·专题综述·

【编者按】 后循环搭桥术是神经外科最具挑战的领域之一，目前其术式体系的完善依然存在巨大的提升空间。后循环向脑干等关键结构供血使手术极具风险且被密集的骨质封闭远离常规供体血管是外在因素，更深层次的原因在于椎基底动脉系统有别于前循环独特的血管系统构筑及穿支分布形态。自从Ausman教授创立颞浅动脉-小脑上动脉/大脑后动脉（STA-SCA/PCA）搭桥术与枕动脉-小脑后下动脉（OA-PICA）搭桥术两种术式以来，依靠前循环为供血主体，以椎基底动脉系统主干发出的小脑相关血管作为受血"中转站"，打开了两条通向后循环的道路，成为传统后循环搭桥术的基石。随着血流动力学研究与颅底外科技术的进步，新的搭桥构型正在逐步形成。基于此，我们邀请天津市环湖医院佟小光教授团队对其中最具代表性的"颅外椎动脉V3段搭桥术"进行系统阐述，这也是该团队近年提出的创新性概念——"颅外段椎动脉搭桥体系"中的一部分，其学术意义在于将颅外段椎动脉由治疗的"客体（object）"转换为"主体（subject）"。该搭桥体系存在两方面的"难度大"，其一是"所处理的疾病难度大"，针对的对象主要是后循环复杂动脉瘤或后循环缺血搭桥；其二是"手术难度大"，需结合复杂颅底入路，例如V3-P2＋OA-PICA组合搭桥术需远外侧入路联合乙状窦前入路，以及对于搭桥术式设计的血流动力学素养和想象力。因此，我们希望通过《颅外椎动脉V3段相关血管重建术进展》一文穿针引线使这一尚未被广泛意识到但实际已隐然成型的体系真正建立起来，为广大神经外科医师提供借鉴。

颅外椎动脉V3段相关血管重建术进展

王轩　佟小光

【摘要】 传统后循环搭桥术以前循环血管为供血主体，属于颅外-颅内低流量搭桥。颅外椎动脉V3段搭桥可结合复杂的颅底技术，以颅内-颅内或联合搭桥形式对后循环整体一期进行更深入的改造；不仅可作为血管搭桥术式设计的主体处理椎基底动脉系统，还可重建前循环血流。本文系统阐述V3段搭桥涉及的重要血管特点和显露方法，以及V3段各种搭桥构型的创新设计理念、疾病适应证和实际应用原则。

【关键词】 脑血管重建术；　椎动脉；　综述

Vascular reconstruction related to V3 segment of extracranial vertebral artery

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【Abstract】 Two major traditional modalities of posterior circulation revascularization are extracranial-intracranial low-flow bypass with donor arteries from anterior circulation and supply mainly for local

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perforators and distal vascular territories. V3 bypass characterized by profound and simultaneous vascular reconstruction of posterior circulation, achieved by intracranial - intracranial or multiple bypasses in conjunction with skull base techniques. These posterior circulation vessels not only play a pivotal role in bypass modality design for vertebrobasilar lesions, but also be implemented to revascularize the anterior circulation. In this article, we review the exposure techniques of the important related vessels, designed philosophy, indications and surgical techniques of the available innovative modalities of V3 bypass.

【Key words】 Cerebral revascularization; Vertebral artery; Review

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目前,前循环搭桥体系已相对固定成型,而后循环体系由于向脑干等重要组织结构供血使手术极具风险,加之受密集骨质封闭远离常规供体血管等因素的影响,尚在完善过程中。传统的后循环搭桥术以前循环血管为供血主体,主要包括枕动脉-小脑后下动脉(OA-PICA)吻合[1-3]、颞浅动脉-小脑上动脉(STA-SCA)吻合[4]等,均属于颅外-颅内低流量搭桥术式,主要向局部穿支群及其流域供血。随着对颅内外血流动力学原理理解的深入,以及颅底手术技术和头颈部解剖学知识的进步,新的搭桥构型逐步出现,如以前循环颌内动脉(IMA)供血的短桥血管中等流量搭桥[5]和后循环颅外段椎动脉(VA)搭桥[6-7],深刻地改变了颅内血管搭桥体系的面貌,而后者尚未彰明昭著。本文拟在重要血管解剖学结构及显露的基础上,就椎动脉V3段各种搭桥构型的创新设计理念、疾病适应证和实际操作要求进行综述。

一、V3段搭桥相关重要血管及显露方法

椎动脉共分为4段,其中V1～V3段为颅外段,V4段为颅内段。V1段起自锁骨下动脉延续至C_6横突孔,V2段为纯椎间段[7],V3段则是离开C_1横突孔进入寰枕区硬膜之前的节段,也有学者将C_2横突孔以远的多个连续并恒定的弯曲划为V3段[8]。V3段具有高流量性和对侧椎动脉可代偿之特点,能够较好地耐受临时阻断,是近年备受推崇的重要供血来源;虽然V3段位置深在,但与不同受体血管的颅内术区之间无需另做远隔切口,甚至可将其与颌内动脉一起归为颅内-颅内搭桥的经典供体血管[9];此外,V3段搭桥结合颅底手术技术可对后循环整体一期进行更深入的改造,此为该术式最具价值之处。椎动脉定位和减少伴行静脉出血是V3段手术显露的难点,Meybodi等[10]主要以寰椎后弓中点与乳突连线或上斜肌作为定位椎动脉的标记,而Wanibuchi等[11]则通过乳突尖等骨性标记的位置关系找到C_1后弓上容纳椎动脉的"J"沟。当选择$C_{1\sim2}$之间的V2段代替V3段供血时,可经由位于枕下三角下外侧的寰椎下三角,即由椎动脉下方外侧的肩胛提肌与颈夹肌、下方内侧的头最长肌与上方的头下斜肌形成的"门户"定位并显露V2段[12]。此外,V3段相关静脉结构形成了与颈内动脉(ICA)海绵窦相似的静脉隔腔(compartment)衬套血管(而非静脉丛),可称为枕下海绵窦[13],该静脉隔腔表面被寰枕区硬膜与枕下三角肌肉筋膜相隔,采用经筋膜间入路沿二者形成的自然层面钝性分离,能够实现无出血显露V3段[14]。

枕动脉(OA)作为后循环的另一主要供血动脉,在V3段搭桥中具有特别意义[15],V3段搭桥既可替代传统OA-PICA搭桥术也可作为其改良术式,甚至还可与之联用形成组合搭桥。日本学者主张采用分页式(layer-by-layer fashion)远外侧入路获取枕动脉,获取之前将胸锁乳突肌(SCM)翻向前方、头夹肌翻向后下方、头最长肌翻向下方,获取之后将头半棘肌翻向后方、头上斜肌翻向前方、头后大小直肌翻向后方[16-17],通过该入路可获得长达15 cm的枕动脉,还有助于在枕下三角显露V3段并将深部术野变浅。Fukuda等[17]认为,理解"过渡段枕动脉"的概念是简化获取枕动脉的关键。过渡段枕动脉位于头夹肌上缘与上项线之间,位于枕动脉由深至浅穿越胸锁乳突肌肌腱与帽状腱膜的层次变化之处;相应的反"C"形切口的上下端则分别位于中线的枕外隆突、C_2棘突,其顶点在乳突,实质是Rhoton"马蹄"形反拐切口(长支位于外侧)的变式[18],利于先显露胸锁乳突肌和头夹肌,以二者为标记定位过渡段枕动脉,而后再分别向其近端和远端分离在单一层次

中走行的肌间段（头夹肌与头半棘肌之间）和腱膜外段的枕动脉（上项线以上）[17]。

二、V3段搭桥主要术式

1. OA-V3搭桥术　OA-V3搭桥术肇始于Spetzler教授团队，他们为1例C_{1-2}椎动脉创伤性动脉瘤患者行孤立术后通过OA-V3搭桥替代病变侧椎动脉血流[19-20]，后经佟小光教授研究团队发展为治疗双侧椎动脉狭窄闭塞性缺血的手术方法[21]。与传统OA-PICA搭桥术相比，OA-V3搭桥术的优势为：(1)将深部搭桥变为浅部搭桥。(2)颅外搭桥无需开颅且可避免术后后颅窝感染风险。(3)缩短全麻手术时间，避免基础状况不佳的患者发生术中缺血事件。(4)供体与受体动脉相毗邻，所需枕动脉长度缩短利于桥血管血流通畅，使后循环搭桥"门槛"显著降低[21]。OA-V3搭桥术的潜在不足在于，枕动脉与V3段管径差异较大，手术患者供血区血管床必须处于血流动力学的低阻力状态，同时结合多种血管吻合技巧的调整（如双支搭桥等）以确保桥血管血流通畅，并使血流顺向充盈整个后循环[21]。此外，不熟悉枕下区域解剖结构的术者可将V2段搭桥（移植血管在颈部连接颈动脉与V2段）作为备选，但移植桥血管须完成两处血管吻合，且不适用于椎动脉广泛性闭塞并累及颅外段的病例。

2. V3-PICA搭桥术　V3-PICA搭桥术是另一种针对传统OA-PICA搭桥术的改良术式。该术式是由处理累及小脑后下动脉的椎动脉夹层动脉瘤发展而来，其供体动脉经历了从V4段到V3段的演变。最初Durward[22]在行动脉瘤孤立术后将小脑后下动脉由动脉瘤壁直接移位，行端侧吻合再植至动脉瘤近端的椎动脉。该术式以椎动脉作为供体动脉可省略冗繁的枕动脉留取过程，同时避免枕动脉末端变细影响血流量的风险，成为OA-PICA搭桥术的良好替代。但Hamada等[23]认为，该术式对术者技术要求高，且小脑后下动脉起始部有足够长度的情况较少，此时小脑后下动脉在与椎动脉吻合后多出现张力，易伤及小脑后下动脉近端1.50 cm范围内的延髓穿支，故改为移植颞浅动脉（STA）作为桥血管。Benes等[24]采用经髁经颈静脉结节入路优化术区深部显露并且增加操作空间，使V4段与小脑后下动脉直接吻合更为简便，无须额外留取移植血管，称之为小脑后下动脉转位术，但是无法确保再植处V4段管壁未被夹层病变所累及，因此Czabanka等[25]改为以V3段作为供血动脉，以与枕动脉血流量相匹配的桡动脉作为桥血管。与小脑后下动脉转位术相似，V3-PICA搭桥术可顺向血流重建小脑后下动脉血运，后循环由对侧椎动脉供血[25-26]。Czabanka等[25]还拓展了常规模式以外的适应证，即当对侧椎动脉条件不佳时仅阻断病变侧椎动脉及小脑后下动脉近端，而不阻断椎动脉远端，经V3-PICA搭桥逆向供应整个后循环区域。此外，若OA-PICA搭桥血流不通畅，可将枕动脉作为桥血管，自近端切断与V3段吻合口，以V3-PICA搭桥术作为补救手段。

3. V3-V4搭桥术及组合搭桥术　V3-V4搭桥术与OA-V3搭桥术的最初意图相似，主要针对局部血管病变。Evans等[27]采用经乙状窦前后联合入路治疗1例位于小脑后下动脉以远的巨大血栓性动脉瘤患者，行塑形夹闭失败后即刻改为移植大隐静脉行V3-V4搭桥术并切除动脉瘤。该术式的思路类似前循环大脑中动脉（MCA）M2段动脉瘤原位插入置换搭桥，甚至还可采用经后正中入路将双侧椎动脉动脉瘤（均位于小脑后下动脉近端）均置换切除[28]。该策略对于根治复杂颅底肿瘤也同样重要，Sekhar团队采用V3-V4搭桥术重建椎动脉治疗1例位于岩斜区、枕髁及枕大孔的复发性骨巨细胞瘤获得成功，从而避免了保留椎动脉则残留部分肿瘤组织或肿瘤全切除而损伤椎动脉等不良后果[29-30]；而当病变累及小脑后下动脉时，采用V3搭桥最具特征性的组合搭桥形式，可实现后循环的整体改建。组合搭桥的雏形来自Kakino等[31]的报告，其采用球囊扩张术治疗1例椎动脉长段偏心型成角狭窄病例，因患者术中昏迷遂改行血管搭桥术；该病例病变侧小脑后下动脉位于狭窄远端且不发达，而对侧椎动脉闭塞，对侧小脑后下动脉由病变侧椎动脉反向供血，先将病变侧枕动脉与对侧小脑后下动脉吻合以保证后循环供血，而后阻断并切除病变侧椎动脉狭窄病变并以大隐静脉重建。组合搭桥的经典形式是V3-V4联合同侧OA-PICA搭桥术[32]，Saito等[33]在处理双侧椎动脉颅内段夹层动脉瘤时，一侧先行动脉瘤孤立切除并搭桥重建病变侧椎动脉及小脑后下动脉，血管吻合操作临时阻断椎动脉耗时较长，期间由对侧椎动脉保障基底动脉（BA）血供；二期再通过血管介入闭塞对侧动脉瘤及椎动脉，此时基底动脉血供改由搭桥侧负责。相比而言，V3-PICA搭桥术更为简捷，但不适合无法保留对侧椎动脉者[25]，而V3-V4联合同侧OA-PICA搭桥术更符合血管原有解剖结构，如果术者技艺精湛，可替代V3-PICA搭

桥术处理单侧血管病变[34-35]。在实际操作过程中，如OA-PICA吻合口血流欠通畅，可将枕动脉近端转位至V3-V4的桥血管进行应急调整[35]。处理源自椎动脉动脉瘤体的粗大穿支可仿照小脑后下动脉，在动脉瘤V3-V4搭桥置换的同时将枕动脉与穿支搭桥以保护后者，但是如何界定穿支搭桥的适应证目前尚无定论[36]。

4. V3-大脑后动脉搭桥术及组合搭桥术　移植血管将V3段与大脑后动脉（PCA）P2段搭桥的设计初衷是利用后方经岩（乙状窦前）入路自下而上的手术轴向，以理想的垂直视角完成后循环上部的血管吻合，这样可以避免传统以颈外动脉（ECA）系统供血搭桥时对颞叶的过度牵拉[37]；Al-Mefty等[38]切除视交叉后方颅咽管瘤时亦采用该入路以避免对颞叶的过度牵拉，二者思路一致。该入路尤其适用于大型基底动脉顶端动脉瘤；此外，可为处理基底动脉延长扩张型动脉瘤时充分显露被扭曲至高位的基底动脉四联体[39]。Mai等[40]通过V3-P2搭桥建立可靠的侧支血流后闭塞基底动脉末端以形成"血流导向（flow diversion）"效果，将基底动脉顶端动脉瘤转换为"侧壁动脉瘤"，从而消除了末端血流直接冲击效应（jet effect），促进瘤腔血栓化。而对于基底动脉干梭形动脉瘤（包括延长扩张型）的治疗重点则在于利用搭桥产生强大的基底动脉逆向倒灌血流（flow reversal），遏制夹层进展与伴随的壁间血栓化过程[39,41]，V3-P2搭桥术的高流量属性与上述要求相符。此外，该术式还有助于保障基底动脉干重要穿支血供，减少脑干梗死的发生。Horie等[42]曾尝试为1例基底动脉干动脉瘤患者行低流量搭桥，但是在无法通过球囊闭塞试验后不得不改为行V3-P2搭桥术。与其他以后循环上部为受体的高流量搭桥相比，V3-P2搭桥术既可以在一期阻断（或孤立）椎动脉或者直接处理后循环病变，也可以联合OA-PICA搭桥术完成组合搭桥术。但该术式对术者的颅底外科技术要求较高，Mai等[40]将乙状窦前与远外侧入路连通，以获得容纳桥血管直接走行的路径，由于操作复杂甚至将其手术规划为两日完成。Lawton等[39]为简化操作仅将远外侧入路与颞下入路联合，但代价是桥血管须绕过乳突而跨越幕上、幕下两个术区，造成桥血管长度明显延长。V3-P2组合搭桥术是V3-V4组合搭桥术处理双侧椎动脉夹层动脉瘤的备选术式，适用于对侧椎动脉动脉瘤既往已先行孤立术或椎动脉闭塞的情况，此时动脉瘤有增大趋势且已无法借用对侧椎动脉血流来保障V3-V4组合搭桥术的超长阻断时间。故Saito等[43]采用联合经岩入路，先行STA-小脑上动脉（SCA）联合OA-PICA搭桥术，分别从上方与下方供血替代椎动脉功能，以V3-P2搭桥术作为血流不足时的后备手段，即由V3-V4的顺血流改为逆血流，高流量与血流翻转倒灌匹配；但在近端闭塞同侧椎动脉后神经电生理指标与载瘤动脉远端灌注压（测量位置在枕动脉即后循环下部）提示代偿血流尚可时，则无需行联合V3-P2搭桥术。椎动脉瘤体积较大时，在切除动脉瘤解除占位效应后，扩大的术野空间足以完成V3-V4搭桥术，而如果动脉瘤延伸至V4段末端甚至接近基底动脉，或动脉瘤将椎动脉远端扭曲至深部甚至对侧时，难以显露V4段受血端则可直接行V3-P2组合搭桥术，该术式是V3段搭桥最具操作难度的一种后循环改建构型，目前仅Ota等[44]报告采用经髁窝联合颞下经乳突入路完成1例小脑后下动脉受累的双侧椎动脉动脉瘤V3-P2组合搭桥术，其中OA-PICA搭桥既与STA-SCA搭桥共同作为保护性手段，其载瘤动脉远端灌注压测量位置在颞浅动脉即后循环上部，且因动脉瘤累及小脑后下动脉，也组成血管重建的一部分；V3-P2搭桥的桥血管则相当于另建了一根基底动脉，先行远端即桥血管与P2段端侧吻合无需阻断同侧椎动脉，缩短了缺血总时间。当无法用V3段供血（如V2段存在动脉瘤）处理单侧巨大型椎动脉颅内段动脉瘤时，可采用颈外动脉供血至V4段搭桥作为后备手段，并以STA-SCA联合OA-AICA搭桥进行血流保护[34]。

5. V3-MCA搭桥术　V3段作为供体血管不仅可以改建后循环，同时也适合为颈总动脉（CCA）闭塞的前循环供血。颈总动脉闭塞搭桥的挑战在于常规供体血管颈外动脉或颞浅动脉灌注不足。Schneider等[45]采用V3-M2搭桥术将后循环血流引入前循环治疗颈总动脉闭塞缺血，虽然并不能像真正的"后交通动脉（PCOM）搭桥"一样具备短桥血管与双向血流调控的特点，但较经典的Bonnet搭桥，已将桥血管长度缩减至可接受的范围，血流量也较以对侧颞浅动脉作为供体血管高。采用锁骨下动脉供血重建颈总动脉[46]或V2段颈部PCOM搭桥[47]是重要的备选术式，二者均要求颈内动脉残留管腔通畅作为受血通路（即证实代偿血流在管腔中显影），仅有部分病例满足条件。V3-MCA搭桥术的优势是直接向目标流域大脑中动脉供血，更具有普适

性[45]。该术式的峰值流速可达70 ml/min,平均流速为25 ml/min,其高流量特性能为动脉瘤孤立术提供有效的血流替代[47]。Miele等[48]采用复合手术治疗1例曾行Hunterian结扎颈总动脉的巨大型颈内动脉床突上段动脉瘤患者,先行STA-MCA搭桥术无法改善脑灌注,动脉瘤单纯栓塞后由于后交通动脉仍持续供血,短期内即复发,后改行V3-M2搭桥术,在其强劲的血流灌注保障下,再次栓塞动脉瘤并闭塞后交通动脉完成孤立术。上述病例同样不宜行V2段搭桥,因为动脉瘤孤立将阻断其受血路径。与其他血管搭桥术多用于颅底肿瘤不同,V3-MCA搭桥术在颈部肿瘤切除手术的多方面具有重要用途,当颈总动脉受颈部恶性肿瘤侵犯需一并切除以完成根治性治疗[49],或者术后颈部放疗造成颈总动脉闭塞时,均可以V3-MCA搭桥术替代颈总动脉的供血功能[9]。此外,V3-M2搭桥术还有助于控制因广泛分离颈部结构引起的感染性腮腺瘘继发颈动脉严重出血,桥血管走行处远离污染的颈部切口容许后者愈合完全[50]。

综上所述,颅外椎动脉V3段因高流量与耐受临时阻断的属性成为重要的供血动脉,可结合复杂颅底技术以颅内-颅内或联合搭桥形式对后循环整体一期进行更为深入的改造,不仅可以作为血管搭桥术设计的主体处理椎基底动脉系统,甚至还可以用于重建前循环血流,将会对个体化搭桥体系的建立形成深刻的影响。

利益冲突 无

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