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Advances in the Application of Ultrasonic Multimodal New Technology in Hepatic Solid Lesions

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Abstract

With the rapid development of medical imaging technology, the application of ultrasound technology as the preferred method for the screening and diagnosis of liver diseases, from traditional two-grayscale ultrasound to today's intelligent multimodal ultrasound imaging technology, plays an important role in formulating reasonable treatment plans and prolonging the survival time of patients. This article systematically expounds on the application progress of eight ultrasound new technologies in liver lesions, analyzes the advantages and limitations of each technology, and provides references for clinical practice and scientific research.

Subject Areas

Health Policy

Keywords

Liver Solid Lesions, New Ultrasound Technology, Ultrasonic Artificial Intelligence, Ultrasonic Molecular Imaging, 5G Remote Ultrasound Robot

1. Preface

Liver space-occupying lesions are common clinical diseases. In addition to benign cystic lesions, in order to further clarify the nature of liver solid lesions and choice of treatment options, clinicians can use new multi-modal ultrasound technology for their differential diagnosis, interventional therapy and efficacy evaluation.

2. Contrast-Enhanced Ultrasound

Contrast-enhanced ultrasound, CEUS, Liver blood perfusion can be displayed in real time by intravenously injecting microbubble contrast agents containing inert gases, which generate strong signals by taking advantage of their nonlinear oscillation characteristics in the ultrasound field, and selectively receiving the second harmonic signals of microbubbles by using harmonic imaging technology. The differential enhancement of lesions in the arterial, portal venous, and delayed phases can be observed to achieve the differential diagnosis of hepatic space-occupying lesions. This technique has the advantages of non-radiation, real-time dynamics, and high spatiotemporal resolution, which can accurately evaluate the changes in hepatic microcirculatory hemodynamics. The blood supply system of the hepatic artery and portal vein makes the liver the best target organ for contrast-enhanced imaging. Benign liver lesions generally show high or equal enhancement in the arterial phase and unchanged or equal enhancement in the portal venous and delayed phases in ultrasound contrast imaging; malignant lesions show high enhancement in the arterial phase and regression to enhancement in the venous and delayed phases. The biggest difference between benign and malignant lesions is the performance in the venous and delayed phases [1]. In addition to the differential diagnosis of focal liver lesions, contrast enhanced ultrasound can also help detect small lesions that are not detectable by conventional ultrasound, such as satellite nodules surrounding hepatocellular carcinoma [2].

3. Ultrasound Elastography

Ultrasound Elastography, UE Mechanical vibration or acoustic radiation force pulse is applied to the tissue through the probe, and the degree of tissue deformation is detected by ultrasound, the tissue elastic information is converted into quantitative values (such as Young's modulus, unit: kPa) or color elastic images according to the characteristic that the hardness of the tissue inversely proportional to the deformation (the harder the tissue, the smaller the deformation), so as to evaluate the degree of liver fibrosis invasively; among them, transientastography (FibroScan) uses one-dimensional shear wave measurement, while two-dimensional shear wave elastography (2D-SWE) can achieve real- and multi-point hardness detection, and provide objective and quantitative basis for the staging of liver fibrosis. At present, the main elastic imaging technologies used in clinics for liver stiffness detection are transient elastography (TE), acoustic radiation force impulse elastography (ARFI) and strain elastography (SE); among them, ARFI technology includes point shear elastography (PSWE) and two-dimensional shear wave elastography (2D SWE). Meitner Schellhaas B *et al.* [3] studied 79 patients with liver cirrhosis and chronic hepatitis, and performed liver biopsy and PSWE examination, and conducted a prospective validation in 107 patients with liver cirrhosis and 68 non-cirrhotic patients, confirming that point shear wave elastography (PSWE) is an effective non-invasive technology for liver tissue hardness based on ultrasound.

4. Superb Microvascular Imaging

Superb microvascular imaging, SMI, by combining a high-frequency ultrasound probe with adaptive Doppler signal processing algorithms, it can clearly show the low-speed blood flow (<0.1 cm/s) at the micrometer level, which is difficult to detect by traditional ultrasound. Its core technologies include: ① using motion artifact filtering technology to eliminate interference; ② using a high-sensitivity blood flow signal extraction algorithm to enhance microvascular imaging; ③ improving the signal-to-noise ratio through real-time overlay technology. Ultimately, it achieves high-resolution visualization of the hepatic microvascular network (diameter < 100 μm), providing important hem evidence for the early diagnosis of hepatocellular carcinoma and the differentiation of liver lesions. It has two display modes: grayscale (mSMI) and color (SMI). mSMI can detect even lower-speed blood flow that cannot be detected by ordinary color Doppler ultrasound examination, making it more sensitive than color Doppler and power Doppler. Compared with CDFI, microvascular imaging can show more blood vessels in the liver tumor and can show the distribution of blood flow in the tumor more clearly, which is useful for the detection of blood flow in liver tumors [4]. mSMI cannot distinguish between arteries and veins in the display of microvessels in liver tumors, nor does it show the changes in phases like CEUS [5], but overall, the emergence of mSMI has provided important help for the diagnosis of blood flow signals in malignant tumors.

5. Three-Dimensional Ultrasonography

Three-dimensional ultrasonography, 3DUS, can clearly show the surface contour and internal structure of the lesion. When contrast-enhanced ultrasound is combined with three dimensional ultrasound technology, the origin, course, and the size, shape, and spatial relationship with surrounding blood vessels of the tumor vessels can be more clearly displayed. TV *et al.* conducted a prospective study of 39 patients with focal hepatic lesions (FLLs), confirming that the 3D-CEUS technique provided consistent measurement results for volume calculation of FLLs among different readers, and the consistency of the volume calculation was nearly perfect [6].

Ultrasonic-CT/MRI image fusion technologys real-time ultrasound images with preoperative CT/MRI volume data in three dimensions through a spatial registration algorithm, and uses electromagnetic or optical positioning systems to track the position of the, achieving real-time overlay display of multimodal images; its core lies in the elastic registration technology based on feature points and dynamic calibration algorithms, which complement the real-time performance ultrasound and the advantages of high-resolution CT/MRI, mainly used for liver interventional navigation and difficult lesion localization. For focal hepatic lesions that cannot be displayed by ultrasound, fusion imaging combined with ultrasound contrast can significantly improve the detection rate of lesions [7] [8]. Before performing radiofrequency ablation for HCC, accurate characterization and localization of the lesion are crucial for developing a treatment plan. During radiofrequency ablation for HCC, the use of fusion imaging is beneficial for accurate puncture and needle placement as well as for immediate assessment of efficacy and guidance of treatment. Some scholars [9] have studied 56 cases (59 lesions) of

HCC patients who underwent thermal treatment under the guidance of 3DUS FI, three-dimensional ultrasound fusion imaging. Before the operation, the patient's three-dimensional ultrasound volume image was collected and fused and registered with the real-time two-dimensional ultrasound image, and the tumor and a 5 mm safety margin were segmented and marked out for preoperative planning under three-dimensional and real-time guidance of thermal ablation. As a result, all lesions could be successfully registered and three-dimensionally displayed during the operation, and postoperative ultrasound contrast showed that lesions had achieved complete ablation, 86.5% of the lesions had achieved complete ablation and the ablation margin ≥ 5 mm, and the cumulative LTP (Local tumor) rate of all lesions was 7.1% at 1 and 2 years. The combined application of ultrasonic-CT/MRI fusion imaging technology and ultrasound contrast has become a research hotspot in the field of ultrasound interventional therapy.

6. Laparoscopic Ultrasonography

Laparoscopic ultrasonography, LUS, by placing a high-frequency ultrasound probe (usually 5 - 10 MHz) in laparoscopic surgery, the ultrasound beam penetrates the parenchyma and receives the reflected signal, directly enters the abdominal cavity through the operating hole, and is attached to the surface of the liver for scanning, avoiding the interference abdominal wall and intestinal gas, to obtain high-resolution cross-sectional images of the liver in real time, so as to accurately locate liver tumors (especially < 1 cm) and key vascular structures (such as hepatic vein branches) in minimally invasive surgery, and provide real-time imaging navigation for hepatic resection or ablation therapy There are studies [10] that report that 43 cases of patients with tumors at the confluence of hepatic veins can also use laparoscopic ultrasound examination for evaluation of hepatic hemodynamics safely, thereby improving the success rate of substantive surgery. The highest resolution of laparoscopic ultrasound can reach 2 mm, and the detection can reach 20 cm, which has shown great advantages in discovering small lesions in the liver. Microwave ablation guided by LUS can accurately locate tumors, improve the completeness of, and reduce the recurrence rate after surgery [11].

7. Ultrasound Radiomics and Ultrasonic Artificial Intelligence

Ultrasound Radiomics, by high-throughput extraction of texture, morphological and functional features in ultrasound images combined with machine learning algorithms to construct a prediction model for the differentiation of benign and malignant liver focal lesions, staging of liver fibrosis and prognosis evaluation, which significantly improves diagnostic specificity compared with traditional ultrasound. In the future, it can be deeply integrated with AI to achieve automated analysis. Dong *et al.* [12] conducted a prospective analysis of 100 cases of hepatocellular carcinoma lesions confirmed tissue pathology, and established and evaluated a machine learning model based on grayscale and ultrasound contrast agent for the prediction of microvascular invasion preoperative in hepatocellularoma patients, using age and Kupffer's final prediction model to achieve 0.804 (95% CI: 0.723, 0.878), the accuracy was 75.0%, the sensitivity was 87.5%, and the specificity was 69.%.

Ultrasonic artificial intelligence AI, uses AI algorithms (such as deep learning) to automatically analyze the characteristics of ultrasound images, to assist in diagnosis and treatment. It can automatically detect and identify tumors, intelligently segment the image lesions, and assist the doctor in the prognosis evaluation of the disease, and provide real-time diagnosis and treatment support [13].

8. Ultrasonic Molecular Imaging

Ultrasonic molecular imaging (UMI) is a technique that can image specific molecular biomarkers by using targeted microbubble contrast agents, thus imaging liver lesions at the molecular level. UMI uses microbubble contrast agents surface-modified with specific ligands, such as antibodies, peptides, etc., which can bind to specific molecular biomarkers in diseased tissues. When the microbubbles oscillate in the ultrasonic field, they produce strong echo signals, thus realizing the imaging of specific molecular biomarkers. UMI can be used for early detection of hepatocellular carcinoma, assessment of cirrhosis, detection of liver metastases, etc. application of UMI in liver metastases is mainly through the targeting of tumor neovascular biomarkers, such as VEGFR2, $\alpha v\beta 3$ integrin, etc, to improve the early detection rate of metastases [14] [15].

9. 5G-Remote Ultrasound Robot

The 5G remote ultrasound robot combines the high bandwidth and low latency characteristics of the 5G network with the precise operation capabilities of robotic technology, providing a new solution for the diagnosis and treatment of liver lesions. This technology is particularly suitable for remote areas, emergency situations, and scenarios requiring multidisciplinary consultations. Early diagnosis and precise detection of liver cancer require high-quality imaging support, and the 5G remote ultrasound robot can transmit high-definition ultrasound images in real-time, combined with an artificial intelligence assisted diagnosis system, to help experts remotely identify the location, size, and characteristics of liver tumors [16].

10. Summary

Ultrasonic new technology has significant advantages such as non-invasive, real-time, accurate and efficient in liver solid lesions, which improves detection rate and diagnostic accuracy of lesions, and at the same time provides strong support for minimally invasive treatment and personalized medicine. Liver ultrasound has formed a "structure-function-molecular trinity evaluation system, and AI and remote technology are reconstructing the diagnosis and treatment ecology [17]. The future breakthrough depends on the integration of four aspects: multi-modal imaging integration, and treatment means integration, medical engineering technology integration, and clinical-basic research integration. With the infiltration of molecular probes, quantum sensing, brain-computer interface and other technologies, it is expected to become the core platform of "non-invasive pathological diagnosis" of liver diseases, and finally achieve the paradigm shift from diagnostic tools to diagnostic decision-making.

Conflicts of Interest

The author declares no conflicts of interest.

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