·泛血管医学时代:脑心共病诊断与治疗·

经颅多普勒超声在心血管外科手术中的应用

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【摘要】 心血管外科手术后神经系统并发症严重影响患者预后。经颅多普勒超声(TCD)作为一种无创性、便捷的神经监测技术,可以实时反映脑血流动力学改变,进行微栓子评价、指导脑保护措施制定,减少脑损伤的发生。本文综述TCD在心血管外科手术中的应用,以为提高围手术期安全性提供理论依据。

【关键词】 心血管疾病; 神经系统疾病; 手术后并发症; 超声检查,多普勒,经颅; 综述

Application of transcranial Doppler ultrasonography in cardiovascular surgery

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【Abstract】 The neurological complications following cardiovascular surgery can significantly affect the prognosis of patients. As a convenient and non-invasive intraoperative neurological monitoring method, transcranial Doppler ultrasonography (TCD) can provide real-time assessment of cerebral hemodynamics and microemboli signals, guide the development of neuroprotective strategies, and reduce the brain injury events. This review systematically summarizes the basic methods and technical performance of TCD monitoring, its clinical application in cardiovascular surgery, as well as the main limitations and future trends of this technology, in order to improve perioperative safety.

【Key words】 Cardiovascular diseases; Nervous system diseases; Postoperative complications; Ultrasonography, Doppler, transcranial; Review

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心血管外科手术技术的提高和麻醉管理的进步为严重心血管病患者提供了更多治疗机会。尽管围手术期病死率和并发症发生率逐渐下降,但术后神经系统并发症仍是困扰临床医师和患者的难题。心血管外科手术后脑卒中发生率约2.16%[1],但MRI检查发现逾30%的心血管外科手术后患者新发颅内缺血性改变[2-3],术后早期认知功能障碍发生率高达40%~50%[4]。心血管外科手术引起脑损伤的主要机制包括脑栓塞、脑缺血、炎症反应、代谢紊乱等[4],多元病因学机制促进术中神经监测手段的多模态发展,常用于脑血流量(CBF)、脑氧饱和度(ScO_2)或神经电生理的监测。目前术中常用的近红外光谱(NIRS)技术操作简便,可以无创实时监测脑氧饱和度,但监测范围局限,仅反映额颞交界区小面积皮质的脑氧饱和度,无法推测低氧部位和原因;脑电图和脑电双频指数(BIS)易受药物、低温及不同生理状态的影响,术中监测结果可能受其他仪器的干扰;术中应用经颅多普勒超声(TCD)可根据病情选择性监测前循环和后循环不同深度的血管,较近红外光谱更敏感、实时,且观察参数更稳定,监测结果不易受其他干扰。TCD依据多普勒频移原理,探头接收不同频率声波反射并进行转换处理,产生具有收缩期峰值流速和舒张期末流速的频谱

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波形，可以直观反映脑血流速度和血管搏动的动态变化，同时具备识别栓子的高度敏感性[5]。术中TCD监测可以为围手术期神经损伤的机制研究提供更加客观、翔实的依据，基于监测数据制定合理的神经保护措施可以有效降低术后神经损伤发生率，改善患者预后。本文拟综述TCD在心血管外科手术中的应用，以为提高围手术期安全性提供理论依据。

一、经颅多普勒超声在心血管外科手术中应用

1. Willis环完整性及功能评价　选择性顺行脑灌注(ASCP)联合全身亚低温治疗是主动脉弓部手术中常规应用的脑保护技术，而术中双侧或单侧选择性顺行脑灌注的脑保护效果是否存在差异，至今尚未达成统一[6-7]。术中脑灌注方式的选择通常取决于医疗机构的常规策略或术者的技术偏好，约2/3的欧洲心血管外科医师在主动脉弓部手术中采取双侧选择性顺行脑灌注[8]。与单侧相比，双侧选择性顺行脑灌注后脑卒中发生率无明显降低，但永久性神经功能障碍发生率下降50%[9]。单侧选择性顺行脑灌注时若前交通动脉和后交通动脉结构不完整，即使在低温降低脑代谢的情况下也难以保障充足脑灌注，因此，Willis环结构完整是单侧选择性顺行脑灌注时全脑灌注充分的前提，而超过50%的正常人群存在不同形式的Willis环结构变异[10]。TCD可用于评估Willis环完整性及其交通支代偿能力，压迫颈动脉若同侧大脑前动脉(ACA)A1段血流方向逆转、对侧A1段流速增快，则定义为有效的前交通动脉代偿；若同侧大脑后动脉(PCA)P1段流速增快>20%，则定义为有效的后交通动脉代偿[11]。2019年，Smith等[12]将TCD作为主动脉弓部手术前的常规检查，并进一步细化交通支代偿能力的评估方式，根据交通支代偿途径及灌注范围提出"红绿灯"算法以划分交通支代偿等级，"绿灯"为安全、"黄灯"为中度安全、"红灯"为危险，从而为术中脑灌注方式的决策提供指导。

2. 脑灌注评价　颈动脉内膜切除术(CEA)围手术期发生脑卒中严重影响患者预后。2022年，*Stroke*发表的一项观察性研究共纳入13 469例颈动脉内膜切除术患者，常规转流组术后脑卒中发生率低于选择性转流组[1.68%(12/716)对3.07%(59/1922)，$P = 0.049$]，表明术中维持夹闭侧脑灌注具有重要意义[13]。TCD是颈动脉内膜切除术中监测脑血流量的有效手段，通常将大脑中动脉(MCA)作为目标血管，其流速变化可实时反映脑灌注情况。Meta分析显示，颈动脉内膜切除术中大脑中动脉流速变化预测围手术期脑卒中特异性较高(84.1%，95%CI：74.4%～90.6%)[14]，故该方法被借鉴用于心血管外科手术中神经监测。对于维持正常搏动性脑灌注的手术(如非体外循环下心脏手术)，将大脑中动脉平均流速下降50%作为干预阈值[15-16]，但不适用于体外循环、血液稀释、体温下降和酸碱度变化等影响红细胞完整性、浓度及血液黏稠度等血流变参数的心脏手术。目前认为，体外循环下脑血流量显著下降可以更可靠地反映脑低灌注。一项回顾性研究将体外循环下冠状动脉旁路移植术(CABG)中脑缺血定义为术中大脑中动脉平均流速下降80%，其发生率约为13%，且与脑电图抑制和脑氧饱和度下降呈正相关[17]。根据术中TCD反映的脑血流量变化及时采取纠正措施，如增加平均动脉压(MAP)、体外循环泵流出量或二氧化碳分压($PaCO_2$)，可有效改善脑灌注。

3. 微栓子检测　微栓子系血流中正常血液细胞以外的其他异常成分，例如凝血块、血小板聚集颗粒、动脉粥样硬化斑块颗粒(血小板、纤维蛋白原、胆固醇)、脂肪或空气等。微栓子的TCD特征表现为短时程(<300 ms)、信号强度比背景≥3 dB、单方向、具有尖锐鸟鸣音或哨音、不同深度之间存在时间差[16]。不同类型心脏手术操作方式的区别可导致微栓子数目或性质差异。研究显示，非体外循环下冠状动脉旁路移植术(OPCABG)、体外循环下冠状动脉旁路移植术和开放手术中微栓子数目的中位值分别为40(28，80)、275(199，472)和860(393，1321)个[18]。微栓子负荷增加是心血管外科手术后缺血性神经功能损害的重要原因，TCD可敏锐地捕捉到微栓子信号，明确术后神经系统并发症的发生机制；更重要的是，TCD还可及时发现术中急性脑缺血事件，最大限度地减轻神经损伤[19]。

4. 脑血流自动调节检测　脑血流自动调节(CA)是维持脑血流量稳定的生理性保护机制。正常人群平均动脉压波动于60～150 mm Hg，血压下降时脑血管反应性舒张；血压升高时脑血管反应性收缩，以维持脑血流量稳定[20]。当血压<60 mm Hg或>150 mm Hg时，脑血流自动调节能力受损，可出现缺血性脑损伤或充血性脑水肿等。近年来，心脏手术围手术期脑血流自动调节改变逐渐受到关注。Meta分析显示，体外循环下脑血流自动调节障碍发

生率较高(7.2%～20%),尤其是复温阶段[21]。脑血流自动调节障碍的危险因素主要包括高龄、男性、合并脑小血管病、术中体温偏高等[22],TCD是心血管外科手术中监测脑血流自动调节能力的常用手段,为保障术中充足的脑灌注,将TCD指标纳入术中血压管理对预防脑损伤、保护多器官功能具有重要意义[23]。

二、经颅多普勒超声与心血管外科手术后神经系统并发症的相关性

1.脑卒中　脑卒中是心血管外科手术中最为严重的并发症之一,使术后死亡率增加5倍以上[24]。动脉栓塞和脑低灌注是脑卒中的主要病因。早在20世纪90年代,术中TCD监测即已用于心脏手术后脑卒中发生机制的研究,术中微栓子数目和脑血流速度下降可反映栓塞和脑低灌注对脑卒中的影响。一项纳入82例冠状动脉旁路移植术患者的研究显示,围手术期并发缺血性卒中的患者(4例)微栓子数目远多于未并发脑卒中的患者(78例;449个对169个,$P = 0.005$)[25]。同期另一项研究发现,心脏手术后未出现神经功能缺损的患者术中脑血流量较基线下降17%,而术后并发脑卒中的患者术中脑血流量下降43%[26]。随着TCD的发展与推广,越来越多的心血管外科手术开始采用该项技术检测脑卒中相关事件。经导管主动脉瓣置换术(TAVR)后缺血性卒中和短暂性脑缺血发作(TIA)发生率均高于传统主动脉瓣置换术[27-28],但其发生机制一直困扰心血管外科医师。2012年,Kahlert等[29]通过TCD确定术中定位和植入支架时对钙化瓣膜的操作是导致缺血性卒中的主要原因,该项研究推动了经导管主动脉瓣置换术中各类脑保护装置(CEPD)的研究与探索[30]。此外,TCD还可用于房颤射频消融术(RFA)[31-32]、经导管二尖瓣缘对缘修复术[33]等介入治疗,作为探寻缺血性卒中原因和改进手术方式的依据。

2.认知功能障碍及谵妄　心脏手术后认知功能障碍及谵妄最常见于开放性主动脉弓部手术、经导管主动脉瓣置换术和冠状动脉旁路移植术,发生机制尚未阐明,可能涉及微栓子栓塞、脑低灌注和脑血流自动调节障碍[34-35]。心脏手术中插管方式、主动脉弓钳夹、体外循环等可使微栓子数目存有差异,而微栓子负荷较小的患者术后发生认知功能障碍的概率较低,因此推测,微栓子数目、性质与术后认知功能障碍具有一定相关性[36];亦有研究认为,微栓子与术后认知功能障碍无直接关联[37-38]。既往认为,神经心理症状多因脑低灌注所致,但现有证据表明,脑过度灌注对心脏手术后谵妄的发生亦具有重要作用。一项横断面研究采用TCD监测心脏手术中大脑中动脉流速,将体外循环下不同时间点检测值与基线流速进行归一化处理以获得流速比值,并根据术后是否出现谵妄分为谵妄组和无谵妄组,结果显示,谵妄组流速比值明显高于无谵妄组[(112 ± 32)%对(90 ± 21)%,$P < 0.05$][39],表明心脏手术中TCD监测除提示脑低灌注风险外,其流速过高还可引起术后神经功能障碍,应引起临床医师重视。此外,TCD在脑血流自动调节检测方面独具优势,越来越多的外科手术开始考虑其用于术中靶向平均动脉压的标定。2019年的一项随机对照临床试验将194例冠状动脉旁路移植术患者分为调节干预组(103例)和对照组(91例),调节干预组通过TCD对血压和多普勒信号进行数字化处理并绘制相关函数以确定每例患者的血压调节下限,对照组仅采用常规术中血压维持标准将平均动脉压维持于60 mm Hg以上,结果显示,调节干预组术后谵妄发生率明显低于对照组[37.86%(39/103)对52.75%(48/91),$P = 0.040$],且谵妄风险下降45%($OR = 0.550$,95%CI:0.310～0.970;$P = 0.040$)[40]。2021年的另一项随机对照试验纳入460例心血管外科手术患者,其中232例(50.43%)于体外循环前以TCD监测的脑血流自动调节数据为基础,建立个体化平均动脉压控制靶点,余228例(49.57%)采用术中常规血压控制标准,结果显示,两组术后神经系统并发症发生率无明显差异,但前者术后谵妄发生率低于后者[8.19%(19/232)对14.91%(34/228),$P = 0.035$],且术后4～6周Rey听觉-词汇学习测验(RAVLT)评分显著增加($P = 0.019$)[41]。

综上所述,TCD是目前唯一用于心血管外科手术中实时监测微栓子的技术[16],但仅可提供特定血管内的微栓子数目,区分固体栓子与气体栓子缺乏足够可靠性,难以明确单个栓子大小和成分[42-43]。目前,对固体与气体栓子有效鉴别的技术正在研究阶段,一种TCD音频信号时域分析的新算法颇具应用前景[44]。此外,约20%行TCD检测的患者因颞窗条件欠佳,前循环观察受限,导致诊断困难[45],因此,具有丰富临床经验和知识储备以及训练有素的检查者是获得可靠数据、有效指导临床的必要条件,对检查者的较高要求也在一定程度上限制了

TCD的推广应用。在心血管外科手术质量不断提高、脑保护观念广为接受的现今,基于包括TCD在内的多模态神经监测技术必将有效改善患者预后。

利益冲突 无

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下期内容预告　本刊2024年第3期报道专题为帕金森病及运动障碍疾病,重点内容包括:抗Aβ单克隆抗体临床应用建议(2024版);自主神经损害在中枢性α-突触核蛋白病中的应用价值;前庭诱发肌源性电位在帕金森病中的研究进展;脂质代谢在帕金森病发生及进展中的意义;*GBA*基因变异在帕金森病中的研究进展;帕金森病构音障碍研究进展;机器人辅助步行训练改善帕金森病步态障碍研究进展;表面肌电在评估帕金森病患者肌强直中的应用;帕金森病患者血清8-羟基脱氧鸟苷酸、丙二醛与认知功能障碍的相关性研究;帕金森病患者黄斑区视网膜浅层血管密度及神经纤维层厚度的观察研究;老年帕金森病患者自主神经功能与认知功能相关分析;*GBA*基因变异患者帕金森病遗传风险基因分析一例;*LRRK2*基因R1067Q和*GBA*基因R202Q双突变致早发型帕金森病一例