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卵圆孔未闭(patent foramen ovale, PFO)作为一种常见的先天性心脏结构异常,在普通人群中的发生率为15%~35%。多数PFO患者虽无明显临床症状,但当咳嗽、Valsalva动作等致使右心房压力一过性或持续性超过左心房压力时,则会诱发心房水平的右向左分流(right-to-left shunt, RLS),此时静脉系统中的微血栓、空气栓子等物质得以绕过肺循环的过滤屏障,直接经未闭卵圆孔进入左心系统,进而随体循环在脑部引发反常性栓塞(paradoxical embolism, PE),最终导致脑卒中及偏头痛等一系列严重并发症。近年来,PFO对脑功能网络的潜在影响逐渐受到关注。认知功能作为人类最易受损的特征之一,其减退可能早于心血管系统疾病的典型临床表现,这为早期识别PFO相关性认知功能改变提供了重要机会。然而,目前关于PFO与认知功能改变之间神经病理联系尚不清晰,缺乏客观的影像学评估工具。

动脉自旋标记(arterial spin labeling, ASL)技术可无创定量测量静息态脑血流量(cerebral blood flow, CBF)。目前,基于CBF概率分布形态相似性构建功能网络的新方法已被证实具有良好的稳定性和拓扑属性,且与认知行为存在关联。然而,当前PFO的影像学研究多集中于结构磁共振、基于血氧水平依赖(blood oxygen level-dependent, BOLD)信号的静息态功能磁共振及类淋巴系统相关成像,从脑血流网络角度探讨其认知改变的研究仍较少。

本研究采用ASL技术获取静息态CBF数据,以Schaefer图谱划分脑区节点,通过Jensen-Shannon散度(Jensen-Shannon divergence, JSD)度量区域CBF概率分布的形态相似性,构建PFO患者的脑血流功能网络,探究PFO患者脑血流网络在全局与节点层面的拓扑属性是否存在异常,并探索网络特征与认知功能评分、PFO解剖学数据及RLS分级之间的关联,为阐明PFO相关认知功能改变的神经机制提供新的影像学证据。详见内文第33页。

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Patent foramen ovale (PFO), a common congenital structural abnormality of the heart, has an estimated prevalence of 15% to 35% in the general population. Although most patients with PFO are asymptomatic, episodes such as coughing or Valsalva maneuver can cause right atrial pressure to transiently or persistently exceed left atrial pressure, thereby inducing a right-to-left shunt (RLS) at the atrial level. Under these conditions, microthrombi, air emboli, and other substances in the venous system can bypass the filtering function of the pulmonary circulation, pass directly through the unclosed foramen ovale into the left heart, and subsequently travel through the systemic circulation to the brain, where they cause paradoxical embolism (PE) and eventually lead to a series of serious complications including stroke and migraine. In recent years, the potential impact of PFO on brain functional networks has attracted growing attention. As one of the most vulnerable functions in humans, cognitive function may decline earlier than the typical clinical manifestations of cardiovascular diseases, providing an important window for early identification of PFO-related cognitive changes. However, the neuropathological link between PFO and cognitive alterations remains unclear, and objective imaging assessment tools are still lacking.

Arterial spin labeling (ASL) allows non-invasive quantification of resting-state cerebral blood flow (CBF). Currently, a novel method for constructing functional networks based on the morphological similarity of regional CBF probability distributions has been validated to possess good stability and topological properties, and has been shown to correlate with cognitive behaviors. Nevertheless, existing imaging studies on PFO have largely focused on structural magnetic resonance imaging, resting-state functional MRI based on the blood oxygen level-dependent (BOLD) signal, and diffusion tensor imaging analysis along the perivascular space (DTI-ALPS), with relatively few investigations addressing cognitive changes from the perspective of cerebral blood flow networks.

In this study, we employ ASL to acquire resting-state CBF data, parcellate brain regions using the Schaefer atlas, and quantify the morphological similarity of regional CBF probability distributions via the Jensen-Shannon divergence (JSD) to construct cerebral blood flow functional networks in PFO patients. We aim to systematically examine whether the global and nodal topological properties of these networks are altered in PFO patients, and to explore the associations between network characteristics and cognitive function scores, PFO anatomical parameters, and RLS grading. This work is expected to provide novel imaging evidence for elucidating the neural mechanisms underlying cognitive alterations associated with PFO. Please see text page 33.

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