·综述·

弓形束扩散张量纤维束示踪成像研究进展

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【摘要】 弓形束是人类语言网络的重要组成部分。扩散张量纤维束示踪成像(DTT)是目前在体无创性显像大脑白质纤维束的最常用方法。本文对DTT在显像弓形束解剖结构和功能特性基础研究,以及神经外科手术临床研究中的进展进行简要概述,但其准确性尚待进一步研究。

【关键词】 神经纤维; 磁共振成像; 综述

Research progress of arcuate fasciculus with diffusion tensor tractography

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【**Abstract**】 Arcuate fasciculus (AF) is a crucial part of human language network. Diffusion tensor tractography (DTT) is the most common method for reconstruction of white matter fibers *in vivo*. DTT is widely applied in both basic researches on the anatomical structure and functions of AF and clinical studies on AF navigation. However, the validity of AF with DTT needs further investigation in the future.

【**Key words**】 Nerve fibers; Magnetic resonance imaging; Review

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弓形束(AF)是人类语言网络系统的重要组成部分,与语言功能关系密切[1]。扩散张量纤维束示踪成像(DTT)是以扩散张量成像(DTI)为基础的白质纤维束重建技术,是目前无创性显示在体白质纤维束结构的最常用方法[2]。本文拟对DTT在显像弓形束解剖结构和功能特性基础研究,以及神经外科手术临床研究中的进展进行简要概述。

一、扩散张量纤维束示踪成像在弓形束解剖结构显像方面的研究进展

目前,弓形束解剖结构的研究方法主要有尸体解剖时钝性分离白质纤维束技术、DTT、扩散波谱成像(DSI)和术中皮质下电刺激技术等[3]。经典的Wernicke-Geschwind语言模型认为,弓形束是连接Broca区(额下回后2/3)与Wernicke区(颞上回后部,部分包括颞上沟附近皮质、顶下小叶和颞中回后部)的白质纤维束[4],该模型弓形束解剖结构的研究采用尸体解剖时钝性分离白质纤维束技术。

Makris等[5]率先采用DTT对弓形束解剖结构进行研究,认为弓形束起源于颞上回后部,弓形围绕侧裂末端,延伸至额下回后部,与经典的Wernicke-Geschwind语言模型中弓形束解剖结构的观点相似。但也有学者提出不同观点,Catani等[6]将弓形束分为三部分,即连接Broca区和Wernicke区的直接部分,以及分别连接Broca区和Geschwind区、Wernicke区和Geschwind区的两个间接部分。Matsumoto等[7]将弓形束分为额颞部和额顶部两部分,前者连接额叶和颞叶,后者连接额叶和顶叶。Glasser和Rilling[8]亦将弓形束分为两部分,但与Matsumoto等[7]的观点不同,其划分的连接位置更加详细:一部分连接颞上回后部与额下回岛盖部和中央前回下部,另一部分连接颞中回后部与额下回岛盖部、额下回三角部、中央前回下部和额中回后部。Hong等[9]将弓形束分为水平部和垂直部,认为其起源于颞上回后部和颞中回后部,终止于额下回岛盖部、额下回三角部和中央前回下部。Bernal和Ardila[10]则认为,弓形束并非直接连接Broca区和Wernicke区,而是在语言相关运动区或运动前区中转后,再连接Broca区。总之,DTT对弓形束解剖结构和走行的显像大致相似,但细微结构尚存争议。

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语言功能区的不对称分布是人类语言网络系统的重要特征。弓形束作为其中重要联系纤维，是否在解剖结构上也呈现不对称分布？Nucifora等[11]率先采用DTT进行弓形束解剖结构的不对称性研究，共纳入27名正常受试者，均为右利手，结果显示，26名左侧弓形束相对密度高于右侧。Vernooij等[12]对20名正常受试者（其中13名为左利手）进行语言优势半球研究，结果显示，采用血氧水平依赖性功能磁共振成像（BOLD-fMRI）判断语言优势半球时，5例左利手受试者在右侧、2例左利手呈均势，其余13例均在左侧；采用DTT进行判断时，16例受试者在左侧，其余4例（左、右利手各2例）呈均势，提示DTT通过解剖结构显像的判断与BOLD-fMRI通过功能显像存在不一致现象。Catani等[13]对40名均为右利手的正常受试者弓形束直接部分体积进行研究，结果显示，62.50%（25/40）呈明显左侧优势、20%（8/40）呈轻度左侧优势、17.50%（7/40）呈双侧对称分布；同时还发现，40%（8/20）女性和85%（17/20）男性呈明显左侧优势，表明性别对弓形束直接部分的不对称分布有一定影响。Thiebaut de Schotten等[14]也得出相似结论。由此可见，采用DTT观察弓形束的不对称分布是可行的，而且弓形束在大多数正常人群中呈左侧优势，其中性别因素可能起一定作用；弓形束解剖结构的不对称分布可能与语言功能侧化相关。

二、扩散张量纤维束示踪成像在弓形束功能特性显像方面的研究进展

采用DTT研究弓形束的功能特性通常需通过语言功能进化论的观点、语言障碍症状学的反推和术中语言功能区皮质下电刺激技术等共同实现。经典的Wernicke-Geschwind语言模型认为，弓形束与复述相关[4]。有学者支持这一观点，Breier等[15]研究发现，弓形束部分各向异性（FA）值降低与复述障碍和语言理解障碍有关，表明弓形束与复述和语言理解具有关联性。也有学者对这一观点提出质疑，Bernal和Ardila[10]研究发现，一些导致传导性失语的病变仅局限于优势大脑半球侧裂末端皮质而未累及皮质下结构，另一些病变累及弓形束却未出现传导性失语，因此他们认为，弓形束损伤可能并非传导性失语的必要条件。Hickok和Poeppel[16]提出，主要由弓形束组成的语言网络系统背侧通路与语音功能相关。Saur等[17]采用DTT与BOLD-fMRI相联合的方法研究发现，主要由弓形束组成的语言网络系统背侧通路与复述等语言功能相关。Berthier等[18]认为，弓形束与复述相关，并推测左侧弓形束损伤后未出现复述障碍可能与较发达的左侧弓形束损伤程度小、右侧弓形束或左侧语言网络系统腹侧通路功能代偿有关。Yeatman等[19]研究发现，左侧弓形束FA值与语音意识（phonological awareness）呈负相关，而左侧弓形束体积和密度与语音记忆和阅读能力呈正相关。Marchina等[20]发现，左侧弓形束可能与语速、语言信息量、语言效率和命名能力相关。López-Barroso等[21]研究发现，左侧弓形束直接部分的径向扩散程度与词语学习能力呈负相关，而左侧弓形束间接部分或右侧弓形束的径向扩散程度与词语学习能力无明显关联性。Kamada等[22]采用术中皮质下电刺激技术发现，左侧弓形束与命名能力相关，但与语言流畅性无关联性。Leclercq等[23]采用皮质下电刺激技术对3例语言功能区低级别胶质瘤患者的弓形束功能进行观察，均表现出发音困难、语音停顿、语音音位错乱和语义错乱。尽管，目前大多数学者认为，弓形束与语音功能尤其是复述相关，但其是否与语言理解、命名、阅读、词语学习能力等语言功能相关，尚无明确结论。

三、扩散张量纤维束示踪成像显像弓形束在神经外科手术中的应用进展

临床上应用DTT研究弓形束，最初主要是观察弓形束损伤与语言障碍的关系，后来逐渐扩展至疾病诊断、治疗和预后评价等方面。DTT显像弓形束在术前判断语言优势半球、术中语言传导束导航和术后评价语言功能预后方面均有价值。

术前准确判断语言优势半球有利于指导语言功能区手术。Wada试验是判断语言优势半球的“金标准”，但是由于其为有创性检查，临床应用受到限制[24]。目前，Matsumoto等[7]、Ellmore等[25]和Tiwari等[26]尝试采用DTT无创性显像双侧弓形束密度、体积和FA值等以判断语言优势半球，并与Wada试验进行对比，二者一致性分别为95.80%、82.60%和90.90%；若联合利手和BOLD-fMRI检查，有可能提高判断的准确性[25]。因此，采用DTT对比显像双侧弓形束以判断语言优势半球简单且无创，结果相对可靠，有潜在临床价值。

由于语言双通道模型[16]的提出，近年不断有学

者应用术中皮质和皮质下电刺激技术发现新的语言传导束[27]。目前，大多数国外学者在语言功能区手术中应用功能神经导航时，不仅局限于弓形束的DTT显像，而且扩展至下枕额束、下纵束、钩束、运动前区白质纤维束、胼胝体下内侧束等语言相关皮质下结构[22-23,28-30]。由于DTT的局限性，如中枢神经系统肿瘤对白质纤维束的挤压甚至破坏、瘤周水肿对DTT重建效果的影响、DTT对交叉纤维或分支纤维的区分能力、术中脑漂移等[31]，大多数国外学者不再单纯采用DTT显示语言传导束，而是与术中皮质或皮质下电刺激技术相联合[22-23,28-30]。Bello等[29]认为，联合应用DTT与术中电刺激技术具有重要意义，前者可为后者提供解剖学信息、提高操作效率，后者亦可验证前者的准确性和可靠性；他们以术中皮质下电刺激技术作为"金标准"，对42例左侧语言功能区胶质瘤患者上纵束进行DTT显像，显示其灵敏度为97.62%（41/42）[28]。术中脑漂移可能影响两种检测技术的结果[2,28-29]，辅助应用术中MRI系统可以减少这种负面影响[2]。目前，已有少数学者在语言功能区胶质瘤手术中联合应用包括弓形束在内的语言传导束DTT显像、术中高场强MRI系统和术中电刺激技术，语言功能保护作用满意，但病例数较少，尚待扩大样本量进一步研究[32-34]。解放军总医院神经外科对48例语言功能区胶质瘤患者，采用单纯术中DTT显像或与BOLD-fMRI联合显示语言功能区，同时利用术中MRI系统纠正导航漂移，取得良好手术效果，术后长期（3个月以上）随访结果显示，仅1例（2.08%）高级别胶质瘤患者语言障碍较术前加重[35]。

DTT显像弓形束还具有语言预后评价作用。Hayashi等[36]对7例语言功能区胶质瘤患者弓形束进行手术前后DTT显像，并与西部失语症检查量表（WAB）评分相关性进行分析，结果显示，弓形束术后显像较好者预示其有更好的语言功能。Kinoshita等[37]对12例语言优势半球肿瘤患者进行研究发现，术前患侧弓形束FA值与术后WAB总评分及命名、阅读和书写分评分呈正相关。

综上所述，DTT显像弓形束在基础与临床研究方面均进展迅速，但是由于该项技术的局限性，使弓形束精细解剖、功能研究和临床应用受到限制。近年来，DTT重建方法[38-40]和算法[41]在不断改进，一些替代性的白质纤维束重建方法[42-44]不断涌现并持续发展。相信随着影像学的发展、医学设备的优化，在体无创性精确显像白质纤维束、精确定位脑功能区很可能将实现。

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