·文献综述·

OCT 影像学特征在高度近视视网膜劈裂分期及诊治的应用进展

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摘要
高度近视视网膜劈裂是导致视功能损害和致盲的重要并发症之一,其发生与眼轴延长、屈光度增加及玻璃体-视网膜界面牵拉等因素密切相关,但发病机制尚未完全明确。由于早期病变隐匿、进展过程复杂,给临床早期诊断与精准管理带来挑战。伴随着高分辨率眼底影像技术的迭代升级,高度近视视网膜劈裂特征性光学相干断层扫描(OCT)影像学的准确识别成为该疾病早期诊断、分期及治疗的重要依据。文章以高度近视视网膜劈裂 OCT 影像学特征为核心,详细描述了高度近视视网膜劈裂的分期、诊疗及预后,并阐述其流行病学和危险因素,同时进一步综述人工智能与 OCT 结合在高度近视视网膜劈裂自动识别、病情评价、进展预测方面的研究现状及发展展望,为高度近视视网膜劈裂的早期诊断、标准化分期、精准诊治提供理论支撑和临床参考。
关键词:高度近视视网膜劈裂;光学相干断层扫描(OCT)影像学特征;扫频光学相干断层扫描;超广角光学相干断层扫描;人工智能
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Advances in OCT imaging features in staging, diagnosis, and treatment of retinoschisis in high myopia

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Abstract
• Retinoschisis in high myopia is one of the important complications leading to visual impairment and blindness. Its occurrence is closely related to factors such as axial extension, diopter increase, and vitreous-retinal interface traction, but the pathogenesis is not yet fully understood. Due to the concealment of early lesions and the complexity of the progression process, it brings challenges to early clinical diagnosis and precise management. With the iterative upgrading of high-resolution fundus imaging technology, the accurate identification of characteristic optical coherence tomography (OCT) imaging of retinoschisis in high myopia has become an important basis for early diagnosis, staging, and treatment of the disease. This article focuses on the OCT imaging features of myopic retinoschisis, focusing on its epidemiology and risk factors, and the progress of characteristic OCT imaging in disease staging, diagnosis, treatment, and prognosis evaluation. At the same time, it further reviews the research status and development prospects of the combination of artificial intelligence and OCT in the automatic identification, disease evaluation, and progression prediction of myopic retinoschisis, so as to provide theoretical support and clinical reference for the early diagnosis, standardized staging, and accurate diagnosis and treatment of myopic retinoschisis.
• KEYWORDS: myopic retinoschisis; optical coherence tomography (OCT) imaging features; swept-source optical coherence tomography; ultra-widefield optical coherence tomography; artificial intelligence

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0 引言

高度近视(high myopia, HM)已成为全球主要的致盲性眼病之一,尤其是在东亚地区,高度近视的患病率正在迅速上升。根据国际近视研究所(international myopia institute, IMI)的定义,眼轴长度(axial length, AL)≥26 mm或屈光不正≥-6.00 屈光度(diopter, D)为高度近视[1-2],而高度近视视网膜劈裂是其常见的致盲性并发症之一[3-4]。高度近视视网膜劈裂可累及视网膜多个解剖部位,包括血管旁区域、视盘周围区域及黄斑区域,甚至周边部视网膜,而且不同部位劈裂的病理机制存在复杂关联。其病变早期多为隐匿性进展,患者常无明显视力下降或视物变形症状,仅在病变累及黄斑区时才出现视觉功能

异常,导致早期无法精确诊断。常规眼底检查,如直接检眼镜、眼底照相和谱域光学相干断层扫描(spectral domain optical coherence tomography, SD-OCT)受限于视野范围和分辨率,较难精准区分劈裂部位及合并病变[5]。光学相干断层扫描(optical coherence tomography,OCT)技术的迭代升级为高度近视视网膜劈裂的精准诊断提供关键支撑。

1 高度近视视网膜劈裂的流行病学与危险因素

当前,全球近视患病率超过 28.3%,预计到 2050 年将达到 49.8%,而高度近视患病率将由目前的 4.0%上升为 9.8%[6-7],高度近视视网膜劈裂在高度近视人群中的患病率为 8%-34%[8]。

高度近视人群黄斑视网膜劈裂的患病率与更高的屈光不正、更长的眼轴、更薄的脉络膜下层厚度、更宽的视盘周围 γ 区以及青光眼和黄斑前膜的存在相关[9]。研究结果显示,球镜等效值(spherical equivalen, SE)每降低 1 D,患病风险增加 5%-10%。随着 SE 的降低,眼轴延长增加,这会导致黄斑区牵引力增大、视神经乳头变形,以及黄斑中心凹视网膜病变发生率升高[10]。视网膜劈裂(retinoschisis, RS)的发展机制和牵引来源已被广泛讨论但尚未证实。

2 高度近视视网膜劈裂的分期及 OCT 的临床表现特征

高度近视视网膜劈裂并非静态病变,其病变进展受后巩膜葡萄肿、不完全性玻璃体后脱离(posterior vitreous detachment, PVD)、视网膜前膜(epiretinal membrane, ERM)、玻璃体黄斑牵引(vitreomacular traction, VMT)等因素的影响,是一个动态演变的过程[11-17]。其病变的各阶段特征性形态改变可在 OCT 上清晰显现,这一特点也是临床分期系统建立的核心基础。

Takano 等[18]利用当时尚处早期的 OCT,首次在高度近视伴后巩膜葡萄肿眼中对黄斑视网膜劈裂进行了识别;随着 OCT 的扫描速度提升及轴向分辨率的推进,Panozzo 等[19]通过 OCT 首次提出了近视牵引性黄斑病(myopic traction maculopathy, MTM)这一概念,其涵盖了影响高度近视眼部黄斑部的一系列牵引变化;Shimada 等[20]在此基础上利用频域 OCT 将劈裂累及的空间范围转化为可随访的分级,提出的 S0-S4 分期直观展示了病变从旁中心浅层劈裂向中心凹受累再向全层结构破坏的连续扩展。

波长较长、穿透力较强的扫频光学相干断层扫描(swept-source optical coherence tomography, SS-OCT)可以清晰地显示巩膜和眶脂肪组织,从而有助于高度近视眼的眼后极部进行形态学分析,临床效果优于 SD-OCT。基于此,Ruiz-Medrano 等[21]提出的 ATN 分类表分类系统中,SS-OCT 成为界定牵引性成分(T 分级)的核心工具,将视网膜劈裂按受累层分为内层、外层及混合型,同时精准区分中心凹劈裂、视网膜脱离与全层黄斑裂孔,把牵引性病变纳入近视黄斑病变整体分类体系,弥补了既往仅聚焦萎缩性病变的缺陷;Parolini 等[12]基于 OCT 创建了“近视性牵引性黄斑病变分期系统”(myopic traction maculopathy staging system,MSS),从垂直牵拉与切线牵拉两个维度阐释了 MTM 的连续演变规律:纵轴反映视网膜劈裂至脱离的进展,横轴体现黄斑中心凹完整性的破坏。该分期方法可实现病变的标准化评估,且明确了病变 3 期到 4 期最短进展时长约 3 mo,为临床随访规划与手术干预时机的把控提供了客观的形态学依据。

Zhao 等[22]在 108 只高度近视眼中用 24×20 mm 超广角光学相干断层扫描(ultra-widefield optical coherence tomography, UWF-OCT)将劈裂评估从传统的中心凹邻域扩展至包括血管旁区在内的广视野,并引入高斯曲率作为局部后极几何不连续的量化指标,发现最高曲率点 K1 最频繁位于血管弓区,同时近视性视网膜劈裂(myopic retinoschisis, MRS)与血管旁劈裂(paravascular retinoschisis, PVRS)之间存在互为风险因素的结构耦合关系。UWF-OCT 能够同时扫描视网膜中央和周边区域,有望成为早期发现中心凹外视网膜劈裂的成像技术。

OCT 技术的迭代更新,推动高度近视视网膜劈裂的分类体系从单一解剖分级向多维度综合分期演进,从静态形态成像到动态力学评估、从黄斑中心聚焦到超广角全域检测,成为早期筛查、风险分层与个体化治疗的核心技术支撑。

3 OCT 在诊疗决策中的应用

Shimada 等[23]的随访研究显示,未接受手术干预的近视性中心凹劈裂(myopic foveoschisis, MF)患者,近半数患眼会在 2 a 内进展为黄斑裂孔,或是继发黄斑裂孔源性视网膜脱离,致盲风险突出。因此,何时干预、如何选择术式、如何预判视力恢复上限,成为临床核心难题。而 OCT 技术的迭代更新,不仅决定了劈裂本身的诊断,更从根本上重塑了手术适应证制定、术式精细化选择和以 OCT 微观结构为锚点的预后分层体系。

目前临床常用的主流术式包含三类:玻璃体切割术(pars plana vitrectomy, PPV)、黄斑扣带术与后巩膜加固术(posterior scleral reinforcement, PSR)。Song 等[24]对 PPV 联合内界膜剥除和气体填充治疗近视性黄斑劈裂的疗效进行了荟萃分析,结果显示,接受该术式后,患者预后的最佳矫正视力与黄斑中心凹视网膜厚度均得到了明显改善。同时证实,在 MF 还未出现继发黄斑裂孔、视网膜脱离等并发症的发病早期进行手术治疗,其预后效果更好。这就提示了在临床诊疗中,要定期对患者进行 SS-OCT和 UFW-OCT 检查,实现对病变的早发现、早干预。

Quiroz-Reyes 等[25]对黄斑保留内界膜剥离术(fovea-sparing internal limiting membrane peeling, FSIP)与标准内界膜剥离术(internal limiting membrane peeling, ILMP)进行了比较分析,结果显示 FSIP 手术用于早期近视性黄斑病变安全且疗效确切;术后 OCT 随访结果显示黄斑解剖复位率更高,术后新发黄斑裂孔的概率也更低。FSIP 有望成为早期高度近视相关黄斑病变的首选术式。

OCT 技术的革新不仅对手术方式的选择及术后评估等方面有着影响,不同类型 OCT 还能从术前规划、术中引导两个维度优化手术安全与效果:术中光学相干断层扫描(intraoperative optical coherence tomography, iOCT)与眼前节 OCT(anterior segment optical coherence tomography, AS-OCT)在手术中能够将巩膜手术切口安全后移,改善长眼轴带来的手术器械操作受限问题,减少医源性视网膜裂孔的发生风险[26]。

高度近视性黄斑劈裂的诊疗已形成“OCT 精准诊断+早期手术干预”的核心逻辑,PPV 联合 ILM 剥除、FSIP 等术式及 iOCT,AS-OCT 的技术辅助,为患者带来了可靠的

疗效与安全性保障。

4 OCT在临床诊治中的挑战及技术展望

4.1 临床诊治中的挑战　在临床诊疗中较多病例可见术后常规OCT提示视网膜分层复位完整,无劈裂残留,患者却持续主诉视物变形、夜间视物不清等不适。相关研究指出,近视性黄斑劈裂患者术后最终视力预后并不仅仅取决于视网膜解剖复位效果,术后视网膜厚度重塑、光感受器层修复状态同样是影响预后的重要因素[27-29]。因此,在临床实际应用中,即使部分患眼有明显视网膜劈裂,视力也未必很差。已有预后研究证实,黄斑浅层毛细血管丛血管密度、术前椭圆体带断裂范围是近视性黄斑劈裂患者术后视力恢复的独立预测因子[30],而传统OCT形态学评估无法识别此类隐匿的功能性损伤。目前国内外尚无统一规范的多模态OCT影像预后预测模型,术前难以精准评估患者手术获益、术后视功能恢复水平与病变复发风险,无法满足临床个体化预后评估的需求。

临床应用中也存在一些不足:图像质量影响因素:(1)AL过长:导致SS-OCT信号衰减,脉络膜-巩膜交界处显示不清,影响测量准确性,需采用信号增强算法(如深度学习降噪)改善图像质量[31];(2)儿童患者注视不稳定:传统OCT扫描需患者配合注视≥10 s,儿童患者难以耐受,而UWF-OCT仅需4 s扫描,可显著提升儿童患者的图像合格率;(3)屈光介质混浊(如白内障、玻璃体积血),导致OCT信号穿透不足;诊断一致性问题:高度近视视网膜劈裂的诊断依赖医师对OCT图像的主观解读,不同经验医师的诊断一致性存在差异。这就提示需要建立标准化诊断标准或引入辅助诊断工具。

4.2 技术展望

4.2.1 深度学习模型及基于OCT黄斑图像的有效人工智能系统的应用　近些年,以深度学习(deep learning, DL)为代表的人工智能(artificial intelligence, AI)技术发展迅速,已在医学诊断领域得到大量验证并投入应用[32]。在眼科临床与科研领域,不少学者运用深度学习算法对OCT、OCT血管造影、超广角眼底图像进行智能分析[33-42]。而且AI系统还可运用热成像显示病变重要区域(如MRS的劈裂分层、近视性脉络膜新生血管的高反射团),增强诊断结果的可解释性[43]。有研究发现,深度学习技术可降低眼科医师在筛查和随访过程中的工作负荷,以在保证诊断准确性的同时缩短检测时间、节省人力成本,既可用于大规模人群近视筛查,也可为高度近视患者长期随访管理提供帮助[43]。

4.2.2 SS-OCT与UWF-OCT的融合应用　SS-OCT可清晰显示视网膜微血管,UWF-OCT可获得更大范围眼底结构信息,二者的结合从结构和功能上对眼底病变进行综合评估,为高度近视病理机制研究提供新思路。结合刘明慧等[44]学者研究,多模态成像与AI联用可实现高度近视眼底生物参数的准确测量,为近视性视网膜劈裂的个体化诊疗提供可行方案。

与刘明慧等[44]研究相比,本文的创新点是,未对高度近视眼底病变进行广谱性分析,而是主要针对高度近视视网膜劈裂这一主要致盲并发症进行讨论,主要围绕高度近视视网膜劈裂OCT影像学特征在分期及诊治中的应用及AI辅助展开针对性讨论,可为该并发症的早期识别、准确分期、个体化治疗及预后判断提供相应临床依据。

5 结论

高度近视视网膜劈裂早期症状隐匿,加之发病部位广泛,增加了临床确诊和诊治的难度。OCT技术的迭代升级,尤其是SS-OCT与UWF-OCT,通过高分辨率成像与超广角扫描,实现了从黄斑中心至周边视网膜的全域可视化,推动了分期体系从单一解剖描述向动态演变评估的转化。尽管面临长眼轴信号衰减、儿童患者配合度低及诊断一致性不足等挑战,但基于深度学习的AI辅助系统与多模态OCT融合技术,正逐步解决上述问题,为大规模筛查与长期随访提供高效工具。未来需进一步通过多中心研究验证分期效能,并探索OCT参数与视觉功能的关联,最终实现高度近视视网膜劈裂的精准防控,减少致盲性结局。

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