·综述·

隐源性卒中相关肺动静脉瘘超声及影像学诊断进展

陈昱均 陈虹秀 邢英琦

【摘要】 隐源性卒中是一种病因不明的缺血性卒中类型，右向左分流与其发生发展密切相关。卵圆孔未闭和肺动静脉瘘是两种常见的右向左分流类型，目前对卵圆孔未闭的研究较多，但对肺动静脉瘘的研究和关注相对较少。本文对肺动静脉瘘的临床特征、超声及影像学诊断进展，以及治疗方法及预后进行综述，旨在为临床实践提供参考。

【关键词】 动静脉瘘； 肺疾病； 超声检查； 血管造影术； 综述

Advances in ultrasonography and radiologic diagnosis of pulmonary arteriovenous fistula associated with cryptogenic stroke

CHEN Yu-jun, CHEN Hong-xiu, XING Ying-qi

Department of Vascular Ultrasonography, Xuanwu Hospital, Capital Medical University; Beijing Vascular Ultrasound Diagnosis Center; Institute of Vascular Ultrasound, Beijing Institute of Brain Major Diseases, Beijing 100053, China

Corresponding author: XING Ying-qi (Email: xingyq2009@sina.com)

【Abstract】 Cryptogenic stroke (CS) is a type of ischemic stroke with an unknown cause, and it is closely associated with right-to-left shunt (RLS). Patent foramen ovale (PFO) and pulmonary arteriovenous fistula (PAVF) are two common types of RLS. While there has been extensive research on PFO, there has been relatively less attention paid to PAVF. Writer provides a review of the clinical features, advances in ultrasonography and imaging diagnostic techniques, as well as treatment methods and prognosis analysis of PAVF, with the aim of providing reference for clinical practice.

【Key words】 Arteriovenous fistula; Lung diseases; Ultrasonography; Angiography; Review

This study was supported by the Development Center for Medical Science & Technology, National Health Commission of The People's Republic of China, Establishment of an Early Identification and Prediction System for Stroke Risk Factors (No. WKZX2023CZ0102).

Conflicts of interest: none declared

右向左分流（RLS）是左心房与右心房之间存在异常开放通道而出现的反常血流，与隐源性卒中（CS）密切相关，心内分流中的卵圆孔未闭（PFO）和心外分流中的肺动静脉瘘（PAVF）是两种常见类型。目前卵圆孔未闭研究较多，诊断较明确，卵圆孔未闭封堵术预防脑卒中业已成为神经内科医师的共识；然而对肺动静脉瘘的研究较少，早期识别和及时干预对降低脑卒中复发风险具有重要意义。本文拟对肺动静脉瘘的临床特征、超声和影像学诊断进展进行综述，以为临床实践提供参考。

一、肺动静脉瘘的临床特征与隐源性卒中

1. 流行病学特点 既往认为肺动静脉瘘是一种罕见病，人群发病率约为0.03%[1]，近年研究表明其发病率被严重低估，每2600人中即有1例肺动静脉瘘患者[2]。肺动静脉瘘是隐源性卒中的重要病因之一，其右向左分流机制导致反常性栓塞（PDE），使未经滤过的血栓直接进入体循环。隐源性卒中患者中肺动静脉瘘发病率为5%～10%[3]，肺动静脉瘘患

doi：10.3969/j.issn.1672-6731.2025.05.014

基金项目：国家卫生健康委医药卫生科技发展研究中心脑卒中危险因素早期识别与预测体系的建立（项目编号：WKZX2023CZ0102）

作者单位：100053 首都医科大学宣武医院血管超声诊断科 北京市血管超声诊断中心 北京脑重大疾病研究院血管超声研究所

通讯作者：邢英琦，Email：xingyq2009@sina.com

者脑卒中发病率为10%～19%[4]。大多数肺动静脉瘘系先天发育异常所致，仅20%与肝硬化、感染性疾病等病理改变有关。应注意的是，肺动静脉瘘可能存在家族遗传性，与常染色体显性遗传性出血性毛细血管扩张症（HHT）密切相关，二者因共同参与调控血管内皮生成和血管损伤相关基因而有所关联[5]，其中高度相关基因为*ENG*[6]、*ALK1*（*ACVRL1*）、*SMAD4*[7-8]，尤以*ENG*基因关联性最强，有60%～90%的*ENG*基因变异人群存在肺动静脉瘘，且此类患者病情更严重、并发症风险更高[9]。

2.临床表现　肺动静脉瘘患者通常无明显症状，随着年龄增长，病灶在肺动脉压（PAP）冲击下逐渐增大，当右向左分流＞20%时可出现呼吸急促或呼吸困难的典型特征，伴紫绀、多发性红细胞增多症和杵状指的典型“三联征”；体位型、氧合矫正困难、短暂性或持续性低氧血症是另一典型特征[10]，特别是青年患者，伴杵状指的低氧血症高度提示肺动静脉瘘。肺动静脉瘘患者还可出现短暂性脑缺血发作、癫痫、偏头痛、脑脓肿和脑卒中等因反常性栓塞引起的中枢神经系统并发症[11]，血栓相关标志物D-二聚体、同型半胱氨酸具有提示意义[12-14]。右向左分流可采用纯氧吸入法进行简单评估，患者吸入纯氧20 min后测定氧分压并计算分流分数[分流分数（%）=（PAO_2－PaO_2）/（PAO_2－PaO_2＋1670）×100%，其中PAO_2为肺泡氧分压、PaO_2为动脉血氧分压]，若分流分数＞5%则疑似右向左分流[9]，需进一步通过影像学技术寻找病因、确定分流量。动脉血气分析若动脉血氧分压＜85 mm Hg或动脉血氧饱和度（SaO_2）＜96%均表明潜在的分流分数＞5%，提示低氧血症[15]。肺动静脉瘘合并遗传性出血性毛细血管扩张症患者反复鼻衄，鼻、口腔、唇和指尖黏膜毛细血管扩张，呼吸困难是常见临床症状。

3.与隐源性卒中的关系　隐源性卒中定义为经广泛血管、血清学和心脏评估后未归因于大动脉粥样硬化（LAA）、脑小血管病（CSVD）或心源性栓塞（CE）的缺血性卒中[16]，占全部缺血性卒中的25%～40%[17-18]，常见于缺乏传统动脉粥样硬化风险因素的青年患者[16]。近年越来越多的证据表明，反常性栓塞是导致隐源性卒中的重要原因[19]，且与右向左分流密切相关[20-21]。肺动静脉瘘是肺动脉与肺静脉之间的异常吻合，这种心外途径的右向左分流使血栓绕过肺毛细血管，直接自静脉系统进入动脉系统再进入大脑，引发脑卒中。多项研究支持肺动静脉瘘与缺血性卒中特别是隐源性卒中相关[22-24]，有文献报道1例合并遗传性出血性毛细血管扩张症的复发性缺血性卒中青年患者，确定其脑卒中病因为肺动静脉瘘引起的反常性栓塞[25]。亦有研究显示，肺动静脉瘘是隐源性卒中的独立危险因素[26]，二者之间的关联不容忽视。

二、肺动静脉瘘的超声诊断

超声作为一种无创性实时成像技术，在肺动静脉瘘的筛查中具有重要意义。常规经胸超声心动图（TTE）和经食管超声心动图（TEE）可以提供心脏和大血管的二维成像，尽管其在肺动静脉瘘直接可视化方面不如其他成像技术，但仍可用于心内分流的检测，以提供间接证据。此种情况下，超声心动图声学造影即显示出较高的应用价值。超声心动图声学造影对心脏结构和功能评估具有重要意义，亦是卵圆孔未闭诊断的“金标准”，同时在肺动静脉瘘的检查中具有较高的敏感性[27]。微泡在右心房充盈后，于数个心动周期内经独立的肺静脉充盈左心房，之后右心房和左心房先后排空，排除心脏器质性病变的前提下可提示肺动静脉瘘；若左心房始终不显影，则认为微泡在通过肺毛细血管床时被滤过消失，则排除肺动静脉瘘[15]。研究显示，超声心动图声学造影与DSA具有相似的诊断效能[28]，可检出CT肺动脉造影（CTPA）阴性的肺动静脉瘘，并根据微泡充盈情况对肺动静脉分流程度进行半定量分析，从而对肺内右向左分流进行分级。既往认为可通过心动周期中微泡数目区分卵圆孔未闭与肺动静脉瘘，Valsalva动作（用力呼气并保持呼吸道关闭）后3～5个心动周期内出现左心房微泡提示卵圆孔未闭，5个心动周期后出现左心房持续性微泡则提示肺动静脉瘘[27,29]。理论上，超声心动图声学造影探测到的肺动静脉瘘微泡信号是延迟出现或延迟消失的，故仅依靠心动周期区分卵圆孔未闭与肺动静脉瘘存在一定局限性，目前尚无确定的时间划分界值[30]。二者区分时应观察微泡是否通过房间隔、肺静脉内有无微泡等。临床实践中，卵圆孔未闭患者3～5个心动周期内也可能出现肺动静脉瘘导致的假阳性微泡[31]；此外，肺动静脉瘘部位亦可能对结果造成误判，有文献报道1例肺动静脉瘘邻近心脏患者，超声心动图声学造影并未发现异常而致早期误诊[27]。晚近研究显示，采用微泡直径大于毛细血管的对比剂微泡（直径＞10 μm）区分卵圆孔未闭与肺动静脉瘘是切实可行的方法[32]。

对比增强经颅多普勒超声(cTCD)是另一重要的右向左分流间接检查方法,通过肘静脉快速注射对比剂,若存在卵圆孔未闭或肺动静脉瘘,空气微栓子可绕过肺循环直接进入大脑,于静息态和Valsalva动作时探测到大脑中动脉血流方向一致、强度高、时程短的异常声频信号即微栓子信号[33]。cTCD对微栓子高度敏感,对发现极小的右向左分流较超声心动图声学造影更佳。并且可以根据微栓子信号数目对右向左分流进行定量分级,微栓子数目越多、右向左分流越大,发生反常性栓塞的风险越高[34]。与卵圆孔未闭不同,肺动静脉瘘的微栓子信号多延迟出现或延迟消失,信号强度较强,双侧大脑中动脉探测到的微栓子数目>20个,且静息态和Valsalva动作时微栓子出现时间和信号强度无明显变化[34];此外,微栓子的出现时间并不绝对。既往以微栓子最早出现的心动周期区分卵圆孔未闭与肺动静脉瘘,微栓子出现于注射对比剂后3~5 s或3个心动周期内提示卵圆孔未闭,出现于6~8 s或3个心动周期后提示肺动静脉瘘[35]。与超声心动图声学造影类似,近年研究显示,微栓子最早出现的心动周期不能作为区分心内与心外分流的直接依据,但可提示卵圆孔未闭或肺动静脉瘘数量、解剖位置和大小[34]。应注意的是,cTCD通常仅能提示存在右向左分流,单纯依靠cTCD无法准确区分卵圆孔未闭与肺动静脉瘘。因此,临床怀疑右向左分流时,先进行cTCD初筛,若呈阴性,则可排除诊断;若呈阳性,则进一步行超声心动图声学造影、TTE或CTPA确定右向左分流来源以及区分卵圆孔未闭或肺动静脉瘘。对于隐源性卒中,cTCD是一种较推荐的筛查方法,与卵圆孔未闭反常性栓塞风险(RoPE)评分和卵圆孔未闭相关卒中因果可能性(PASCAL)分类系统相比,肺动静脉瘘与脑卒中相关性的评估标准尚未提出,可考虑cTCD、超声心动图声学造影、CTPA、动脉血气分析等综合评估,尚待更多研究进一步验证。

三、肺动静脉瘘的影像学诊断

相较于卵圆孔未闭,影像学技术在肺动静脉瘘的诊断、治疗和随访中的应用更普遍,X线、DSA、CT、MRI、PET、SPECT均发挥重要作用。X线和超声心动图声学造影共同推荐用于遗传性出血性毛细血管扩张症患者肺动静脉瘘筛查[36],特征为轻微钙化的肺叶中界限清晰的均匀块状不透明斑片状阴影,或弥漫性微小动静脉瘘伴肺泡外毛细血管扩张。进行X线检查时,选择直立位并同时行后前位和侧位照射可获得最佳诊断[36]。DSA对血管病变和异常的评估效果更佳,可清晰显示血流速度、方向、狭窄程度及有无闭塞、侧支循环、动静脉分流等。CT被认为是肺动静脉瘘诊断的“金标准”[37],具有较高的敏感性和分辨率,特征表现为边缘光滑、边界清晰的圆形或椭圆形结节以及伴随的供血动脉、引流静脉,尤其对外周型肺动静脉瘘的诊断更加精准。CTPA可直接显示肺动静脉瘘与其相关血管的关系,较超声心动图声学造影的阴性预测值略低,但阳性预测值更高。故认为肺动静脉瘘的诊断主要依靠CT及CTPA,但CT对大量分流的肺动静脉瘘有漏诊可能,约55%的右向左分流分级2级和8%的右向左分流分级3级患者的CT检查结果呈阴性[38],故应考虑超声心动图声学造影或cTCD进行互补。MRI增强扫描是遗传性出血性毛细血管扩张症患者肺动静脉瘘的有效筛查工具,敏感性和特异性均优于DSA,尤其适用于婴儿和儿童[39]。三维对比增强MRI对较大(直径>1 cm)的肺动静脉瘘具有较好的识别率,但对较小(直径≤1 cm)病变的诊断准确性较低,限制其在治疗方案选择中的应用[40]。近年来,PET和SPECT的发展提高其在检测和量化肺动静脉瘘方面的敏感性和特异性,可以通过放射性示踪剂评估肺部血流灌注、量化右向左分流和定位肺动静脉瘘部位,特别是对于复杂肺动静脉瘘如伴多发性瘘管或小型瘘管的患者或者其他成像方法无法准确评估时,PET和SPECT可以有效提供补充信息[41]。

四、肺动静脉瘘的治疗及预后

肺动静脉瘘的治疗方法包括手术切除和介入封堵术。较小(直径≤1 cm)的肺动静脉瘘通常采用经导管血栓栓塞术,较大(直径>1 cm)的肺动静脉瘘应用Amplatzer封堵器[42],复杂或弥漫性肺动静脉瘘则需手术切除。随访对血管再通、栓塞材料移位或残留瘘增大等的术后观察至关重要,通常采用X线或CT,DSA是评估血管再通的最可靠方法,但为有创性检查。超声心动图声学造影亦是一种选择,用于评估肺内右向左分流变化,判断是否需再次栓塞或手术治疗,以避免不必要的辐射暴露[43]。应根据患者个体情况如病变大小、部位及患者整体健康状况等选择不同的治疗方法。尽管随访观察和药物治疗也是一种治疗策略[44],但未治疗的肺动静脉瘘患者病死率更高,且部分患者可能病灶增大

或出现并发症。介入封堵术和手术切除在长期生存率方面显示出较好疗效[45-46],尤其对于儿童和合并遗传性出血性毛细血管扩张症患者[47];但二者的预后比较尚待更多研究,未来应进一步对比分析不同治疗方法的长期预后,以指导临床决策。

综上所述,肺动静脉瘘作为隐源性卒中的潜在病因正在引起越来越多的关注。尽早识别肺动静脉瘘并进行有效干预对降低脑卒中复发风险具有重要意义。未来研究应进一步完善肺动静脉瘘的诊断与治疗标准,并探索更加精准的预后评估方法,从而提升临床决策的科学性和改善患者的整体预后。

利益冲突 无

参 考 文 献

[1] Bodilsen J, Madsen T, Brandt CT, Müllertz K, Wiese L, Demirci ST, Suhrs HE, Larsen L, Gill SUA, Hansen BR, Nilsson B, Omland LH, Fosbøl E, Kjeldsen AD, Nielsen H; DASGIB Study Group. Pulmonary arteriovenous malformations in patients with previous brain abscess: a cross - sectional population-based study[J]. Eur J Neurol, 2024, 31:e16176.

[2] Agarwal J, LaBranche J, Dhillon S, Allison WT, Jeerakathil T, Vethanayagam D. Neurologic complications in hereditary hemorrhagic telangiectasia with pulmonary arteriovenous malformations: a systematic review[J]. Can J Neurol Sci, 2023, 50:561-572.

[3] Topiwala KK, Patel SD, Pervez M, Shovlin CL, Alberts MJ. Ischemic stroke in patients with pulmonary arteriovenous fistulas [J]. Stroke, 2021, 52:e311-e315.

[4] Delcroix M, Torbicki A, Gopalan D, Sitbon O, Klok FA, Lang I, Jenkins D, Kim NH, Humbert M, Jais X, Vonk Noordegraaf A, Pepke-Zaba J, Brénot P, Dorfmuller P, Fadel E, Ghofrani HA, Hoeper MM, Jansa P, Madani M, Matsubara H, Ogo T, Grünig E, D'Armini A, Galie N, Meyer B, Corkery P, Meszaros G, Mayer E, Simonneau G. ERS statement on chronic thromboembolic pulmonary hypertension [J]. Eur Respir J, 2021, 57:2002828.

[5] Faughnan ME, Mager JJ, Hetts SW, Palda VA, Ratjen F. Second international guidelines for the diagnosis and management of hereditary hemorrhagic telangiectasia [J]. Ann Intern Med, 2021, 174:1035-1036.

[6] Liu K, Fu J, Guo K, Maghsoudloo M, Cheng J, Fu J. The ENG/VEGFα pathway is likely affected by a nonsense variant of endoglin (ENG)/CD105, causing hereditary hemorrhagic telangiectasia type 1 (HHT1) in a Chinese family [J]. Genes (Basel), 2024, 15:304.

[7] Wang QY, Feng YX, Zhu YW, Sun YX, Xu JD, Shi HM, Mao YM, Jiang HW. Case report: clinical characteristics and genetic analysis of two patients with hereditary hemorrhagic telangiectasia[J]. Front Genet, 2022, 13:954796.

[8] Iwasa T, Yamada O, Morisaki H, Morisaki T, Kurosaki K, Shiraishi I. Relationship between mutations in *ENG* and *ALK1* genes and the affected organs in hereditary hemorrhagic telangiectasia [M]//Nakanishi T, Baldwin HS, Fineman JR, Yamagishi H. Molecular mechanism of congenital heart disease and pulmonary hypertension. Singapore: Springer Singapore, 2020: 197-199.

[9] Iqbal M, Rossoff LJ, Steinberg HN, Marzouk KA, Siegel DN. Pulmonary arteriovenous malformations: a clinical review [J]. Postgrad Med J, 2000, 76:390-394.

[10] Shu L, Luo L, Zuo Y. Attention to pulmonary arteriovenous fistula in a case of transient hypoxemia and cerebral infarction during pregnancy: a case report and literature review[J]. BMC Pregnancy Childbirth, 2023, 23:626.

[11] Zheng J, Wu QY, Zeng X, Zhang DF. Transient ischemic attack induced by pulmonary arteriovenous fistula in a child: a case report[J]. World J Clin Cases, 2023, 11:2009-2014.

[12] Lin Q, Zhou D, Cheng Y, Wu C, Deng B. The potential predicting value of D - dimer to fibrinogen ratio on functional outcome at 1 year after acute ischemic stroke: a longitudinal study[J]. Gerontology, 2024, 70:115-124.

[13] Kwok CS, Alisiddiq Z, Will M, Schwarz K, Khoo C, Large A, Butler R, Lip GYH, Qureshi AI, Borovac JA. The modified risk of paradoxical embolism score is associated with patent foramen ovale in patients with ischemic stroke: a nationwide US analysis [J]. J Cardiovasc Dev Dis, 2024, 11:213.

[14] Hao M, Jiang S, Tang J, Li X, Wang S, Li Y, Wu J, Hu Z, Zhang H. Ratio of red blood cell distribution width to albumin level and risk of mortality [J]. JAMA Netw Open, 2024, 7: e2413213.

[15] Li RB, Cao L, Fu M, Cai XD. Detection rate and shunt grading with synchronous testing of contrast transcranial Doppler and contrast transthoracic echocardiography: preliminary findings [J]. Medicine (Baltimore), 2023, 102:e33928.

[16] Saver JL. Clinical practice: cryptogenic stroke [J]. N Engl J Med, 2016, 374:2065-2074.

[17] Kheiri B, Simpson TF, Osman M, Golwala H, Radaideh Q, Dalouk K, Stecker EC, Zahr F, Nazer B, Rahmouni H. Meta-analysis of secondary prevention of cryptogenic stroke [J]. Cardiovasc Revasc Med, 2020, 21:1285-1290.

[18] Härtl J, Berndt M, Poppert H, Liesche-Starnecker F, Steiger K, Wunderlich S, Boeckh - Behrens T, Ikenberg B. Histology of cerebral clots in cryptogenic stroke varies according to the presence of a patent foramen ovale[J]. Int J Mol Sci, 2022, 23: 9474.

[19] Ratajczak - Tretel B, Lambert AT, Atar D, Aamodt AH. Cryptogenic stroke and TIA: suggested diagnostic approach while waiting for evaluation and treatment guidelines[J]. Acta Neurol Scand, 2022, 145:641-646.

[20] Liu W, Song B, Li B. Myocardial infarction caused by in situ thrombosis of a patent foramen ovale assessed by optical coherence tomography[J]. Eur Heart J, 2024, 45:403.

[21] Delabays C, Correia P, Eeckhout E, Delabays A, Michel P. Comparison of atrial septal defect and patent foramen ovale in cryptogenic strokes [J]. J Stroke Cerebrovasc Dis, 2024, 33: 107664.

[22] Topiwala KK, Patel SD, Saver JL, Streib CD, Shovlin CL. Ischemic stroke and pulmonary arteriovenous malformations: a review[J]. Neurology, 2022, 98:188-198.

[23] Ramaswamy S, Marczak I, Mulatu Y, Eldokmak M, Bezalel A, Otto A, Levine SR. Ischemic strokes due to pulmonary arteriovenous malformations: a systematic review[J]. Brain Circ, 2024, 10:213-219.

[24] Das A, Greisman JD, Vazquez S, Feldstein E, Spirollari E, Lui A, Yang K, Dominguez JF, Epelbaum O, Harris K, Patel N, Chong J, Mayer S, Gandhi C, Al-Mufti Fawaz. Acute ischemic stroke in patients with pulmonary arteriovenous malformations: paradoxical embolism or epiphenomenon[J]? Stroke Vasc Interv Neurol, 2023, 3:e000571.

[25] Ishikawa T, Takamori S, Kohno M, Miura N, Takenaka T, Yoshizumi T. Lobectomy for pulmonary arteriovenous fistula in a patient with Rendu-Osler-Weber disease: a case report[J]. In Vivo, 2023, 37:2854-2858.
[26] Holzer RJ, Cua CL. Pulmonary arteriovenous malformations and risk of stroke[J]. Cardiol Clin, 2016, 34:241-246.
[27] Liang SC, Liu ZY, Huang H, Fan LL. Pulmonary arteriovenous fistula diagnosed with the assistance of right heart contrast echocardiography: one case report[J]. Zhongguo Hu Xi Yu Wei Zhong Jian Hu Za Zhi, 2023, 22:657-659.[梁士楚, 刘志月, 黄鹤, 樊莉莉. 右心声学造影协助诊断肺动静脉瘘一例[J]. 中国呼吸与危重监护杂志, 2023, 22:657-659.]
[28] Zhang YL, Zhang ZL, Li X. Analysis on the clinical application value of contrast-enhanced echocardiography in the diagnosis of pulmonary arteri-ovenous fistula[J]. Lin Chuang Yi Xue Gong Cheng, 2021, 28:1447-1448.[张亚利, 张周龙, 李新. 超声心动图声学造影在肺动静脉瘘诊断中的临床应用价值分析[J]. 临床医学工程, 2021, 28:1447-1448.]
[29] Li Y, Zhai YN, Wei LQ, Zhang L. Comparison of transthoracic contrast echocardiography and transesophageal contrast echocardiography for detecting right to left shunt in patients with petent foramen ovale[J]. Zhonghua Yi Xue Chao Sheng Za Zhi (Dian Zi Ban), 2013, 10:916-921.[李越, 翟亚楠, 魏丽群, 张丽. 经食管与经胸超声心动图造影检出卵圆孔未闭右向左分流效果比较[J]. 中华医学超声杂志(电子版), 2013, 10:916-921.]
[30] Lei QS, Zhang YZ, Han MY, Jia G. Significance of contrast-enhanced transcranial Doppler in diagnosis of pulmonary arteriovenous malformation-associated cerebral infarction[J]. Zhong Feng Yu Shen Jing Ji Bing Za Zhi, 2024, 41:189-192.[雷淇松, 张医芝, 韩梦岩, 贾革. c-TCD在肺动静脉畸形相关脑梗死中的诊断意义[J]. 中风与神经疾病杂志, 2024, 41:189-192.]
[31] Bhatia N, Abushora MY, Donneyong MM, Stoddard MF. Determination of the optimum number of cardiac cycles to differentiate intra-pulmonary shunt and patent foramen ovale by saline contrast two- and three-dimensional echocardiography[J]. Echocardiography, 2014, 31:293-301.
[32] Wu T, Zhang KY, Yao JY, Li YJ. Comparative study of contrast-enhanced transthoracic echocardiography and contrast-enhanced transcranial Doppler in the diagnosis of cryptogenic ischemic stroke patients with patent foramen ovale[J]. Lin Chuang Chao Sheng Yi Xue Za Zhi, 2023, 25:395-399.[吴婷, 张坤燕, 姚静远, 李颖嘉. 右心声学造影与经颅多普勒发泡试验诊断隐源性卒中患者卵圆孔未闭的对比研究[J]. 临床超声医学杂志, 2023, 25:395-399.]
[33] Jordan LC, Rodeghier M, Donahue MJ, DeBaun MR. Reduction in transcranial doppler ultrasound (TCD) velocity after regular blood transfusion therapy is associated with a change in hemoglobin S fraction in sickle cell anemia[J]. Am J Hematol, 2020, 95:E308-E310.
[34] Angriman F, Ferreyro BL, Wainstein EJ, Serra MM. Pulmonary arteriovenous malformations and embolic complications in patients with hereditary hemorrhagic telangiectasia[J]. Arch Bronconeumol, 2014, 50:301-304.
[35] Chhabra N, Kumar G, Fruin J, Dumitrascu OM. Right-to-left shunt detection using transforaminal insonation of the basilar artery[J]. J Neuroimaging, 2021, 31:696-700.
[36] Contegiacomo A, Del Ciello A, Rella R, Attempati N, Coppolino D, Larici AR, Di Stasi C, Marano G, Manfredi R. Pulmonary arteriovenous malformations: what the interventional radiologist needs to know[J]. Radiol Med, 2019, 124:973-988.
[37] Gill SS, Roddie ME, Shovlin CL, Jackson JE. Pulmonary arteriovenous malformations and their mimics[J]. Clin Radiol, 2015, 70:96-110.
[38] Velthuis S, Buscarini E, Mager JJ, Vorselaars VM, van Gent MW, Gazzaniga P, Manfredi G, Danesino C, Diederik AL, Vos JA, Gandolfi S, Snijder RJ, Westermann CJ, Post MC. Predicting the size of pulmonary arteriovenous malformations on chest computed tomography: a role for transthoracic contrast echocardiography[J]. Eur Respir J, 2014, 44:150-159.
[39] Balci NC, Yalçin Y, Tunaci A, Balci Y. Assessment of the anomalous pulmonary circulation by dynamic contrast-enhanced MR angiography in under four seconds[J]. Magn Reson Imaging, 2003, 21:1-7.
[40] Maki DD, Siegelman ES, Roberts DA, Baum RA, Gefter WB. Pulmonary arteriovenous malformations: three - dimensional gadolinium - enhanced MR angiography - initial experience[J]. Radiology, 2001, 219:243-246.
[41] Drubach LA, Jenkins KJ, Stamoulis C, Palmer EL 3rd, Lee EY. Evaluation of primary pulmonary vein stenosis in children: comparison of radionuclide perfusion lung scan and angiography[J]. AJR Am J Roentgenol, 2015, 205:873-877.
[42] Botsford A, Tradi F, Loubet A, Tantawi S, Soulez G, Giroux MF, Faughnan ME, Gauthier A, Perreault P, Bouchard L, Holderbaum do Amaral R, Chartrand-Lefebvre C, Therasse E. Transarterial embolization of simple pulmonary arteriovenous malformations: long-term outcomes of 0.018-inch coils versus vascular plugs[J]. J Vasc Interv Radiol, 2024, 35:349-360.
[43] DePietro DM, Curnes NR, Chittams J, Ferrari VA, Pyeritz RE, Trerotola SO. Postembolotherapy pulmonary arteriovenous malformation follow-up: a role for graded transthoracic contrast echocardiography prior to high-resolution chest CT scan[J]. Chest, 2020, 157:1278-1286.
[44] Cai R, Xu J, Yan C, Wang J, Wang LI, Ku L, Zhou D, Zhu LI, He C, Zhao X, Ma X. Imaging characteristics and ECG distribution of coronary fistulas: the first large-scale study[J]. Clin Imaging, 2024, 105:110016.
[45] Behrend L, Schaeffer T, Osawa T, Palm J, Di Padua C, Niedermaier C, Heinisch PP, Piber N, Hager A, Ewert P, Hörer J, Ono M. Outcomes after bidirectional cavopulmonary shunt with antegrade pulmonary blood flow in high-risk patients[J]. Cardiol Young, 2024, 34:2122-2131.
[46] Bialkowski J, Zabal C, Szkutnik M, Montes JA, Kusa J, Zembala M. Percutaneous interventional closure of large pulmonary arteriovenous fistulas with the amplatzer duct occlude[J]. Am J Cardiol, 2005, 96:127-129.
[47] Song Y, Choi ES, Kim DH, Kwon BS, Park CS, Yun TJ. Surgical management of coronary artery fistulas in children[J]. J Chest Surg, 2024, 57:79-86.

（收稿日期：2025-02-12）
（本文编辑：彭一帆）