

DOI: 10.16781/j.CN31-2187/R.20240330

• 专题报道 •

人工智能在结直肠无蒂锯齿状病变中的应用进展

赵优冬, 卫佳慧, 张 颂, 李兆申, 赵胜兵, 柏 愚*

海军军医大学(第二军医大学)第一附属医院消化内科, 国家消化病临床医学研究中心, 上海 200433

[摘要] 结直肠无蒂锯齿状病变(SSL)是一种重要的结直肠癌癌前病变,也是间期结直肠癌的重要原因。结直肠 SSL 虽然具有独特的组织结构和形态学特征,但内镜下检出率低,组织病理学诊断变异度高,是结直肠癌筛查中最易漏诊的病变之一。近年来,人工智能在结直肠疾病诊断中的应用迅速增多,已有研究发现人工智能辅助内镜技术可提高结直肠 SSL 的检出率和诊断准确性,辅助病理诊断可提高诊断效率和一致性。本文就当前人工智能在结直肠 SSL 中的应用进展进行综述。

[关键词] 人工智能; 结直肠肿瘤; 无蒂锯齿状病变; 结肠镜检查; 病理诊断

[引用本文] 赵优冬,卫佳慧,张颂,等. 人工智能在结直肠无蒂锯齿状病变中的应用进展[J]. 海军军医大学学报, 2025, 46(1): 24-31. DOI: 10.16781/j.CN31-2187/R.20240330.

Artificial intelligence in colorectal sessile serrated lesion: recent progress

ZHAO Youdong, WEI Jiahui, ZHANG Song, LI Zhaoshen, ZHAO Shengbing, BAI Yu*

Department of Gastroenterology, The First Affiliated Hospital of Naval Medical University (Second Military Medical University) & National Clinical Research Center for Digestive Diseases, Shanghai 200433, China

[Abstract] Sessile serrated lesion (SSL) is a major precancerous lesion type of colorectal cancer and one of the main causes of colorectal cancer. SSL has unique tissue structures and morphological features, with low detection rate under endoscopy and high variability in histopathological diagnosis, making it one of the most easily missed lesions in colorectal cancer screening. In recent years, the application of artificial intelligence (AI) in the diagnosis of colorectal cancer has been rapidly increasing. Previous studies have found that AI-assisted endoscopic technology can improve the detection rate and diagnostic accuracy of colorectal SSL, and AI-assisted pathological diagnosis can improve diagnostic efficiency and consistency. This article aims to provide a review of current research on AI technology in colorectal SSL.

[Key words] artificial intelligence; colorectal neoplasms; sessile serrated lesions; colonoscopy; pathologic diagnosis

[Citation] ZHAO Y, WEI J, ZHANG S, et al. Artificial intelligence in colorectal sessile serrated lesion: recent progress[J]. Acad J Naval Med Univ, 2025, 46(1): 24-31. DOI: 10.16781/j.CN31-2187/R.20240330.

2023 年全球癌症数据统计显示,结直肠癌(colorectal cancer, CRC)预计发病率和死亡率已经跻身恶性肿瘤前 3 位,严重威胁人类健康^[1]。近年来,随着饮食结构和生活方式的改变,我国 CRC 发病率与患病率迅速升高,已逐渐成为最常见的消化系统恶性肿瘤,严重威胁人们的生命和健康^[2]。作为预防手段,结肠镜检查 and 息肉摘除术可

使 CRC 的发病率明显降低^[3]。结肠镜检查是早期筛查 CRC 的重要手段,操作简单、安全有效,被公认为诊断和治疗肠道病变的“金标准”。但结肠镜检查并不能完全预防 CRC 发生,在日常实践中诊断的 CRC 病例中有高达 8.6% 发生在之前进行过结肠镜检查但未检测到癌症的患者身上,即间期 CRC^[4]。随着结肠镜筛查意识的提高,间期 CRC 的发生引

[收稿日期] 2024-05-15 **[接受日期]** 2024-10-30

[基金项目] 国家自然科学基金(82170567, 82300627),上海市科技创新行动计划优秀学术/技术带头人计划(22XD1425000),上海市自然科学基金面上项目(23ZR1478700)。Supported by National Natural Science Foundation of China (82170567, 82300627), Project of Outstanding Academic/Technological Leader of Shanghai Scientific and Technological Innovation Action Plan (22XD1425000), and General Program of Natural Science Foundation of Shanghai (23ZR1478700)。

[作者简介] 赵优冬,硕士生。E-mail: zhaoyoudong2023@126.com

*通信作者(Corresponding author)。Tel: 021-31162770, E-mail: changhaibaiyu@smmu.edu.cn

起了人们的极大关注,其检出率成为评估结肠镜筛查质量的重要指标。大量的研究数据表明,首次检查时遗漏是发生间期CRC最主要的原因,是一半以上间期CRC发生的根源^[5]。分子病理学研究发现,结直肠无蒂锯齿状病变(*sessile serrated lesion, SSL*)与间期CRC密切相关^[6],然而,SSL的检测具有挑战性,内镜医师和病理医师对SSL的识别也不一致,因此很容易漏诊。近年来,人工智能(*artificial intelligence, AI*)在结直肠疾病中的应用受到重视,将AI与已知的CRC筛查和诊断方法结合应用以提高诊断SSL准确性成为研究热点,具有深远的科学意义和临床意义。

1 结直肠 SSL 概述

CRC常见的癌变路径包括腺瘤-腺癌路径、锯齿状路径、*de novo*癌和炎症-癌路径。近年研究显示,有高达15%~30%的散发性CRC来源于锯齿状息肉前体而不是常规腺瘤,锯齿状路径在CRC癌变路径中占比较高^[7]。2019年修订的WHO消化系统肿瘤分类引入了术语“无蒂锯齿状病变”(SSL),以取代之前使用的术语“无蒂锯齿状腺瘤/息肉”(sessile serrated adenoma/polyp, SSA/P),推荐将结直肠锯齿状病变分为SSL、SSL伴异型增生(SSL with dysplasia, SSL-D)、增生性息肉(hyperplastic polyp, HP)、传统锯齿状腺瘤(traditional serrated adenoma, TSA)和未分类的锯齿状腺瘤5类^[8]。相较于HP和SSL, TSA十分少见,HP约占结直肠锯齿状病变的75%,SSL约占25%,而TSA不足1%^[9]。传统上认为HP是非肿瘤性病变,其一个亚类——微泡型增生性息肉(microvesicular hyperplastic polyp, MVHP)被认为是SSL的前体病变^[10],而SSL和TSA存在恶变潜能,尤其是SSL-D可快速进展至浸润癌^[11]。有研究证实,SSL-D病例在未来10年内发生CRC的风险为4.43%,高于传统腺瘤(2.33%),这突显了SSL患者发生CRC的长期风险显著增加^[12]。同样,相关研究发现,在发生SSL-D之前,SSL的平均持续时间为7~15年,3.03%~12.5%的SSL-D在随访5~7年后发展为CRC^[13]。近端锯齿状息肉(尤其是直径≥10 mm的锯齿状息肉)患者发生CRC的风险显著增加,相较于没有息肉的病例,近端大锯齿状息肉患者发生CRC的风险升高了7倍

($HR=8.0$, 95% CI 3.6~16.1)^[14]。

CRC早期筛查策略强调结肠镜检查及结肠镜下腺瘤切除,这一系列早期筛查措施有效降低了CRC的发病率和死亡率。然而,仍然有大量患者在接受结肠镜检查后发生间期CRC,相关研究发现结肠镜检查3年后间期CRC的发生率为3.4%~9.0%^[15-16]。分子病理学研究发现,间期CRC中出现较高水平的CpG岛甲基化、微卫星不稳定性、染色体不稳定性及B-Raf原癌基因丝氨酸/苏氨酸蛋白激酶(B-Raf proto oncogene, serine/threonine protein kinase; *BRAF*)突变与SSL存在密切相关性^[6]。近年来的大量研究表明,提高SSL检出率可有效降低间期CRC的发生风险和死亡风险^[17-20]。因此,作为重要的CRC癌前病变,有效区分并检出SSL对助力CRC的筛查和早诊、早治极为关键。

2 结直肠 SSL 诊断的挑战性

2.1 内镜检查易漏诊 结肠镜检查因高灵敏度、高特异度以及对癌变的直接可视化作用被认为是筛查CRC的金标准。既往研究表明,结肠镜筛查能够显著降低CRC的发病率和死亡率^[21]。然而,肉眼有可能错过微小病变或扁平息肉。本中心团队前期一项纳入15 000多例结肠镜检查的meta分析发现,腺瘤的漏诊率为26%(95% CI 23%~30%),锯齿状息肉的漏诊率为27%(95% CI 16%~40%)^[22]。SSL常发生在近端结肠,常有黏液帽覆盖,在常规白光内镜下病变往往边界模糊,多呈无蒂或扁平形态,较难发现,容易遗漏^[23-24],而且往往不能完全切除,这都是导致间期CRC发生的重要原因。常规白光内镜显示SSL与HP在形态及大小方面无显著差异,这进一步说明了两通过内镜下形态学及大小有时难以区别^[25]。在病变检出率上,内镜医师对锯齿状病变的检出率极其不稳定,波动大(2%~22%)^[12,26],美国总体锯齿状病变检出率仅在6%左右^[27],我国总体上处在相对较低的水平,本团队前期多中心研究显示锯齿状病变检出率不足4%^[28]。这对CRC早期筛查及早防、早治提出了挑战,提高锯齿状病变检出率成为改善CRC早期筛查的重要环节。

随着内镜技术的发展,电子染色技术越来越普及。目前最常用的电子染色技术包括窄带成像技术(narrow band imaging, NBI)、联动成像技术

(linked color imaging, LCI)等,然而,相较于腺瘤而言,各种内镜技术对SSL的检出结论尚不一致,有待进一步探索。NBI是目前应用最广泛的电子染色技术之一,有研究证实内镜诊断非腺瘤性息肉时,NBI优于常规白光内镜^[29]。NBI下SSL隐窝的外观呈云雾状,形状不规则,隐窝内有黑点,腺管开口为pit pattern II型。NBI可能会比常规白光内镜检出更多近端结肠锯齿状病变(204/399 vs 158/401),但是差异无统计学意义($P=0.085$)^[30]。另有研究比较了LCI与NBI对SSL的检出效能,虽未分出优劣(检出率:12.3% vs 9.4%, $P=0.356$),但两者SSL检出率均高于常规白光内镜。两项平行对照试验发现,LCI与常规白光内镜相比能提高SSL的检出率^[31-32]。一项随机对照试验表明,LCI与常规白光内镜相比可以更好地检出腺瘤,而对SSL的检出率具有临界统计学意义($P=0.05$)^[33]。Paggi等^[34]的研究则显示,LCI与常规白光内镜对SSL的检出率差异无统计学意义($P=0.829$)。

2.2 病理诊断变异度高 基于结肠镜检查的病理诊断是鉴别结直肠病变性质的金标准,组织形态学特征是目前诊断SSL的唯一可靠方法。自锯齿状病变概念提出以来,其诊断名词及病理诊断标准经过多轮更新,既往称为锯齿状腺瘤、SSA/P^[35-37],这些诊断名词在病理医师间存在较多争议。2019年WHO消化系统肿瘤分类提出SSL这一诊断名词,并规定有1个及以上隐窝出现特征性的结构改变即可诊断SSL。这些结构改变包括隐窝呈锯齿状,隐窝沿黏膜肌层水平生长,基底部(隐窝的底部三分之一)扩张、异常成熟,以及不对称的增殖(增殖区从基底向侧面迁移)^[8]。存在上述超过1个明确的结构改变的锯齿状隐窝就足以诊断SSL,“明确”一词很重要,因为仅具有细微结构异常的隐窝时不应被视为SSL诊断。然而,这些形态学特征与增生性息肉存在重叠,缺少可量化的鉴别点。具有深且扩张的隐窝和锯齿状上皮的HP与SSL相似,反之HP也可能有几个典型的、扩张的、有严重锯齿的隐窝。这使得病理医师在诊断SSL时存在着较大差异,组织病理学诊断的一致性差、变异度高^[38]。欧洲和美国病理医师对SSL诊断的总体一致性评估Kappa值仅为0.44,表现中等^[39]。随着对SSL认识的不断深入,其病理诊断并不困难,诊断不一致的原因可能是取材和制片的局限性所致。

目前我国SSL的诊断率和诊断准确性、一致性尚需进一步系统论证,探讨提升SSL病理诊断准确性和一致性的方法对提高SSL检出率尤为重要。

3 AI辅助诊断结直肠SSL的研究进展

基于机器学习和深度学习算法的AI可以通过大数据学习将简单的特征组合为复杂特征,从而更快速、更便捷地刻画出数据丰富的内在信息。AI在辅助病变诊断中通常以深度学习的方式进行,深度学习模型主要包括监督学习和无监督学习。监督学习模式是提供人工注释来训练模型,模型的性能取决于所提供注释的质量,因此,在将这些数据纳入模型训练之前,往往需要有关领域内的专家达成一致意见。也有一些模型以无监督学习模式构建,在训练过程中不包括人工注释,AI从数据中找规律并自动提取数据特征。弱监督学习模式结合了监督学习和无监督学习,可以提高病变预测的准确性,节省时间和成本^[40]。近年来提出的自监督学习(self-supervised learning)通过从大量无标签的数据集中挖掘自身的监督信息,学习有用特征以开发稳健的识别模型,在疾病诊断和鉴别方面具有较好的应用前景^[41-42]。AI辅助在内镜中的重要应用包括计算机辅助检出(computer-aided detection, CADe)和计算机辅助诊断(computer-aided diagnosis, CADx),CADe的目的是帮助内镜医师在结肠镜检查中发现息肉,CADx的目的是在不需要组织活检的情况下准确预测息肉的组织学分类。SSL作为重要的CRC癌前病变,目前在临床实践中内镜和病理诊断率均未达到预期,未来10年要突出评估专门针对SSL的AI系统^[43]。

3.1 AI在SSL内镜检出中的应用(CADe) AI检出结直肠息肉是AI技术在消化病学领域应用研究中的第1个目标,目前全球范围内有关CADe在SSL检出、减少漏诊方面的研究已有一些报道。新加坡一项使用实时AI辅助系统(GI GeniusTM智能内镜系统,Medtronic公司)的队列研究显示,AI辅助对SSL的检出率为5.6%,高于临床预期检出率(2%~3%)^[44];另一项研究表明,使用GI GeniusTM智能内镜系统的CADe对包括SSL在内的近端锯齿状病变的检出率为12.6%,高于标准结肠镜检查(10.5%)^[45]。Soons等^[46]研究发现CADe(DISCOVERY系统,Pentax Medical公司)的SSL

检出率达到 11.1%, 并且未观察到与 CAdE 系统相关的不良反应。美国一项前瞻性、多中心、随机背靠背结肠镜检查研究证明, 与单独使用白光结肠镜相比, CAdE [EndoScreener 系统, 微识医疗科技(上海)有限公司] 可降低 SSL 漏检率 (7.14% vs 42.11%)^[47]。另一项背靠背结肠镜检查研究同样发现, 先行 CAdE 组的 SSL 漏检率明显低于先行标准结肠镜检查组 (13.0% vs 38.5%)^[48]。一篇共纳入 7 项随机对照试验的 meta 分析显示, 与非 CAdE 组相比, CAdE 组 SSL 的漏检率显著降低 (合并 $RR=0.43$, 95% CI 0.20~0.92, $P<0.05$)^[49]。Shah 等^[50] 纳入 14 项研究、10 928 例患者的 meta 分析提示, CAdE 能使 SSL 漏检率降低 78%。Neumann 等^[51] 的研究结果显示, 在 LCI 模式下使用 CAdE (CAD EYE 系统, Fujifilm 公司) 对 SSL 的检出率达到 100%。另外一篇纳入了 5 项随机对照试验的 meta 分析显示, CAdE 组每次结肠镜检查检出的 SSL 数量较对照组有所提升 (6% vs 4%, $P<0.01$)^[52]。

然而, 另有一些研究未能证实 CAdE 在 SSL 检出中的作用^[53-55]。Wang 等^[56] 应用 EndoScreener 系统进行了双盲设计, 引进伪 AI 系统, 发现 CAdE 组 SSL 检出率与伪 AI 对照组差异无统计学意义 (4% vs 5%, $P=0.50$)。Lau 等^[57] 进行的一项评估 CAdE (ENDO-AID 系统, Olympus 公司) 辅助初级内镜医师结肠镜检查的单盲随机对照试验显示, SSL 检出率与无 CAdE 组差异无统计学意义 (2.1% vs 1.8%, $P=0.801$)。一篇纳入 50 项 RCT 研究共 34 445 例患者的网状 meta 分析发现, CAdE 没有明显提高 SSL 的检出率 ($OR=1.37$, 95% CI 0.65~2.88)^[58]。

CAdE 系统对 SSL 的检出效果异质性大, 可能存在于诸如 SSL 本身形态学差异、患者肠道准备不佳、黏膜暴露质量低、内镜医师的非盲性等因素, AI 系统应该使用大规模 SSL 数据集进行专门训练, 以提高检测的灵敏度和特异度。此外, 还应当接受足够的干扰因素样本训练 (包括粪便、黏膜皱襞等) 以减少误报。程序开发人员应继续优化 CAdE 系统性能, 避免遗漏病变, 还需要限制假阳性的结果。

3.2 AI 在 SSL 内镜诊断中的应用 (CADx) 基于结肠镜检查的组织病理诊断是鉴别结直肠病变性质的金标准, 然而内镜和病理诊断之间不一致的情

况并不少见, 尤其在 SSL 病理诊断率低、一致性欠佳的情况下, 因此, 在切除前获得准确的内镜诊断是有利的。CADx 技术可以提供结肠息肉组织病理学预测, 在支持内镜医师的光学诊断方面发挥重要作用, 目前 CADx 技术通常依赖于电子染色内镜图像, 如 NBI 等。Houwen 等^[59] 开发了基于 YOLOv4 算法的 AI 息肉识别系统, 训练集为前瞻性收集的 1 339 个息肉的 2 637 张 NBI 非放大图像 (其中 41 例 SSL), 临床验证结果显示 CADx 区分 SSL 和非 SSL 的准确度为 88.9%, 特异度 96.6%, 但灵敏度只有 17.1%。Kader 等^[60] 开发了一个卷积神经网络 (convolutional neural network, CNN) 模型, 训练集包括 149 例腺瘤、56 例 SSL、35 例 HP 和 1 例 TSA 的 NBI 非放大和放大视频, 在测试集上的结果显示 CADx 区分腺瘤和非腺瘤的准确度达到 90%, 但未明确区分 SSL 的准确度。在一项单中心研究中, 采用 42 例 SSL 和 103 例 HP 数据对 CADx 系统进行诊断性能测试, 结果显示 CADx 系统鉴别 SSL 的灵敏度和特异度分别为 80.9% 和 62.1%^[61]。一篇系统评价和 meta 分析显示, 在纳入的 3 项前瞻性研究中, AI 鉴别 SSL 和 HP 的灵敏度为 95.2%, 特异度为 95.9%^[62]。有研究使用 ResNet-50 网络开发了 AI 分类器, 区分腺瘤和锯齿状病变的分类器 AUC 为 86%, 优于内镜医师或与内镜医师相当; 区分 SSL 和 HP 的分类器 AUC 为 55%, 劣于内镜医师^[63]。

CADx 在助力内镜医师进行光学诊断方面很有前景, 然而, 要成功实施这一方法还需将 CADx 工具与内镜工作流程无缝集成, 且无须进行图像增强或放大。在未来, CADx 技术有望在高清白光内镜下完成对 SSL 的诊断。

3.3 AI 在 SSL 病理诊断中的应用 近年来的研究证明, 深度学习方法在组织学图像的分类和分割任务中具有优越性^[64-65]。随着全自动病理切片数字扫描仪和高通量组织库的应用范围扩大^[66], 数字病理学领域逐渐成熟, 开发和应用计算模型可以协助病理医师进行组织病理学分析和疾病诊断。Byeon 等^[67] 构建了 2 种 CNN 模型——DenseNet-161 和 EfficientNet-B7, 2 种深度学习模型能够自动对从结肠镜检查相关资料中获得的显微镜数字病理图像进行分类, 在 SSL 的病理分类中都显示出非常高的灵敏度和特异度 (均超过

95%)，AUC 分别为 0.993 和 0.995。Korbar 等^[68]使用高通量徕卡 Aperio 病理切片扫描仪对包括 SSL 在内的结直肠息肉病理图像进行全景扫描和标注，基于 ResNet 构建了深度学习模型并进行训练，分类性能测试结果显示，该模型对 SSL 的诊断准确度为 89.5%。Wu 等^[69]开发和验证了一个用于鉴别 SSL 和 HP 的逻辑拟人化病理诊断系统（logical anthropomorphic pathology diagnostic system, LA-SSLD），其准确度、灵敏度和特异度分别为 85.71%、86.36% 和 85.00%，与病理学专家的诊断准确性相当。Wei 等^[70]构建了一个基于 ResNet 的病理诊断模型，并对 4 种结直肠息肉类型（管状腺瘤、管状绒毛状或绒毛状腺瘤、HP 和 SSL）进行分类性能评估，发现 AI 诊断 SSL 的准确度、灵敏度和特异度分别为 93%、78.9% 和 97.5%，其中有 27.3% 的 HP 被错误归类为 SSL。

CRC 早癌筛查通常需要对患者的组织学标本开展病理学评估，尽早明确病理诊断，这对后续治疗、跟踪和随访至关重要。AI 可以作为一种辅助手段，将可疑病变区域突出显示以供人工审查，使病理医师专注异常部位，通过数字化方式对组织学标本进行评估和分析，从而提高结直肠疾病病理诊断的效率和一致性。

4 小 结

SSL 作为日益突出的疾病负担，存在诊断困难、检出率不稳定等问题，结合 AI 辅助诊断技术具有深远的现实意义。将 CADe 与 CADx 相结合、AI 内镜与 AI 病理相结合等，有望为诊断和管理结直肠 SSL 提供更有效的方法。AI 是内镜医师和病理医师检测和诊断 SSL 的有用辅助工具，但必须辅有良好的内镜技术和病理诊断能力才能有效发挥其性能。

[参 考 文 献]

- [1] SIEGEL R L, MILLER K D, WAGLE N S, et al. Cancer statistics, 2023 [J]. *CA Cancer J Clin*, 2023, 73: 17-48. DOI: 10.3322/caac.21763.
- [2] ZHENG R, ZHANG S, ZENG H, et al. Cancer incidence and mortality in China, 2016 [J]. *J Natl Cancer Cent*, 2022, 2(1): 1-9. DOI: 10.1016/j.jncc.2022.02.002.
- [3] ZAUBER A G, WINAWER S J, O'BRIEN M J, et al. Colonoscopic polypectomy and long-term prevention of colorectal-cancer deaths [J]. *N Engl J Med*, 2012, 366(8): 687-696. DOI: 10.1056/NEJMoa1100370.
- [4] MORRIS E J, RUTTER M D, FINAN P J, et al. Post-colonoscopy colorectal cancer (PCCRC) rates vary considerably depending on the method used to calculate them: a retrospective observational population-based study of PCCRC in the English National Health Service [J]. *Gut*, 2015, 64(8): 1248-1256. DOI: 10.1136/gutjnl-2014-308362.
- [5] ROBERTSON D J, LIEBERMAN D A, WINAWER S J, et al. Colorectal cancers soon after colonoscopy: a pooled multicohort analysis [J]. *Gut*, 2014, 63(6): 949-956. DOI: 10.1136/gutjnl-2012-303796.
- [6] BOGIE R M M, LE CLERCQ C M C, VOORHAM Q J M, et al. Molecular pathways in post-colonoscopy versus detected colorectal cancers: results from a nested case-control study [J]. *Br J Cancer*, 2022, 126(6): 865-873. DOI: 10.1038/s41416-021-01619-z.
- [7] BATEMAN A C. The spectrum of serrated colorectal lesions-new entities and unanswered questions [J]. *Histopathology*, 2021, 78(6): 780-790. DOI: 10.1111/his.14305.
- [8] NAGTEGAAL I D, ODZE R D, KLIMSTRA D, et al. The 2019 WHO classification of tumours of the digestive system [J]. *Histopathology*, 2020, 76(2): 182-188. DOI: 10.1111/his.13975.
- [9] CROCKETT S D, NAGTEGAAL I D. Terminology, molecular features, epidemiology, and management of serrated colorectal neoplasia [J]. *Gastroenterology*, 2019, 157(4): 949-966.e4. DOI: 10.1053/j.gastro.2019.06.041.
- [10] O'BRIEN M J, ZHAO Q, YANG S. Colorectal serrated pathway cancers and precursors [J]. *Histopathology*, 2015, 66(1): 49-65. DOI: 10.1111/his.12564.
- [11] LINDHOLM C R, ANDERSON J C, SRIVASTAVA A. The dark side of the colon: current issues surrounding the significance, prevalence, detection, diagnosis and management of serrated polyps [J]. *Curr Opin Gastroenterol*, 2019, 35(1): 34-41. DOI: 10.1097/MOG.0000000000000495.
- [12] ERICHSEN R, BARON J A, HAMILTON-DUTOIT S J, et al. Increased risk of colorectal cancer development among patients with serrated polyps [J]. *Gastroenterology*, 2016, 150(4): 895-902.e5. DOI: 10.1053/j.gastro.2015.11.046.
- [13] IJSPEERT J E, VERMEULEN L, MEIJER G A, et al. Serrated neoplasia-role in colorectal carcinogenesis and clinical implications [J]. *Nat Rev Gastroenterol Hepatol*, 2015, 12(7): 401-409. DOI: 10.1038/nrgastro.2015.73.
- [14] LI D, LIU L, FEVRIER H B, et al. Increased risk of colorectal cancer in individuals with a history of serrated polyps [J]. *Gastroenterology*, 2020, 159(2): 502-511.e2. DOI: 10.1053/j.gastro.2020.04.004.

- [15] BURR N E, DERBYSHIRE E, TAYLOR J, et al. Variation in post-colonoscopy colorectal cancer across colonoscopy providers in English National Health Service: population based cohort study[J]. *BMJ*, 2019, 367: l6090. DOI: 10.1136/bmj.l6090.
- [16] HAUG U, REGULA J. Interval cancer: nightmare of colonoscopists[J]. *Gut*, 2014, 63(6): 865-866. DOI: 10.1136/gutjnl-2013-305686.
- [17] ANDERSON J C, HISEY W, MACKENZIE T A, et al. Clinically significant serrated polyp detection rates and risk for postcolonoscopy colorectal cancer: data from the New Hampshire Colonoscopy Registry[J]. *Gastrointest Endosc*, 2022, 96(2): 310-317. DOI: 10.1016/j.gie.2022.03.001.
- [18] ZEISSNER-SPITZENBERG J, WALDMANN E, JIRICKA L, et al. Comparison of adenoma detection rate and proximal serrated polyp detection rate and their effect on post-colonoscopy colorectal cancer mortality in screening patients[J]. *Endoscopy*, 2023, 55(5): 434-441. DOI: 10.1055/a-1974-9979.
- [19] VAN TOLEDO D E F W M, IJSPEERT J E G, BOSSUYT P M M, et al. Serrated polyp detection and risk of interval post-colonoscopy colorectal cancer: a population-based study[J]. *Lancet Gastroenterol Hepatol*, 2022, 7(8): 747-754. DOI: 10.1016/S2468-1253(22)00090-5.
- [20] ANDERSON J C, REX D K, MACKENZIE T A, et al. Higher serrated polyp detection rates are associated with lower risk of postcolonoscopy colorectal cancer: data from the new Hampshire colonoscopy registry[J]. *Am J Gastroenterol*, 2023, 118(11): 1927-1930. DOI: 10.14309/ajg.0000000000002403.
- [21] BRENNER H, CHANG-CLAUDE J, SEILER C M, et al. Protection from colorectal cancer after colonoscopy: a population-based, case-control study[J]. *Ann Intern Med*, 2011, 154(1): 22-30. DOI: 10.7326/0003-4819-154-1-201101040-00004.
- [22] ZHAO S, WANG S, PAN P, et al. Magnitude, risk factors, and factors associated with adenoma miss rate of tandem colonoscopy: a systematic review and meta-analysis[J]. *Gastroenterology*, 2019, 156(6): 1661-1674. e11. DOI: 10.1053/j.gastro.2019.01.260.
- [23] IJSPEERT J E G, BEVAN R, SENORE C, et al. Detection rate of serrated polyps and serrated polyposis syndrome in colorectal cancer screening cohorts: a European overview[J]. *Gut*, 2017, 66(7): 1225-1232. DOI: 10.1136/gutjnl-2015-310784.
- [24] GLOVER B, TEARE J, PATEL N. A review of new and emerging techniques for optical diagnosis of colonic polyps[J]. *J Clin Gastroenterol*, 2019, 53(7): 495-506. DOI: 10.1097/MCG.0000000000001222.
- [25] KESWANI R N, AADAM A A, YANG G Y. Sessile serrated lesion misdiagnosed as a hyperplastic polyp[J]. *Endoscopy*, 2014, 46(Suppl 1 UCTN): E7-E8. DOI: 10.1055/s-0033-1358928.
- [26] MEESTER R G S, VAN HERK M M A G C, LANSDORP-VOGELAAR I, et al. Prevalence and clinical features of sessile serrated polyps: a systematic review[J]. *Gastroenterology*, 2020, 159(1): 105-118. e25. DOI: 10.1053/j.gastro.2020.03.025.
- [27] SHAUKAT A, HOLUB J, GREENWALD D, et al. Variation over time and factors associated with detection rates of sessile serrated lesion across the United States: results from a national sample using the GIQuIC registry[J]. *Am J Gastroenterol*, 2021, 116(1): 95-99. DOI: 10.14309/ajg.0000000000000824.
- [28] ZHAO S, SONG Y, WANG S, et al. Reduced adenoma miss rate with 9-minute vs 6-minute withdrawal times for screening colonoscopy: a multicenter randomized tandem trial[J]. *Am J Gastroenterol*, 2023, 118(5): 802-811. DOI: 10.14309/ajg.0000000000002055.
- [29] ATKINSON N S S, KET S, BASSETT P, et al. Narrow-band imaging for detection of neoplasia at colonoscopy: a meta-analysis of data from individual patients in randomized controlled trials[J]. *Gastroenterology*, 2019, 157(2): 462-471. DOI: 10.1053/j.gastro.2019.04.014.
- [30] REX D K, CLODFELTER R, RAHMANI F, et al. Narrow-band imaging versus white light for the detection of proximal colon serrated lesions: a randomized, controlled trial[J]. *Gastrointest Endosc*, 2016, 83(1): 166-171. DOI: 10.1016/j.gie.2015.03.1915.
- [31] LI J, ZHANG D, WEI Y, et al. Colorectal sessile serrated lesion detection using linked color imaging: a multicenter, parallel randomized controlled trial[J]. *Clin Gastroenterol Hepatol*, 2023, 21(2): 328-336.e2. DOI: 10.1016/j.cgh.2022.03.033.
- [32] SUZUKI S, ANIWAN S, CHIU H M, et al. Linked-color imaging detects more colorectal adenoma and serrated lesions: an international randomized controlled trial[J]. *Clin Gastroenterol Hepatol*, 2023, 21(6): 1493-1502.e4. DOI: 10.1016/j.cgh.2022.10.021.
- [33] OLIVEIRA DOS SANTOS C E, MALAMAN D, PEREIRA-LIMA J C, et al. Impact of linked-color imaging on colorectal adenoma detection[J]. *Gastrointest Endosc*, 2019, 90(5): 826-834. DOI: 10.1016/j.gie.2019.06.045.
- [34] PAGGI S, RADAELLI F, SENORE C, et al. Linked-color imaging versus white-light colonoscopy in an organized colorectal cancer screening program[J]. *Gastrointest Endosc*, 2020, 92(3): 723-730. DOI: 10.1016/j.gie.2020.05.044.
- [35] BOSMAN F, CARNEIRO F, HRUBAN R, et al. WHO

- classification of tumours of the digestive system[M]. 4th ed. Lyon: IARC, 2010.
- [36] REX D K, AHNEN D J, BARON J A, et al. Serrated lesions of the colorectum: review and recommendations from an expert panel[J]. *Am J Gastroenterol*, 2012, 107(9): 1315-1330. DOI: 10.1038/ajg.2012.161.
- [37] 中华医学会病理学分会消化病学组. 胃肠道腺瘤和良性上皮性息肉的病理诊断共识[J]. *中华病理学杂志*, 2020, 49(1): 3-11. DOI:10.3760/cma.j.issn.0529-5807.2020.01.002.
- [38] PAYNE S R, CHURCH T R, WANDELL M, et al. Endoscopic detection of proximal serrated lesions and pathologic identification of sessile serrated adenomas/polyps vary on the basis of center[J]. *Clin Gastroenterol Hepatol*, 2014, 12(7): 1119-1126. DOI: 10.1016/j.cgh.2013.11.034.
- [39] VENNELAGANTI S, CUATRECASAS M, VENNALAGANTI P, et al. Interobserver agreement among pathologists in the differentiation of sessile serrated from hyperplastic polyps[J]. *Gastroenterology*, 2021, 160(1): 452-454.e1. DOI: 10.1053/j.gastro.2020.09.015.
- [40] BILAL M, RAZA S E A, AZAM A, et al. Development and validation of a weakly supervised deep learning framework to predict the status of molecular pathways and key mutations in colorectal cancer from routine histology images: a retrospective study[J]. *Lancet Digit Health*, 2021, 3(12): e763-e772. DOI: 10.1016/S2589-7500(21)00180-1.
- [41] KRISHNAN R, RAJPURKAR P, TOPOL E J. Self-supervised learning in medicine and healthcare[J]. *Nat Biomed Eng*, 2022, 6(12): 1346-1352. DOI: 10.1038/s41551-022-00914-1.
- [42] HUANG S C, PAREEK A, JENSEN M, et al. Self-supervised learning for medical image classification: a systematic review and implementation guidelines[J]. *NPJ Digit Med*, 2023, 6(1): 74. DOI: 10.1038/s41746-023-00811-0.
- [43] MOHAN B P. Artificial intelligence-aided colonoscopy in 10 years[J]. *Gastrointest Endosc*, 2024, 99(3): 452-453. DOI: 10.1016/j.gie.2023.11.034.
- [44] KOH F H, LADLAD J, SKH ENDOSCOPY CENTRE, et al. Real-time artificial intelligence (AI)-aided endoscopy improves adenoma detection rates even in experienced endoscopists: a cohort study in Singapore[J]. *Surg Endosc*, 2023, 37(1): 165-171. DOI: 10.1007/s00464-022-09470-w.
- [45] KARSENTI D, THARSIS G, PERROT B, et al. Effect of real-time computer-aided detection of colorectal adenoma in routine colonoscopy (COLO-GENIUS): a single-centre randomised controlled trial[J]. *Lancet Gastroenterol Hepatol*, 2023, 8(8): 726-734. DOI: 10.1016/S2468-1253(23)00104-8.
- [46] SOONS E, RATH T, HAZEWINCKEL Y, et al. Real-time colorectal polyp detection using a novel computer-aided detection system (CADE): a feasibility study[J]. *Int J Colorectal Dis*, 2022, 37(10): 2219-2228. DOI: 10.1007/s00384-022-04258-9.
- [47] GLISSEN BROWN J R, MANSOUR N M, WANG P, et al. Deep learning computer-aided polyp detection reduces adenoma miss rate: a United States multi-center randomized tandem colonoscopy study (CADET-CS trial)[J]. *Clin Gastroenterol Hepatol*, 2022, 20(7): 1499-1507.e4. DOI: 10.1016/j.cgh.2021.09.009.
- [48] KAMBA S, TAMAI N, SAITOH I, et al. Reducing adenoma miss rate of colonoscopy assisted by artificial intelligence: a multicenter randomized controlled trial[J]. *J Gastroenterol*, 2021, 56(8): 746-757. DOI: 10.1007/s00535-021-01808-w.
- [49] JIN X F, MA H Y, SHI J W, et al. Efficacy of artificial intelligence in reducing miss rates of GI adenomas, polyps, and sessile serrated lesions: a meta-analysis of randomized controlled trials[J]. *Gastrointest Endosc*, 2024, 99(5): 667-675.e1. DOI: 10.1016/j.gie.2024.01.004.
- [50] SHAH S, PARK N, CHEHADE N E H, et al. Effect of computer-aided colonoscopy on adenoma miss rates and polyp detection: a systematic review and meta-analysis[J]. *J Gastroenterol Hepatol*, 2023, 38(2): 162-176. DOI: 10.1111/jgh.16059.
- [51] NEUMANN H, KREFT A, SIVANATHAN V, et al. Evaluation of novel LCI CAD EYE system for real time detection of colon polyps[J]. *PLoS One*, 2021, 16(8): e0255955. DOI: 10.1371/journal.pone.0255955.
- [52] HASSAN C, SPADACCINI M, IANNONE A, et al. Performance of artificial intelligence in colonoscopy for adenoma and polyp detection: a systematic review and meta-analysis[J]. *Gastrointest Endosc*, 2021, 93(1): 77-85.e6. DOI: 10.1016/j.gie.2020.06.059.
- [53] ZHAO S B, YANG W, WANG S L, et al. Establishment and validation of a computer-assisted colonic polyp localization system based on deep learning[J]. *World J Gastroenterol*, 2021, 27(31): 5232-5246. DOI: 10.3748/wjg.v27.i31.5232.
- [54] WANG P, BERZIN T M, GLISSEN BROWN J R, et al. Real-time automatic detection system increases colonoscopic polyp and adenoma detection rates: a prospective randomised controlled study[J]. *Gut*, 2019, 68(10): 1813-1819. DOI: 10.1136/gutjnl-2018-317500.
- [55] LADABAUM U, SHEPARD J, WENG Y, et al. Computer-aided detection of polyps does not improve colonoscopist performance in a pragmatic

- implementation trial[J]. *Gastroenterology*, 2023, 164(3): 481-483.e6. DOI: 10.1053/j.gastro.2022.12.004.
- [56] WANG P, LIU X, BERZIN T M, et al. Effect of a deep-learning computer-aided detection system on adenoma detection during colonoscopy (CAdE-DB trial): a double-blind randomised study[J]. *Lancet Gastroenterol Hepatol*, 2020, 5(4): 343-351. DOI: 10.1016/S2468-1253(19)30411-X.
- [57] LAU L H S, HO J C L, LAI J C T, et al. Effect of real-time computer-aided polyp detection system (ENDO-AID) on adenoma detection in endoscopists-in-training: a randomized trial[J]. *Clin Gastroenterol Hepatol*, 2024, 22(3): 630-641.e4. DOI: 10.1016/j.cgh.2023.10.019.
- [58] SPADACCINI M, IANNONE A, MASELLI R, et al. Computer-aided detection versus advanced imaging for detection of colorectal neoplasia: a systematic review and network meta-analysis[J]. *Lancet Gastroenterol Hepatol*, 2021, 6(10): 793-802. DOI: 10.1016/S2468-1253(21)00215-6.
- [59] HOUWEN B B S L, HAZEWINDEL Y, GIOTIS I, et al. Computer-aided diagnosis for optical diagnosis of diminutive colorectal polyps including sessile serrated lesions: a real-time comparison with screening endoscopists[J]. *Endoscopy*, 2023, 55(8): 756-765. DOI: 10.1055/a-2009-3990.
- [60] KADER R, CID-MEJIAS A, BRANDAO P, et al. Polyp characterization using deep learning and a publicly accessible polyp video database[J]. *Dig Endosc*, 2023, 35(5): 645-655. DOI: 10.1111/den.14500.
- [61] MINEGISHI Y, KUDO S E, MIYATA Y, et al. Comprehensive diagnostic performance of real-time characterization of colorectal lesions using an artificial intelligence-assisted system: a prospective study[J]. *Gastroenterology*, 2022, 163(1): 323-325.e3. DOI: 10.1053/j.gastro.2022.03.053.
- [62] LUI T K L, GUO C G, LEUNG W K. Accuracy of artificial intelligence on histology prediction and detection of colorectal polyps: a systematic review and meta-analysis[J]. *Gastrointest Endosc*, 2020, 92(1): 11-22.e6. DOI: 10.1016/j.gie.2020.02.033.
- [63] NEMOTO D, GUO Z, PENG B, et al. Computer-aided diagnosis of serrated colorectal lesions using non-magnified white-light endoscopic images[J]. *Int J Colorectal Dis*, 2022, 37(8): 1875-1884. DOI: 10.1007/s00384-022-04210-x.
- [64] SIRINUKUNWATTANA K, AHMED RAZA S E, TSANG Y W, et al. Locality sensitive deep learning for detection and classification of nuclei in routine colon cancer histology images[J]. *IEEE Trans Med Imaging*, 2016, 35(5): 1196-1206. DOI: 10.1109/TMI.2016.2525803.
- [65] JANOWCZYK A, MADABHUSHI A. Deep learning for digital pathology image analysis: a comprehensive tutorial with selected use cases[J]. *J Pathol Inform*, 2016, 7: 29. DOI: 10.4103/2153-3539.186902.
- [66] ABELS E, PANTANOWITZ L. Current state of the regulatory trajectory for whole slide imaging devices in the USA[J]. *J Pathol Inform*, 2017, 8: 23. DOI: 10.4103/jpi.jpi_11_17.
- [67] BYEON S J, PARK J, CHO Y A, et al. Automated histological classification for digital pathology images of colonoscopy specimen via deep learning[J]. *Sci Rep*, 2022, 12(1): 12804. DOI: 10.1038/s41598-022-16885-x.
- [68] KORBAR B, OLOFSON A M, MIRAFLOR A P, et al. Deep learning for classification of colorectal polyps on whole-slide images[J]. *J Pathol Inform*, 2017, 8: 30. DOI: 10.4103/jpi.jpi_34_17.
- [69] WU Z, YAO L, LIU W, et al. Development and validation of a deep learning-based histologic diagnosis system for diagnosing colorectal sessile serrated lesions[J]. *Am J Clin Pathol*, 2023, 160(4): 394-403. DOI: 10.1093/ajcp/aqad058.
- [70] WEI J W, SURIAWINATA A A, VAICKUS L J, et al. Evaluation of a deep neural network for automated classification of colorectal polyps on histopathologic slides[J]. *JAMA Netw Open*, 2020, 3(4): e203398. DOI: 10.1001/jamanetworkopen.2020.3398.

[本文编辑] 孙 岩