·专家论坛·

DOI：10.12449/JCH260704

超声新技术在肝细胞癌诊疗中的应用现状与展望

林思嘉，李玲玲，周建华

中山大学肿瘤防治中心超声科，广州 510050

通信作者：周建华，zhoujh@sysucc.org.cn（ORCID：0000-0003-2096-8126）

摘要：作为原发性肝癌的常见类型，肝细胞癌是严重威胁我国民众生命健康的恶性疾病之一。超声作为肝细胞癌临床诊疗过程中的重要影像学手段，其新技术的发展与应用具有较高的临床价值。目前，超声及超声造影联合人工智能在肝局灶性病变的检出、影像学诊断、疗效和预后预测方面已展现出应用潜力；超声融合成像技术在经皮热消融术的引导及疗效评估中展现出临床价值；三维超声在辅助消融与消融灶评估中也有一定优势；而超声内镜可作为经皮超声扫查或引导困难肝细胞癌病灶的一种补充影像学手段。

关键词：癌，肝细胞；超声检查；人工智能；消融技术

基金项目：国家自然科学基金（82320108011）

Current application and prospects of new ultrasound technologies in the diagnosis and treatment of hepatocellular carcinoma

Lin Sijia, *Li Lingling*, *Zhou Jianhua*

Department of Ultrasound, *Sun Yat-sen University Cancer Center*, *Guangzhou 510050*, *China*

Corresponding author: *Zhou Jianhua*, *zhoujh@sysucc.org.cn* (*ORCID*: *0000-0003-2096-8126*)

Abstract: As a common type of primary liver cancer, hepatocellular carcinoma (HCC) is a major health threat in China. Ultrasound is a crucial imaging modality in the clinical diagnosis and treatment of HCC, and the development and application of new ultrasound technologies have high clinical value. Currently, ultrasound and contrast-enhanced ultrasound combined with artificial intelligence have shown promising potential in the detection of focal liver lesions, image-based HCC diagnosis, outcome assessment, and prognostic prediction; furthermore, ultrasound fusion imaging technology has shown certain clinical value in guidance and efficacy evaluation of percutaneous thermal ablation; three-dimensional ultrasound has certain advantages in assisting ablation and assessing ablation margins; endoscopic ultrasonography can be used as a supplementary method for HCC cases that are difficult to scan or guide via percutaneous ultrasound.

Key words: Carcinoma, Hepatocellular; Ultrasonography; Artificial Intelligence; Ablation Techniques

Research funding: National Natural Science Foundation of China (82320108011)

肝细胞癌（hepatocellular carcinoma，HCC）是原发性肝癌最常见的类型，占比80%～90%[1-2]，具有恶性程度高、预后差、致死率高等特点，及时发现、准确诊断及早期治疗是改善HCC患者预后的关键。随着超声新技术的不断发展，超声在HCC诊疗中的临床应用价值逐步提升。

1 超声联合人工智能（artificial intelligence，AI）辅助诊断在HCC诊疗中的进展

超声检查具有便捷、实时、无创、无辐射等优势，是临床上最常用的肝脏影像学检查方法。超声检查的诊断结果常存在显著的操作者间差异，诊断一致性较低。

近年来，以深度学习为核心的AI技术发展迅速，其能自动提取影像中的深层特征，完成病灶的自动化检测、定位、分割、分类等任务，为克服上述问题提供了新的可能性。

1.1 *超声联合AI辅助检出肝局灶性病变* 临床上常将灰阶超声检查用于肝内占位性病变的检出。You Only Look Once（YOLO）模型是一种面向实时目标检测的主流深度学习算法，已有多项研究将其应用于灰阶图像内肝局灶性病变的自动检出。Wu等采用其衍生模型——YOLOR模型进行自动病灶检测，但其平均精度仅为0.51～0.56[3]，未达到临床应用所需的精度。而Rhyou等[4]提出的HCC-Net通过将多个预训练的YOLO模型组织为层级连接的网络结构，且下游的FineNet负责识别上游CoarseNet所遗漏的病变，取得了0.895的平均精度，展现出良好的临床应用潜力。

上述研究只测试了AI算法在静态超声图像中的病灶检出能力，其在连续扫查视频中的检出能力更能反映其临床应用价值。Tiyarattanachai等[5]将预训练RetinaNet模型检测错误的视频帧（将无病灶帧识别为有病灶帧，或反之）用于对原模型的进一步微调，取得了89.8%的检出率，显著优于非超声科医生29.1%和超声科医生70.9%的检出率。前瞻性单中心研究进一步显示，该AI系统可将非专家的检出率从21.4%显著提升至36.9%，但未能明显提升专家的检出率[6]。

1.2 *超声联合AI辅助HCC的影像学诊断*

1.2.1 *灰阶超声联合AI辅助HCC的影像学诊断* 灰阶超声可用于初步判断肝局灶性病变的良恶性。主流深度学习模型如ResNet50、Xception、EfficientNet及Swin等在良恶性分类任务中的曲线下面积（area under the curve，AUC）普遍高于0.8，展现出良好性能[3,7]。然而上述研究只将模型应用于手动或自动勾画的病灶区域，后续研究进一步构建了病灶检出与分类一体化的模型。Schmauch等[8]构建了引入监督注意力机制的深度学习模型，其先检测肝脏灰阶超声图像中是否存在病灶，若存在则进一步判断病灶为良性或恶性，取得了0.891的AUC。而Lu等[9]分别构建了用于局灶性病灶检测的UniMatch模型和用于良恶性分类的LivNet模型，在检测和分类任务中分别达到了0.887和0.891的AUC。Dadoun等[10]则比较了2种通用目标检测算法在病变检测、定位与分类任务中的表现，结果显示，Detection Transformer表现更佳，在病灶检测中达到97%的灵敏度和90%的特异度，正确定位80%的病灶，在病灶分类中取得82%的灵敏度和81%的特异度，与专家水平相当。

1.2.2 *超声造影（contrast-enhanced ultrasound，CEUS）联合AI辅助HCC的影像学诊断* CEUS检查可实时动态观察肝肿瘤血流灌注的变化，鉴别诊断不同性质的肝脏肿瘤，显著提升超声检查的诊断准确性。现已有多项AI相关研究基于CEUS视频或代表帧进行肝局灶性病变的分类任务。在二分类（良恶性）任务中，ResNet模型的准确度为91%，与专家水平相当[11]。在多分类任务中，不同模型的表现差异很大：Urhut等[12]构建的自动分类模型针对HCC准确度仅为69.9%；相比之下，Căleanu等[13]对比了MobileNetV2等多种通用算法在五分类（HCC、富血供转移瘤、乏血供转移瘤、血管瘤和肝局灶性结节性增生）任务中的表现，最高准确度可达88%。此外，Ding等[14]构建了综合CEUS影像、生物标志物及临床基本信息相结合的Model^{-DCB}模型以完成六分类（HCC、肝转移瘤、肝内胆管癌、肝血管瘤、肝脓肿和其他肝疾病）任务，在外部验证集中取得了85%～86%的准确度，和高年资超声医师的表现无明显差异。

我国指南推荐有肝癌高危风险因素的患者采用CEUS肝脏影像报告与数据系统（liver imaging reporting and data system，LI-RADS）提高HCC诊断的特异度[15-16]。CEUS LI-RADS最终诊断HCC的比例在LR-3类为14%～39%，LR-4类为68%～86%，LR-M类为44%～69%，而LR-5类为95%～98%。因此，LR-5类病灶基本可以临床诊断为HCC。Hoopes等[17]利用机器学习将不确定病变（LR-3、LR-4和LR-M）进行再分类（HCC或非HCC），灵敏度和特异度分别达到56.3%和93.9%。此外，增强计算机体层成像（computed tomography，CT）/磁共振成像（magnetic resonance imaging，MRI）也是重要的HCC诊断技术，已有研究将增强CT/MRI LI-RADS用于分类的主要特征嵌入中间层进行深度学习模型构建[18-20]，有效提高了模型可解释性，但尚无针对CEUS LI-RADS的相关研究。

1.2.3 *CEUS联合AI辅助HCC的疗效及预后预测* 肿瘤治疗后早期反应通常表现为内部微循环血流灌注的改变，且该改变往往早于肿瘤大小或坏死区域的变化。因此，CEUS在评估HCC局部治疗反应方面具有独特的优势。一项荟萃分析结果显示，CEUS在检测局部治疗后残留肿瘤的灵敏度和特异度分别为85%和94%，诊断准确度为93.5%[21]。针对TACE治疗反应的预测，Oezdemir等[22]以36例患者的术前CEUS视频开发的模型取得了86%的准确度；Liu等[23]采用Radiomics CNN算法取得了0.93的AUC。但上述研究存在样本量过小、

未进行外部验证等局限性，仍需进一步开发泛化性高的模型。

HCC治疗后的预后预测也是目前临床研究热点。微血管侵犯（microvascular invasion，MVI）是导致HCC复发转移的独立危险因素。Zhang等[24]比较了多种建模方式在预测MVI上的效果，发现综合术前灰阶和CEUS图像进行预测的深度学习模型表现最好，在外部验证集上最高达到0.688的AUC。综合术前CEUS的影像组学评分与临床因素构建的列线图也可用于预测MVI，AUC可达0.75以上[25-26]。在直接预测生存结局方面，Liu等[27]开发的CEUS影像组学模型可用于预测极早期或早期HCC患者行射频消融或外科切除的无进展生存期，有助于此类患者选择更优的治疗方案。针对直径<5 cm的单发HCC热消融后的复发预测，Ma等[28]综合CEUS、灰阶超声影像组学和临床因素开发的模型在早期复发预测上达到0.84～0.89的AUC，而在晚期复发预测上达到0.77的C-index。

2 超声融合影像（fusion imaging，FI）技术在HCC治疗中的进展

灰阶超声因支持任意平面实时引导、空间分辨率高、无电离辐射等优势，已成为经皮热消融治疗中最常用的引导方式；但其对微小、深部或等回声病灶的成像能力劣于增强CT/MRI且成像质量易受肺部或肠道气体干扰。超声FI技术通过进行多模态超声图像（如灰阶超声、CEUS和三维超声等）之间，或超声与其他类型影像（如增强CT/MRI等）之间的配准融合，提升了病灶的可见度，为解决上述问题提供了新的可能性[29]。

2.1 *超声FI技术在HCC消融引导中的应用* 在消融过程中，超声-CT/MRI FI引导的穿刺不受消融产生气体的干扰，从而降低穿刺难度，减少并发症的发生[30-31]。Xu等[32]研究表明，超声-CT/MRI FI引导消融的患者获得了较长的总生存期和无瘤生存期。此外，超声-MRI FI在近肝门部胆管旁HCC病灶的消融中能显著降低胆管并发症的发生率，由常规引导下的约30%降至约0[33]，反映了FI引导可能提升复杂解剖部位病灶的消融安全性。

针对灰阶不可见的病灶，CEUS-CT/MRI FI基于周围解剖标志引导消融，可使该类病灶的消融成功率及预后提升至与灰阶可见病灶相当[34]。CEUS-CT/MRI FI较CEUS单模态引导更适用于肝功能储备较差、多发病灶和病灶位于高风险部位的患者，且能够降低该类患者消融后的局部进展率[35]。此外，当利用FI在消融中实时评估治疗反应并指导补充消融时，疗效、无复发生存期和总生存期均显著优于灰阶超声引导，成功率为85.3%[36]。

2.2 *超声FI技术在HCC消融疗效评估中的应用* 在HCC热消融疗效的评估中，FI也展现出一定临床应用价值。术前与术后灰阶超声影像的叠加融合，或术后CEUS-术前增强CT/MRI的FI均可有效辅助安全消融边界的实现，成功率可分别达到89.3%和100%，进而降低局部进展的风险[37-38]。此外，Xu等[39]发现在消融前进行三维超声（three-dimensional ultrasound，3D US）-CEUS FI，并在消融后10～15 min辅以CEUS评估，约30%的患者接受了补充消融，说明该技术有助于消融医生发现残存病灶并补充消融。然而，目前尚缺乏关于FI在远期预后评估中应用价值的针对性研究。

尽管FI在HCC消融中有多种优势，其实际应用仍受多种临床因素的限制：患者姿势改变、人工腹水或胸腔积液导致肝脏变形、病灶处于缺乏解剖标志物辅助定位的复杂位置、呼吸误差等均会增加配准的误差，甚至导致配准错误[40-41]。

3 3D US和四维超声（four-dimensional ultrasound，4D US）在HCC治疗及疗效评估中的进展

常规使用的灰阶超声为二维超声（two-dimensional ultrasound，2D US），仅提供病灶在单一平面上的信息。3D US是利用计算机三维成像技术从二维超声图像上重建而得，能直观展示病灶的立体形态。

3D US FI导航技术通过将术前3D US与术中实时2D US融合配准，在HCC热消融的引导中已展现一定优势。孙月婷等[42]回顾性收集了3D US FI导航技术引导的HCC消融病例，发现术后1个月的评估中有86.5%的病灶达到完全消融且消融边界达标，证实3D US FI在辅助判断5 mm消融安全边界中的价值。蓝思荣等[43]还发现，在消融后实施3D US与实时CEUS融合能更精准地评估消融范围，辅助补充消融，将完全消融率从78.4%提高至94.1%。

此外，三维超声造影（3D CEUS）也在消融引导和消融灶评估中具有应用价值。在消融引导方面，You等[44]发现当HCC病灶在灰阶超声不可见时，改用3D CEUS与术中CEUS进行FI引导也可实现100%消融成功率，为此类病灶的消融提供了超声引导方案。此外，Long等[45]的研究发现，与2D CEUS点对点比较相比，3D

CEUS融合成像自动化程度更高、操作时间更短，可作为预测HCC消融后局部肿瘤进展的一种手段。

4D US在3D US的基础上引入了时间维度，进一步提供病灶的动态信息。早期个案报告提示，4D US在消融中具有实时、准确定位消融针位置的潜在价值[46-47]，但其近十余年来未见高质量临床进展，临床地位有待验证。

4 超声内镜（endoscopic ultrasonography，EUS）在HCC诊疗中的特殊应用

部分位于肝左叶的HCC病灶因肝左叶萎缩、病灶位于肝左叶边缘、胃肠气体或腹壁手术瘢痕的影响，经皮超声显示病灶困难，导致介入治疗无法通过超声引导下实现。而EUS通过经胃或十二指肠直接扫查肝左叶，可避免上述干扰，清楚显示病灶及其周围关系，在活组织检查或介入治疗时可避开重要解剖结构，使用更安全的穿刺入路，因此可作为经皮超声扫查或引导困难时的一种补充手段。1997年，Bogstad等[48]首次报道了利用EUS检出肝左叶复发性HCC病灶，并成功引导细针穿刺活组织检查。随后的研究证实，对于无经皮穿刺禁忌证的肝硬化患者，EUS引导下细针穿刺活组织检查是诊断肝左叶病变一种敏感且安全的方法[49]。Alina Tantau等[50]与Takano等[51]的研究进一步拓展了其应用范围，证实其在经皮穿刺困难的情况下可作为引导穿刺肝尾叶及右叶病灶的一种补充手段。此外，EUS引导下的尾状叶病灶激光消融术也被证实为一种可行、安全且有效的微创治疗术式，尤其适用于直径<2 cm的病灶[52]。

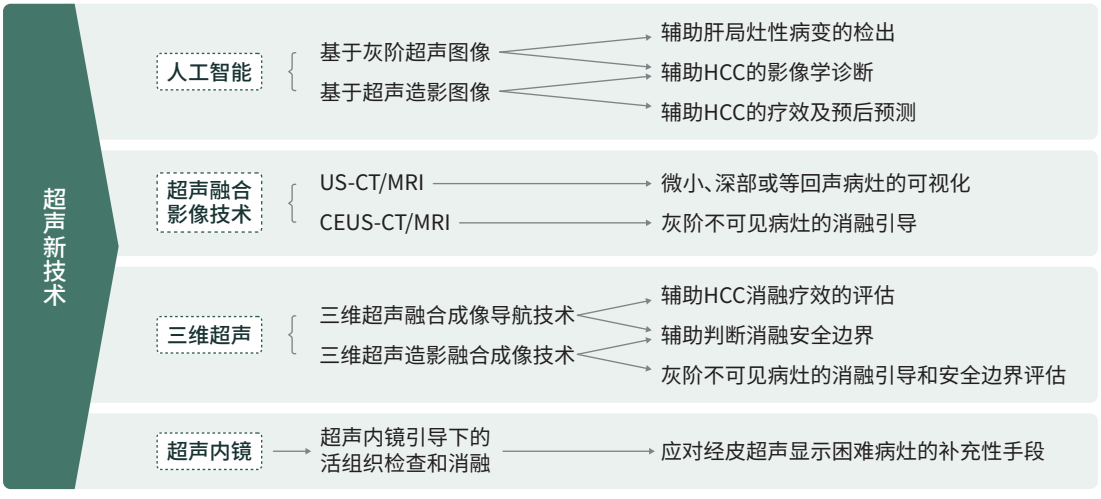
5 总结与展望

超声新技术在HCC诊疗中已取得多方面的突破和进展（图1）。AI辅助诊断系统在肝局灶性病变的检出、影像学诊断、疗效和预后预测方面展现出可观的应用潜力；超声FI技术在HCC消融引导和疗效评估中也具有一定应用价值；3D US和3D CEUS也在HCC局部治疗的实施和疗效评估中展现优势；EUS可作为经皮扫查或引导困难HCC病灶的一种补充影像学手段。

尽管超声新技术在HCC诊疗中展现出巨大潜力，但仍存在许多不足之处：现有超声相关的AI研究大部分存在样本量有限、缺乏外部验证、泛化能力较差的局限性，需要进一步开发诊断效能和稳健性都更高的AI系统；尚无与CEUS LI-RADS语义对齐的AI模型研究，需要进一步提升HCC诊断模型的可解释性与临床可用性；超声FI技术在实际应用中仍受多种临床因素的限制，需要进一步探索解决方法，且目前仍缺乏其在远期预后评估中的针对性研究。随着技术的不断发展和成熟，超声新技术有望在HCC的精准诊疗中发挥更大的应用价值。

利益冲突声明：本文不存在任何利益冲突。

作者贡献声明：林思嘉和李玲玲负责构思及撰写文章；周建华负责全面指导、终审及定稿。



注：US-CT/MRI，超声-计算机体层成像/磁共振成像；CEUS-CT/MRI，超声造影-计算机体层成像/磁共振成像；HCC，肝细胞癌。

图1 超声新技术在肝细胞癌诊疗中的具体应用场景

Figure 1 Specific application scenarios of new ultrasound technology in the diagnosis and treatment of hepatocellular carcinoma

参考文献:

[1] Vogel A, Meyer T, Sapisochin G, et al. Hepatocellular carcinoma [J]. Lancet, 2022, 400(10360): 1345-1362. DOI: 10.1016/s0140-6736(22)01200-4.

[2] Bray F, Laversanne M, Sung H, et al. Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries[J]. CA Cancer J Clin, 2024, 74(3): 229-263. DOI: 10.3322/caac.21834.

[3] Wu C H, Sheu J C, Chou P L, et al. Automatic real-time detection and diagnosis of liver tumor with ultrasound[J]. J Hepatocell Carcinoma, 2025, 12: 1599-1611. DOI: 10.2147/JHC.S524311.

[4] Rhyou S Y, Yoo J C. Automated ultrasonography of hepatocellular carcinoma using discrete wavelet transform based deep-learning neural network[J]. Med Image Anal, 2025, 101: 103453. DOI: 10.1016/j.media.2025.103453.

[5] Tiyarattanachai T, Apiparakoon T, Marukatat S, et al. The feasibility to use artificial intelligence to aid detecting focal liver lesions in real-time ultrasound: A preliminary study based on videos[J]. Sci Rep, 2022, 12: 7749. DOI: 10.1038/s41598-022-11506-z.

[6] Tiyarattanachai T, Apiparakoon T, Chaichuen O, et al. Artificial intelligence assists operators in real-time detection of focal liver lesions during ultrasound: A randomized controlled study[J]. Eur J Radiol, 2023, 165: 110932. DOI: 10.1016/j.ejrad.2023.110932.

[7] Xi I L, Wu J, Guan J, et al. Deep learning for differentiation of benign and malignant solid liver lesions on ultrasonography[J]. Abdom Radiol, 2021, 46(2): 534-543. DOI: 10.1007/s00261-020-02564-w.

[8] Schmauch B, Herent P, Jehanno P, et al. Diagnosis of focal liver lesions from ultrasound using deep learning[J]. Diagn Interv Imaging, 2019, 100(4): 227-233. DOI: 10.1016/j.diii.2019.02.009.

[9] Lu R F, She C Y, He D N, et al. AI enhanced diagnostic accuracy and workload reduction in hepatocellular carcinoma screening[J]. npj Digit Med, 2025, 8: 500. DOI: 10.1038/s41746-025-01892-9.

[10] Dadoun H, Rousseau A L, de Kerviler E, et al. Deep learning for the detection, localization, and characterization of focal liver lesions on abdominal US images[J]. Radiol Artif Intell, 2022, 4(3): e210110. DOI: 10.1148/ryai.210110.

[11] Hu H T, Wang W, Chen L D, et al. Artificial intelligence assists identifying malignant versus benign liver lesions using contrast-enhanced ultrasound[J]. J Gastroenterol Hepatol, 2021, 36(10): 2875-2883. DOI: 10.1111/jgh.15522.

[12] Urhut M C, Săndulescu L D, Streba C T, et al. Diagnostic performance of an artificial intelligence model based on contrast-enhanced ultrasound in patients with liver lesions: A comparative study with clinicians[J]. Diagnostics (Basel), 2023, 13(21): 3387. DOI: 10.3390/diagnostics13213387.

[13] Căleanu C D, Sîrbu C L, Simion G. Deep neural architectures for contrast enhanced ultrasound (CEUS) focal liver lesions automated diagnosis[J]. Sensors (Basel), 2021, 21(12): 4126. DOI: 10.3390/s21124126.

[14] Ding W Z, Meng Y Q, Ma J, et al. Contrast-enhanced ultrasound-based AI model for multi-classification of focal liver lesions[J]. J Hepatol, 2025, 83(2): 426-439. DOI: 10.1016/j.jhep.2025.01.011.

[15] 中华人民共和国国家卫生健康委员会. 原发性肝癌诊疗指南(2026年版)[J]. 临床肝胆病杂志, 2026, 42(4): 794-827. DOI: 10.12449/JCH260409.
National Health Commission of the People's Republic of China. Guideline for diagnosis and treatment of primary liver cancer (2026edition)[J]. J Clin Hepatol, 2026, 42(4): 794-827. DOI: 10.12449/JCH260409.

[16] American College of Radiology. CEUS LI-RADS v2017 core[R/OL]. https://edge.sitecorecloud.io/americancoldf5f-acrorgf92a-productioncb02-3650/media/ACR/Files/RADS/LI-RADS/CEUS-LI-RADS-2017-Core.pdf.

[17] Hoopes J R, Lyshchik A, Xiao T S, et al. Using machine learning to improve the contrast-enhanced ultrasound liver imaging reporting and data system diagnosis of hepatocellular carcinoma in indeterminate liver nodules[J]. Ultrasound Med Biol, 2025, 51(11): 1953-1960. DOI: 10.1016/j.ultrasmedbio.2025.06.029.

[18] Sheng R F, Huang J, Zhang W G, et al. A semi-automatic step-by-step expert-guided LI-RADS grading system based on gadoxetic acid-enhanced MRI[J]. J Hepatocell Carcinoma, 2021, 8: 671-683. DOI: 10.2147/JHC.S316385.

[19] Tran Q H, Sam T B, Tang V H, et al. Feature-driven LI-RADS classification in liver cancer: A CNN-based approach for CT imaging under data scarcity[C]//2025 IEEE 22nd International Symposium on Biomedical Imaging (ISBI). April 14-17, 2025, Houston, TX, USA. IEEE, 2025: 1-5. DOI: 10.1109/ISBI60581.2025.10980650.

[20] Wang K, Liu Y H, Chen H X, et al. Fully automating LI-RADS on MRI with deep learning-guided lesion segmentation, feature characterization, and score inference[J]. Front Oncol, 2023, 13: 1153241. DOI: 10.3389/fonc.2023.1153241.

[21] Hai Y, Savsani E, Chong W, et al. Meta-analysis and systematic review of contrast-enhanced ultrasound in evaluating the treatment response after locoregional therapy of hepatocellular carcinoma[J]. Abdom Radiol (NY), 2021, 46(11): 5162-5179. DOI: 10.1007/s00261-021-03248-9.

[22] Oezdemir I, Wessner C E, Shaw C, et al. Tumor vascular networks depicted in contrast-enhanced ultrasound images as a predictor for transarterial chemoembolization treatment response[J]. Ultrasound Med Biol, 2020, 46(9): 2276-2286. DOI: 10.1016/j.ultrasmedbio.2020.05.010.

[23] Liu D, Liu F, Xie X Y, et al. Accurate prediction of responses to transarterial chemoembolization for patients with hepatocellular carcinoma by using artificial intelligence in contrast-enhanced ultrasound[J]. Eur Radiol, 2020, 30(4): 2365-2376. DOI: 10.1007/s00330-019-06553-6.

[24] Zhang W B, Guo Q H, Zhu Y L, et al. Cross-institutional evaluation of deep learning and radiomics models in predicting microvascular invasion in hepatocellular carcinoma: Validity, robustness, and ultrasound modality efficacy comparison[J]. Cancer Imaging, 2024, 24(1): 142. DOI: 10.1186/s40644-024-00790-9.

[25] Hu H T, Wang Z, Huang X W, et al. Ultrasound-based radiomics score: A potential biomarker for the prediction of microvascular invasion in hepatocellular carcinoma[J]. Eur Radiol, 2019, 29(6): 2890-2901. DOI: 10.1007/s00330-018-5797-0.

[26] Zhang D, Wei Q, Wu G G, et al. Preoperative prediction of microvascular invasion in patients with hepatocellular carcinoma based on radiomics nomogram using contrast-enhanced ultrasound[J]. Front Oncol, 2021, 11: 709339. DOI: 10.3389/fonc.2021.709339.

[27] Liu F, Liu D, Wang K, et al. Deep learning radiomics based on contrast-enhanced ultrasound might optimize curative treatments for very-early or early-stage hepatocellular carcinoma patients[J]. Liver Cancer, 2020, 9(4): 397-413. DOI: 10.1159/000505694.

[28] Ma Q P, He X L, Li K, et al. Dynamic contrast-enhanced ultrasound radiomics for hepatocellular carcinoma recurrence prediction after thermal ablation[J]. Mol Imaging Biol, 2021, 23(4): 572-585. DOI: 10.1007/s11307-021-01578-0.

[29] Calandri M, Mauri G, Yevich S, et al. Fusion imaging and virtual navigation to guide percutaneous thermal ablation of hepatocellular carcinoma: A review of the literature[J]. Cardiovasc Intervent Radiol, 2019, 42(5): 639-647. DOI: 10.1007/s00270-019-02167-z.

[30] Ahn S J, Lee J M, Lee D H, et al. Real-time US-CT/MR fusion imaging for percutaneous radiofrequency ablation of hepatocellular carcinoma [J]. J Hepatol, 2017, 66(2): 347-354. DOI: 10.1016/j.jhep.2016.09.003.

[31] Song K D, Lee M W, Rhim H, et al. Percutaneous US/MRI fusion-guided radiofrequency ablation for recurrent subcentimeter hepatocellular carcinoma: Technical feasibility and therapeutic outcomes[J]. Radiology, 2018, 288(3): 878-886. DOI: 10.1148/radiol.2018172743.

[32] Xu E J, Li K, Long Y L, et al. Intra-procedural CT/MR-ultrasound fusion imaging helps to improve outcomes of thermal ablation for hepatocellular carcinoma: Results in 502 nodules[J]. Ultraschall Med, 2021, 42(2): e9-e19. DOI: 10.1055/a-1021-1616.

[33] You Y J, Long Y L, Yan R H, et al. Improving ablation safety for hepatocellular carcinoma proximal to the hilar bile ducts by ultrasound-MR fusion imaging: A preliminary comparative study[J]. Front Oncol, 2021, 11: 570312. DOI: 10.3389/fonc.2021.570312.

[34] Lu Y B, Huang Y N, Weng Y C, et al. Contrast-enhanced ultrasonography guidance avoids US-CT/MR fusion error for percutaneous radiofrequency ablation of hepatocellular carcinoma[J]. BMC Med Imaging, 2024, 24(1): 323. DOI: 10.1186/s12880-024-01508-w.

[35] Huang Q N, Zeng Q J, Long Y L, et al. Fusion imaging techniques and contrast-enhanced ultrasound for thermal ablation of hepatocellular carcinoma-A prospective randomized controlled trial[J]. Int J Hyperth, 2019, 36(1): 1206-1214. DOI: 10.1080/02656736.2019.1687945.

[36] Ma Q P, Xu E J, Zeng Q J, et al. Intraprocedural computed tomography/magnetic resonance-contrast-enhanced ultrasound fusion imaging improved thermal ablation effect of hepatocellular carcinoma: Comparison with conventional ultrasound[J]. Hepatol Res, 2019, 49(7): 799-809. DOI: 10.1111/hepr.13336.

[37] Minami Y, Minami T, Takita M, et al. Radiofrequency ablation for hepatocellular carcinoma: Clinical value of ultrasound-ultrasound overlay fusion for optimal ablation and local controllability[J]. Hepatol Res, 2020, 50(1): 67-74. DOI: 10.1111/hepr.13407.

[38] Bo X W, Xu H X, Guo L H, et al. Ablative safety margin depicted by fusion imaging with post-treatment contrast-enhanced ultrasound and pre-treatment CECT/CEMRI after radiofrequency ablation for liver cancers[J]. Br J Radiol, 2017, 90(1078): 20170063. DOI: 10.1259/bjr.20170063.

[39] Xu E J, Lv S M, Li K, et al. Immediate evaluation and guidance of liver cancer thermal ablation by three-dimensional ultrasound/contrast-enhanced ultrasound fusion imaging[J]. Int J Hyperth, 2018, 34(6): 870-876. DOI: 10.1080/02656736.2017.1373306.

[40] Minami Y, Kudo M. Image guidance in ablation for hepatocellular carcinoma: Contrast-enhanced ultrasound and fusion imaging[J]. Front Oncol, 2021, 11: 593636. DOI: 10.3389/fonc.2021.593636.

[41] Carriero S, Della Pepa G, Monfardini L, et al. Role of fusion imaging in image-guided thermal ablations[J]. Diagnostics (Basel), 2021, 11(3): 549. DOI: 10.3390/diagnostics11030549.

[42] 孙月婷, 郭语清, 刘家铭, 等. 三维超声融合成像可视化技术在引导肝细胞癌热消融精准布针中的初步应用[J]. 中华超声影像学杂志, 2024, 33(2): 158-164. DOI: 10.3760/cma.j.cn131148-20230926-00142.
Sun Yueting, Guo Yuqing, Liu Jiaming, et al. Preliminary application of three-dimensional ultrasound fusion imaging visualization technology guiding precise needle placement for thermal ablation of hepatocellular carcinoma[J]. Chin J Ultrasonography, 2024, 33(2): 158-164. DOI: 10.3760/cma.j.cn131148-20230926-00142.

[43] 蓝思荣, 徐继威, 张耀明, 等. 实时超声造影与3D超声融合成像导航评估微波消融治疗原发性肝癌患者价值研究[J]. 实用肝脏病杂志, 2022, 25(6): 889-892. DOI: 10.3969/j.issn.1672-5069.2022.06.033.
Lan Sirong, Xu Jiwei, Zhang Yaoming, et al. Guidance of real-time contrast-enhanced ultrasonography and 3D ultrasound fusion imaging for ablation area in patients with primary liver cancer during microwave ablation therapy[J]. J Pract Hepatol, 2022, 25(6): 889-892. DOI: 10.3969/j.issn.1672-5069.2022.06.033.

[44] You Y J, Zhang M, Li K, et al. Feasibility of 3D US/CEUS-US/CEUS fusion imaging-based ablation planning in liver tumors: A retrospective study[J]. Abdom Radiol (NY), 2021, 46(6): 2865-2874. DOI: 10.1007/s00261-020-02909-5.

[45] Long H Y, Zhou X Y, Zhang X E, et al. 3D fusion is superior to 2D point-to-point contrast-enhanced US to evaluate the ablative margin after RFA for hepatocellular carcinoma[J]. Eur Radiol, 2024, 34(2): 1247-1257. DOI: 10.1007/s00330-023-10023-5.

[46] Hotta N, Maeno T, Ayada M, et al. Four-dimensional ultrasonography for therapeutic radiofrequency ablation for hepatocellular carcinoma[J]. Hepatogastroenterology, 2006, 53(70): 521-525.

[47] Hotta N, Yamada S, Murase K, et al. Usefulness of real-time 4D ultrasonography during radiofrequency ablation in a case of hepatocellular carcinoma[J]. Case Rep Gastroenterol, 2011, 5(1): 82-87. DOI: 10.1159/000321721.

[48] Bogstad J, Vilmann P, Burcharth F. Early detection of recurrent hepatocellular carcinoma by endosonographically guided fine-needle aspiration biopsy[J]. Endoscopy, 1997, 29(4): 322-324. DOI: 10.1055/s-2007-1004198.

[49] Chen F, Bao H W, Deng Z, et al. Endoscopic ultrasound-guided sampling using core biopsy needle for diagnosis of left-lobe hepatocellular carcinoma in patients with underlying cirrhosis[J]. J Cancer Res Ther, 2020, 16(5): 1100-1105. DOI: 10.4103/jcrt.JCRT_723_19.

[50] Tantau A, Zaharie T. EUS-guided fine needle biopsy for hepatocarcinoma of the right liver lobe as a rescue diagnostic technique after a negative percutaneousguided liver biopsy[J]. Med Ultrason, 2023, 25(1): 115-116. DOI: 10.11152/mu-3993.

[51] Takano Y, Yamawaki M, Noda J, et al. Endoscopic ultrasound-guided tissue acquisition for focal liver lesions in the caudate lobe: A report of seven cases[J]. Clin J Gastroenterol, 2024, 17(2): 334-337. DOI: 10.1007/s12328-023-01906-7.

[52] Xu M, Xu D X, Deng Z, et al. Long-term outcomes of endoscopic ultrasound-guided laser ablation for liver tumors in the caudate lobe: 5 years of experience[J]. Scand J Gastroenterol, 2023, 58(5): 558-564. DOI: 10.1080/00365521.2022.2148833.

收稿日期：2026-05-21；**录用日期：**2026-07-15

本文编辑：林姣

引证本文：林思嘉, 李玲玲, 周建华. 超声新技术在肝细胞癌诊疗中的应用现状与展望[J]. 临床肝胆病杂志, 2026, 42(7): 1507-1512.
Lin Sijia, Li Lingling, Zhou Jianhua. Current application and prospects of new ultrasound technologies in the diagnosis and treatment of hepatocellular carcinoma[J]. J Clin Hepatol, 2026, 42(7): 1507-1512.