致脑血流动力学紊乱[6-7],引起术后短暂性神经功能障碍[8]或脑梗死[9-10],亦可影响桥血管的长期通畅性,导致管腔狭窄甚至闭塞[11]。理论上认为,供体动脉与受体动脉血流方向一致的顺血流搭桥术更为合理,但一直缺少临床验证;加之各种侧支循环的形成,使烟雾病患者大脑中动脉供血区血流方向错综复杂[12],难以形成固定的顺血流搭桥术或逆血流搭桥术。本研究对复旦大学附属华山医院早期接受顺血流搭桥术或逆血流搭桥术的烟雾病患者的临床资料进行回顾分析,总结此类患者大脑中动脉供血区血流特征,初步探讨两种术式对围手术期并发症和桥血管长期通畅性的影响。

对象与方法

一、研究对象

1.病例选择 (1)烟雾病诊断参照2012年日本烟雾病(Willis环自发性闭塞)诊断与治疗指南[1],并经全脑血管造影证实。(2)排除手术禁忌证后行颅内外联合血管重建术[13]。(3)年龄≥18岁。(4)所有手术均由徐斌教授研究团队完成。(5)所有患者及其家属均对手术方案知情并签署知情同意书。

2.一般资料 选择2010年6-12月在我院神经外科行颅内外联合血管重建术的烟雾病患者共计50例,男性28例,女性22例;年龄19~60岁,平均(42.33±7.81)岁;发病类型为缺血型26例(短暂性脑缺血发作15例、缺血性卒中11例),出血型24例(脑室出血18例、脑血肿5例、自发性蛛网膜下腔出血1例);左侧病变26例,右侧24例。

二、研究方法

1.大脑中动脉供血区血流方向判定 根据术前DSA检查结果分为正向血流和逆向血流。正向血流系指大脑中动脉血流自近颈内动脉一端即解剖近端流向远端,尽管存在大脑中动脉M1段狭窄或闭塞,但经"烟雾"状血管等侧支代偿后形成前向血流,与生理状态相一致,在大脑皮质表面表现为远离侧裂的模式,侧裂上方血流自下而上、侧裂下方血流自上而下;逆向血流则与之相反,主要经大脑前动脉和大脑后动脉(PCA)软膜支代偿,血流自解剖远端流向近端,与生理状态相反,在大脑皮质表面表现为流向侧裂的模式(图1)。

2.STA-MCA搭桥术联合脑-硬膜-颞肌贴敷术 患者仰卧位,气管插管全身麻醉,头偏向对侧,扩大翼点切口,分别形成皮肌瓣,自颅骨表面完整剥离颞肌,形成额颞骨瓣,保护脑膜中动脉,根据脑膜中动脉的主要分支将硬脑膜裁剪成大小不一的三角形,严格止血后翻转至骨窗外硬膜下间隙,使其富含血管网的外表面与该区域皮质表面形成接触。通常以侧裂相邻直径约1 mm的皮质支作为受体动脉,根据吻合口位置,在皮瓣内表面分离适宜长度

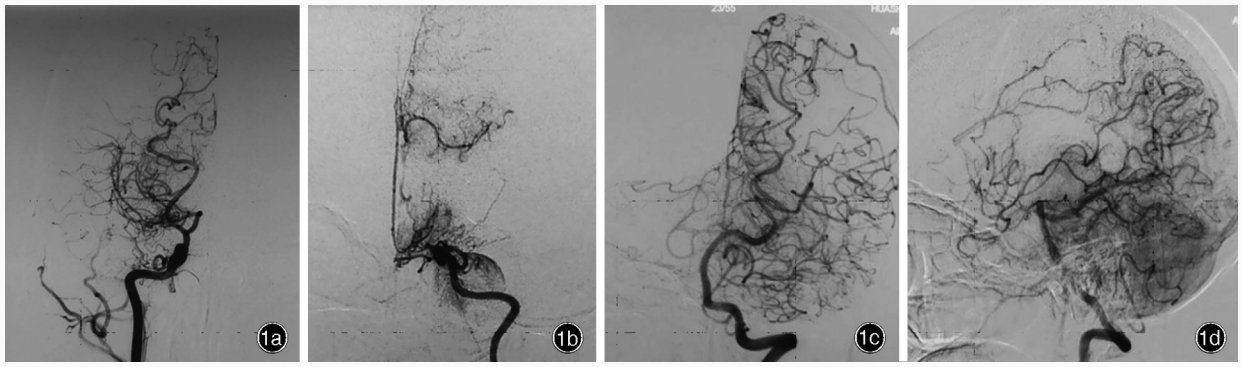


图1　经DSA判断大脑中动脉供血区血流方向　1a　右颈内动脉正位像显示，右大脑中动脉M1段呈“烟雾”状改变，经吻合支形成前向血流，血流方向与生理状态一致，为远离侧裂的正向血流　1b　左颈内动脉正位像显示，左颈内动脉末端完全闭塞，左大脑中动脉主要经软膜支代偿，血流方向与生理状态相反，为指向侧裂的逆向血流　1c，1d　左椎动脉正侧位像显示，左大脑中动脉主要经软膜支代偿，血流方向与生理状态相反，为指向侧裂的逆向血流

Figure 1　Analysis of MCA blood flow direction by DSA　DSA anterior view of right ICA showed moyamoya change in M1 segment, distal vessel was perfused via moyamoya vessels in brain bottom. Blood flow was antegrade, following the physical direction, emerging from the sylvian fissure (Panel 1a). DSA anterior view of left ICA showed totally occlusion of its terminal segment, left MCA mainly compensated via meningeal branch. Blood flow was antidromic, opposite the physical direction, filling into the sylvian fissure (Panel 1b). DSA anterior view (Panel 1c) and lateral view (Panel 1d) of left VA showed left MCA mainly compensated via meningeal branch. Blood flow was antidromic, opposite the physical direction, filling into the sylvian fissure.

的颞浅动脉并于远端切断、穿过颞肌，远端修剪为约45°斜口，肝素生理盐水冲洗后亚甲蓝标记内膜备用；挑开受体表面蛛网膜，临时阻断后“凸透镜”形剪开并以亚甲蓝标记内膜备用；以10-0缝线行颞浅动脉与大脑中动脉端侧吻合，间断缝合吻合口，即刻行吲哚菁绿荧光血管造影术（ICGA）观察吻合口是否通畅、大脑皮质表面是否出现血流对冲现象。将颞肌贴敷于皮质表面，周围缝合于硬脑膜翻转处并固定于骨窗边缘的骨孔以重建附着点，防止颞肌萎缩，少量去除骨瓣下部以免卡压颞肌和颞浅动脉，分层缝合[13]。术后复查DSA，根据术中所见和术后DSA判断桥血管血流方向，与受体动脉血流方向一致为顺血流搭桥术，相反为逆血流搭桥术。

3. 围手术期并发症以及脑血流动力学评估　（1）围手术期：记录术中ICGA显示的血流对冲现象发生率和术后短暂性神经功能障碍（TND）发生率。短暂性神经功能障碍定义为术后出现的失语、偏瘫等症状或体征，且无颅内出血或脑梗死等器质性病变的影像学证据，通常于术后2周内完全消失或者大部分缓解。（2）术后短期随访：记录术后30天脑梗死发生率。（3）术后中期随访：术后平均随访7.31个月，通过DSA评估吻合口通畅性和桥血管供血范围，其中桥血管供血范围采用Matsushima分级系统，A级为桥血管供血范围＞大脑中动脉供血区的2/3，B级为大脑中动脉供血区的1/3～2/3，C级为＜大脑中动脉供血区的1/3，其中A和B级定义为供血范围大、C级为供血范围小。（4）术后长期随访：术后平均随访39.72个月，采用经颅多普勒超声（TCD）评估桥血管血流动力学特征，主要包括收缩期峰值流速（PSV）、舒张期末流速（EDV）和阻力指数（RI）。

4. 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，采用χ^2检验；呈正态分布的计量资料以均数±标准差（$\bar{x}\pm s$）表示，采用两独立样本的t检验。以$P\leq0.05$为差异具有统计学意义。

结　果

本组50例患者根据术前DSA影像，大脑中动脉供血区为正向血流者29例，逆向血流者21例；根据术中所见和术后DSA影像，桥血管血流方向与受体动脉一致（顺血流组）32例，相反（逆血流组）18例，顺血流组与逆血流组患者性别、年龄、发病类型和病变侧别差异无统计学意义（均$P>0.05$，表1）。

术中ICGA证实所有患者均吻合口通畅，顺血流组血流对冲现象（图2，$P=0.031$）和术后短暂性神经功能障碍（$P=0.010$）发生率均低于逆血流组且差异有统计学意义（表2）。术后短期随访，两组缺血性卒中发生率差异无统计学意义（$P=0.674$，表2）。

术后中期随访DSA显示所有患者吻合口保持

表1　顺血流组与逆血流组患者一般资料的比较

Table 1.　Comparison of general information between orthodromic group and antidromic group

观察指标	顺血流组（n=32）	逆血流组（n=18）	χ^2或t值	P值
性别[例(%)]			0.002	0.962
男性	18(56.25)	10(10/18)		
女性	14(43.75)	8(8/18)		
年龄($\bar{x}\pm s$,岁)	42.03±1.73	42.78±2.32	0.258	0.797
发病类型[例(%)]			0.038	0.845
缺血型	16(50.00)	10(10/18)		
出血型	16(50.00)	8(8/18)		
病变侧别[例(%)]			0.045	0.832
左侧	17(53.13)	9(9/18)		
右侧	15(46.88)	9(9/18)		

Two-independent-sample t test for comparison of age, and χ^2 test for comparison of others,年龄的比较行两独立样本的t检验,其余各项的比较行χ^2检验

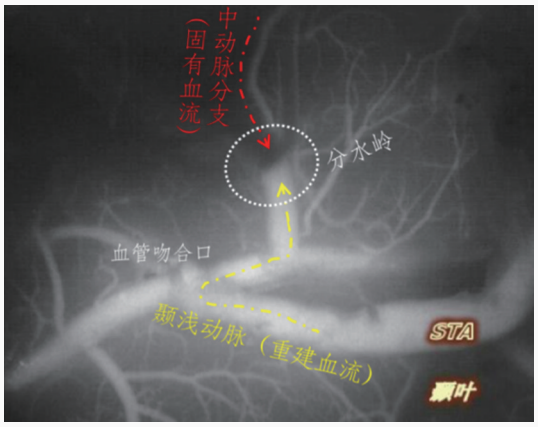
通畅,顺血流组桥血管管径较粗大,可反流至大脑中动脉M2段甚至M1段,与逆血流组形成鲜明对比,间接提示前者桥血管具有更强的供血能力(图3)。根据Matsushima分级系统,顺血流组桥血管供血范围达A和B级者23例(71.88%),逆血流组11例(11/18),组间差异未达到统计学意义($\chi^2=0.613$,$P=0.434$)。

术后长期随访,TCD检测显示顺血流组桥血管PSV($P=0.001$)和EDV($P=0.004$)均高于逆血流组,RI低于逆血流组($P=0.002$),表明顺血流搭桥术可以获得更快的血流速度和更低的阻力指数(表3)。

讨　论

STA-MCA搭桥术是烟雾病的常用治疗术式,但其迅速增加脑血流量(CBF)的特点是一把“双刃剑”,虽有助于快速纠正脑组织缺血但也易引起供体动脉与受体动脉之间的血流竞争,导致局部脑血流动力学紊乱,诱发脑缺血、脑梗死甚至局部过度灌注[14-15],且脑血流量越大、风险越高[16]。此外,严重的血流竞争还可消耗桥血管的血流动力势能,造成远期狭窄或闭塞[11]。理论上讲,顺血流搭桥术可以最大限度地减少这种不必要的血流竞争和能量损耗,是更合理的选择,如对位于侧裂上方的受体动脉,推荐将桥血管的血流方向指向上方,位于侧裂下方者则推荐指向下方[4,17],然而一直缺乏临床研究的验证。由于各种侧支循环的存在,烟雾病患者脑血流方向较为复杂,尤其是大脑中动脉供血区,而该区域为脑血管搭桥术的主要靶区[5,12],目前尚未见关于该区域血流方向的报道。本研究回顾总结50例患者的术前DSA影像,发现大脑中动脉供血区血流方向主要有正向血流(58%,29/50)和逆向血流(42%,21/50)两种模式,可见对于烟雾病患者不能以固定模式,而应在仔细识别血流方向的基础上作个体化调整。由于本研究患者均为早期手术病例,一方面尚处于技术成长期,另一方面尚未将血流方向纳入技术考量范畴,吻合血管时更多关注如何利于操作和缩短阻断时间,故可从中筛选出顺血流搭桥术和逆血流搭桥术病例并进行对比分析。

脑血管搭桥术后不可避免地发生供体动脉与



STA,颞浅动脉

图2　术中ICGA可见大脑皮质表面血流对冲现象:桥血管血流(黄色虚线所示)速度较快、对比剂显影较早,而脑内固有血流(红色虚线所示)速度较慢,尚无对比剂充盈,二者交汇处出现血流淤滞区,称为分水岭推移现象(白色圆圈所示),易诱发缺血性卒中

Figure 2　Intraoperative ICGA showed blood flow interference phenomenon on cortex surface: bypass blood flow (yellow dotted line indicates) was faster and visualized earlier, compared with initial blood flow (red dotted line indicates), creating a blood stasis zone, also called as newly - formed watershed (white circle indicates), which may induced cerebral ischemia.

表2　顺血流组与逆血流组患者围手术期和术后短期并发症的比较[例(%)]

Table 2.　Comparison of complications of perioperation and 30 d after surgery between orthodromic group and antidromic group [case (%)]

组别	例数	血流对冲现象	短暂性神经功能障碍	缺血性卒中
顺血流组	32	1(3.13)	1(3.13)	1(3.13)
逆血流组	18	4(4/18)	5(5/18)	1(1/18)
χ^2值		4.668	6.630	0.177
P值		0.031	0.010	0.674

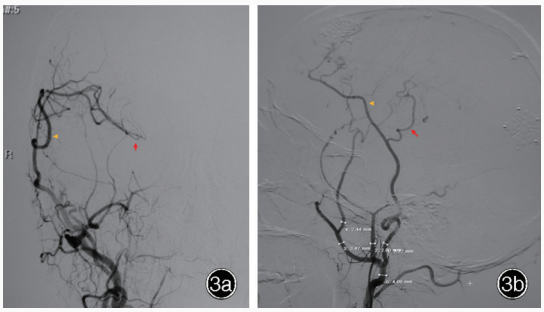


图3　术后中期随访DSA所见　3a　男性，48岁。顺血流搭桥术后7个月右颈外动脉正位像可见粗大的桥血管（黄色三角所示）反向充盈M1段（红色箭头所示），且供血范围较大　3b　男性，52岁。逆血流搭桥术后6个月右颈外动脉侧位像可见萎缩的桥血管（红色箭头所示）管径较颞浅动脉前支（黄色三角所示）更纤细，供血范围较小

Figure 3　Postoperative DSA findings in the mid-term follow-up　A 48-year-old male patient in orthodromic bypass group, 7 months after operation, anterior view of right ECA showed an increase in the bypass vessel (yellow triangle indicates), resulting in reflux to M1 (red arrow indicates) and a wider perfusion area (Panel 3a). A 52-year-old male patient in antidromic bypass group, 6 months after operation, lateral view of right ECA showed an atrophic bypass vessel (red arrow indicates) that thinner than anterior branch of STA (yellow triangle indicates), with limited perfusion area (Panel 3b).

表3　顺血流组与逆血流组患者桥血管血流动力学的比较（$\bar{x} \pm s$）

Table 3.　Comparison of long-term follow-up TCD between orthodromic group and antidromic group ($\bar{x} \pm s$)

组别	例数	PSV（cm/s）	EDV（cm/s）	RI
顺血流组	3	81.53±10.30	36.62±9.07	0.61±0.05
逆血流组	3	71.11± 8.93	29.28±6.72	0.66±0.04
*t*值		3.599	2.993	3.328
*P*值		0.001	0.004	0.002

PSV，peak systolic velocity，收缩期峰值流速；EDV，end diastolic velocity，舒张期末流速；RI，resistant index，阻力指数

受体动脉之间的血流竞争，在桥血管血流与颅内固有血流之间形成三维界面，直至二者压强达到新的平衡，这一过程可被术中实时ICGA捕获，表现为桥血管显影明显早于颅内固有动脉并在二者之间形成一条清晰的分界线，被认为是分水岭推移至新的位置，而称为分水岭推移[6-7]。在新的分水岭区域内可见血流淤滞（图2），导致该三维区域内实际脑血流量减少，引发相应的神经功能障碍[8]。分水岭推移现象如果发生于术野内或吻合口周围区域，表明供体动脉与受体动脉之间压强差较小；反之则表明二者压强差较大，桥血管供血范围更广泛。实际上，术后较长时间内分水岭推移现象可持续存在，尤其是在供体动脉与受体动脉压强差较大的患者中，随着桥血管增粗，脑血流量增加，分水岭逐渐向颈内动脉供血区移动；而对于供体动脉与受体动脉压强差较小的患者，新的分水岭则位于吻合口相邻区域，供血范围较小，甚至有远期闭塞的可能。本研究行逆血流搭桥术的患者围手术期血流对冲现象和短暂性神经功能障碍发生率较高，表明桥血管血流在其主血流方向面临更强的血流竞争，且新建的分水岭更多的位于术野，而术野通常位于侧裂末端，包含语言和运动多个功能区，更易引起短暂性神经功能障碍；行顺血流搭桥术的患者供体动脉与受体动脉血流方向一致，术中实时ICGA表现为更快的血流速度、更少的血流竞争和更广泛的供血范围。值得一提的是，复旦大学附属华山医院近年收治的烟雾病患者均采用顺血流搭桥术，术后短暂性神经功能障碍发生率显著下降。

顺血流搭桥术亦有助于桥血管的正向重塑。TCD广泛用于烟雾病围手术期脑血流动力学评估，具有微创、简单易行和实时动态等诸多优势[18-20]。本研究术后长期随访过程中TCD显示顺血流组桥血管具有更快的血流速度和更低的阻力指数。究其原因，顺血流搭桥术可通过调整入射角度使更多的血流分流进入低压区，远端血管床阻力更低，同时增加供体动脉与受体动脉之间的压强差是桥血管保持长期通畅并不断增粗的唯一动力。虽然血流速度无法完全反映脑血流量，但在目前技术条件下，结合管径增粗、血流增快和阻力降低这3项参数，有理由认为顺血流组的桥血管可提供更多的脑血流量，甚至有部分病例桥血管反向充盈至M1段，供血大部分大脑中动脉区。然而中期随访时，根据Matsushima分级系统，顺血流组与逆血流组桥血管供血范围无显著差异。究其原因，受限于Matsushima分级系统的局限性，该分级系统系从侧位DSA评估侧支代偿供血大脑中动脉的比例，仅可反映血流的二维分布，忽略脑血管搭桥术对脑深部的供血能力。

综上所述，本研究经对烟雾病患者大脑中动脉供血区血流特征的总结，初步证实顺血流搭桥术在安全性方面更具优势，值得临床推广应用。然而，本研究仅为一项回顾性研究，样本量较小，且缺乏手术前后TCD脑血流动力学的对比分析，存在一定的局限性。后续研究将优化测量方法、增加观察指标，从而更客观地对顺血流搭桥术的优势进行评估，例如采用超选择性导管造影或动脉自旋标记

(ASL)量化桥血管供血范围,通过整合DSA与TCD数据更精确地测量桥血管的血流量等。

利益冲突 无

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