iFusion

with Respiration Compensation

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iFusion with Respiration Compensation

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1. Introduction

Diagnosis and interventional therapy by ultrasound-guided hepatic CEUS are a key clinical technique that has shown rapid development in recent years. Compared with MR/CT, ultrasound-guided CEUS and intervention are characterized by good real-time performance, low cost, and no radiation exposure, but it is difficult to obtain decisive images by B-mode ultrasonography or even CEUS, and also difficult to achieve effective interventional treatments, because some lesions are small in size, deep, isoechoic or interfered by gas. With Resona 7, iFusion, Mindray's ultrasound fusion imaging technology, can combine liver ultrasonic images with previously acquired abdominal CT/MR images in real time and in an overlapping manner, as shown by Fig.1. By integrating the information from CT/MR, sonographers can accurately position lesions during ultrasonography. iFusion supports both the fusion of routine B-mode images as well as fusion in CEUS and Color/Power modes, and also allows sonographers to switch freely between these modes as required. Diagnosis and treatment with the help of iFusion can improve the confidence of sonographers in diagnosis of intractable liver diseases, increase the accuracy of positioning of ultrasound-guided interventional therapy in the treatment of liver diseases, and also help them accurately assess the effects of interventional therapies.

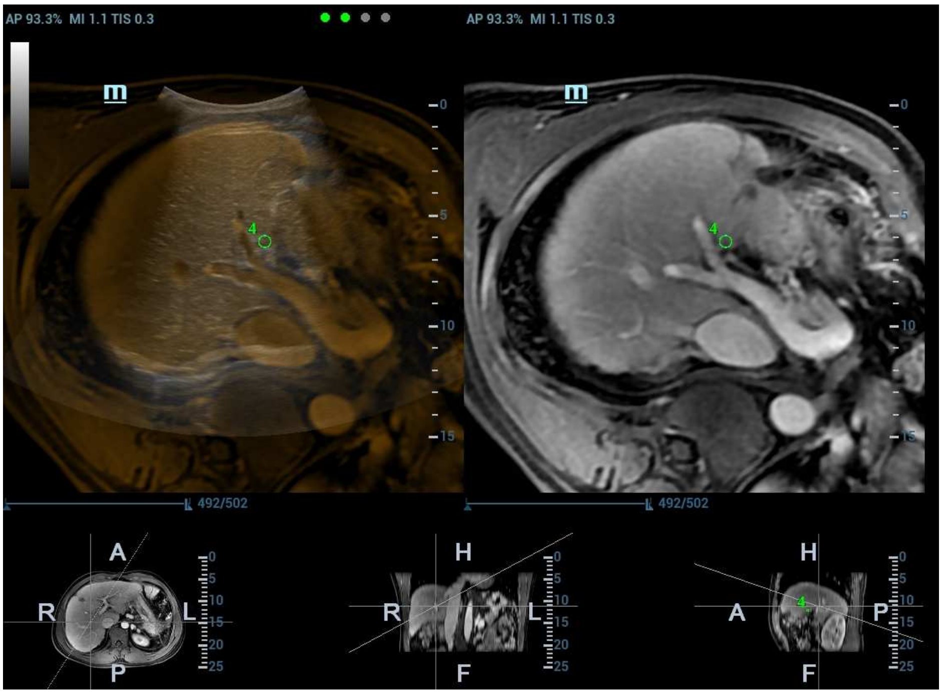

Fig.1 iFusion with tiny hepatic lesion

2. Functional Description

Functions of iFusion are realized through a set of electromagnetic positioning systems consisting of three components as Fig.2 shows: a controller, a magnetic field generator, and a positioning sensor. The magnetic field generator generates the magnetic field used for positioning, while the positioning sensor, binding to a probe, traces the spatial position of the probe in real time in the magnetic field. Resona 7 connects with the controller and uses it to control the running state of the magnetic field generator and acquire the positioning data of the sensor.

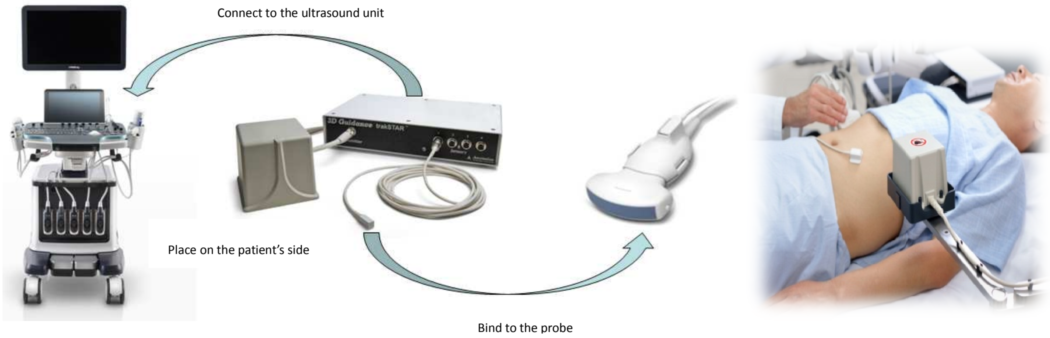

Fig.2 System structure of iFusion

When using the iFusion, users first import the patient's CT/MR data previously acquired in DICOM format into the Resona 7 database to browse and tag histologically, then register the CT/MR image with real time ultrasonography in a single plane manner. Examinations and treatments can be carried out in real-time ultrasonic fusion when the registration is completed, as Fig.3 shows.

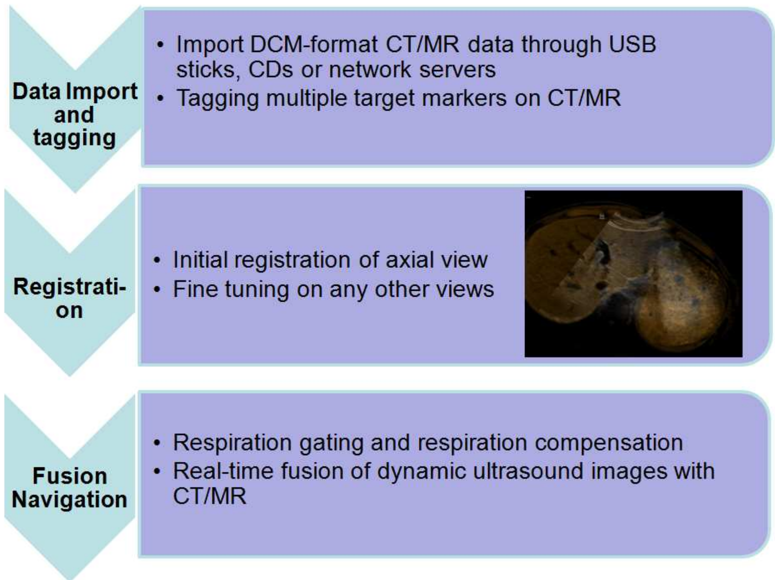

Fig.3 The flow chart of fusion imaging

2.1 Data Import and tagging target markers

CT/MR data can be imported into iFusion in many ways, including USB sticks, CDs, or network servers. The data imported can be browsed by users either in the reading mode or in any arbitrary angle via MPR display mode.

In MPR display mode, iFusion allows users to tag multiple target markers sequentially in a spherical manner. Liver tumors less than 3 cm in diameter are commonly regular and nearly spherical. Tagging is done by browsing to the maximum radial section of the target tissue and determining its central point and radius by mouse clicks and trackball movement, as shown in the green circle in the left figure in Fig.4. In the fusion navigation, when the sonographer rescans these targets from different angles, tags with different colors and serial numbers overlap and display on the fusion image in real time, greatly facilitating rapid and accurate positioning of target tissues during fusion.

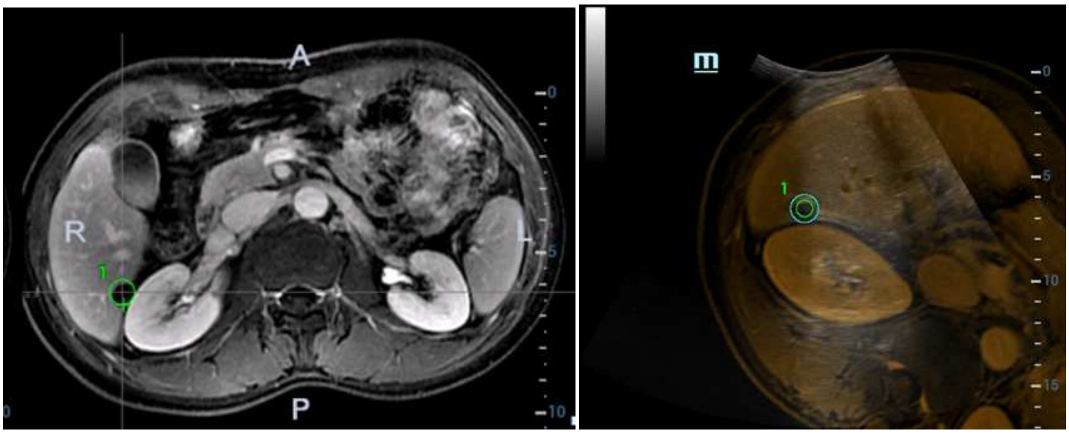

Fig.4 Target marker

2.2 Registration

iFusion achieves registration between ultrasound and CT/MR images in a single plane manner. The registration process is to obtain the transformation matrix, *P*, between the magnetic field generator and CT/MR. The principle is illustrated in Fig.5 below. The term single plane refers to finding out the same planes on ultrasonography and CT/MR. After finding them, they are overlapped and displayed, then CT/MR images are moved to overlap them to determine the mapping matrix *T* between them. The mapping matrix *A*, between the ultrasonic image and probe-position sensor, and the mapping matrix *R*, between probe-position sensor and magnetic field generator are the known quantities for registration. With known *T*, *A,* and *R*, the registration matrix *P* can be calculated based on the formula in the Fig.5.

In clinical applications, the registration is usually carried out in two steps: initial registration and fine tuning, both of which are done in a single plane manner.

- Initial registration is usually conducted in the axial plane of the sagittal part of the left portal vein. You can pre-select a CT/MR section, and then keep the probe vertical to the same section to freeze the ultrasound as far as possible; or you can pre-acquire ultrasound image, and then find a matched CT/MR section. Sonographers determine if ultrasound and CT/MR sections are the same by comparing the contents of two images. You may play back ultrasound images to select the optimal frame or unfreeze the ultrasound for reacquisition if you are not satisfied with the ultrasonic tomogram. After selection of both sections, you enter into a registration state, then overlap and demonstrate two images. Both images are registered by means of adjustment and operation of CT/MR images, such as translation and rotation, and you may complete registration operations and enter into the fusion navigation state once satisfied with the result. In general, the section where the target tissue is located is not the same one as that during the initial registration, and errors often occur in fusion of the section. Fine tuning may therefore be needed after completion of initial registration and entry into the fusion state.
- When fine tuning, move the probe to the feature-rich section near the target tissue, activate the fine tuning, freeze the ultrasound separately, then slowly move the probe and tune the CT/MR sections. When consistent, freeze the CT/MR section, enter into the registration state, translate and rotate the CT/MR section as adjusted and operated during the initial registration, finish fine tuning, and then return to the fusion

navigation state again. During tuning, you may also freeze the CT/MR section separately, and then tune and freeze the ultrasound separately. An unlimited number of tuning operations are allowed, so this may be repeated until you obtain satisfactory fusion accuracy.

During fusion navigation, fine tuning may be carried out at any time if decreased fusion accuracy is found for any reason, for example patient motion.

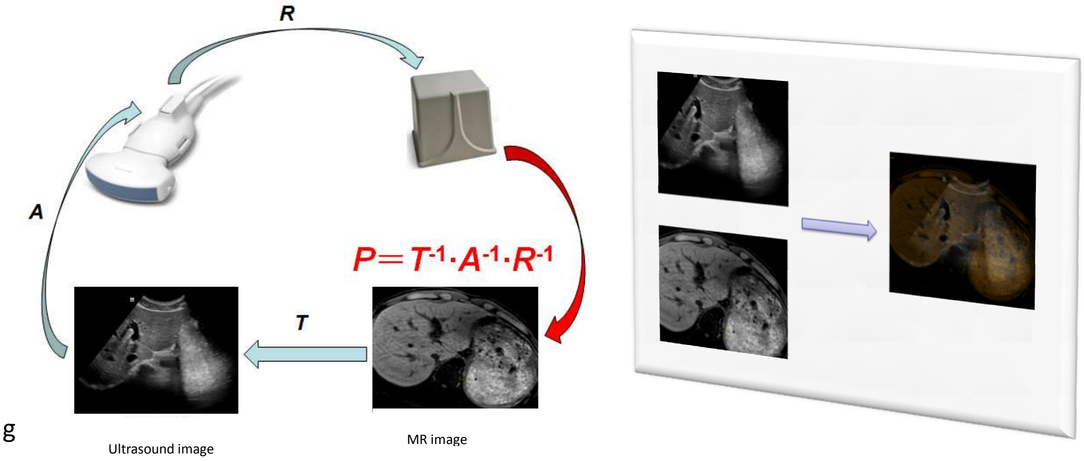

Fig.5 The basic principle of registration

2.3 Fusion Navigation

When the registration is completed, fusion navigation mode can be entered, and fusion modes can be switched among conventional B-mode, Color/Power (Fig.6), and CEUS with regular and dual modes (Fig.7). iFusion also supports user tagging of multiple targets in the fusion window in the real time fusion navigation state. The target marker’s tagging method is consistent with that in the MPR interface, and also determines the central point and radius of the target tissue by mouse clicks and trackball movement.

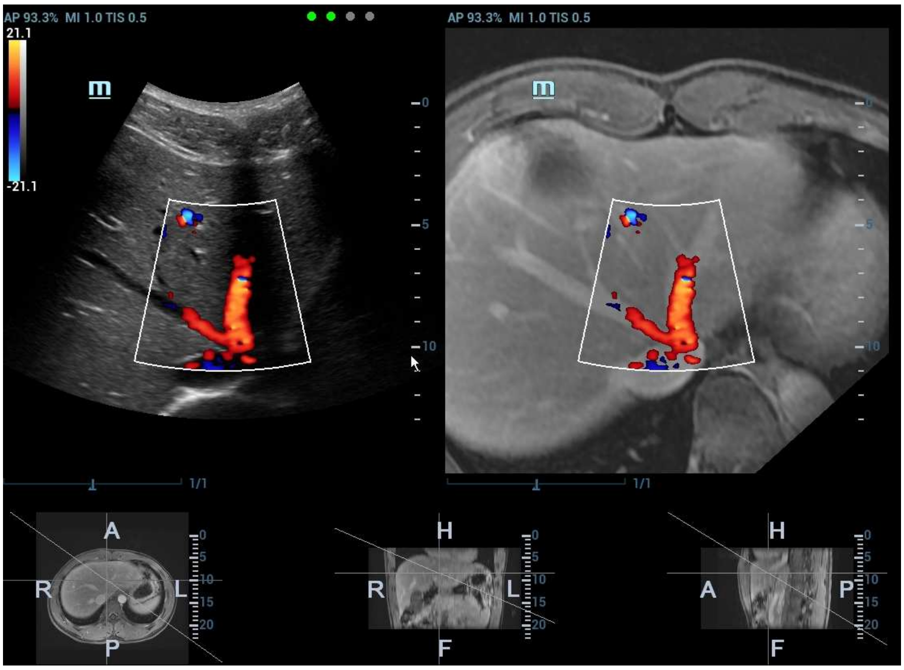

Fig.6 iFusion with color mode

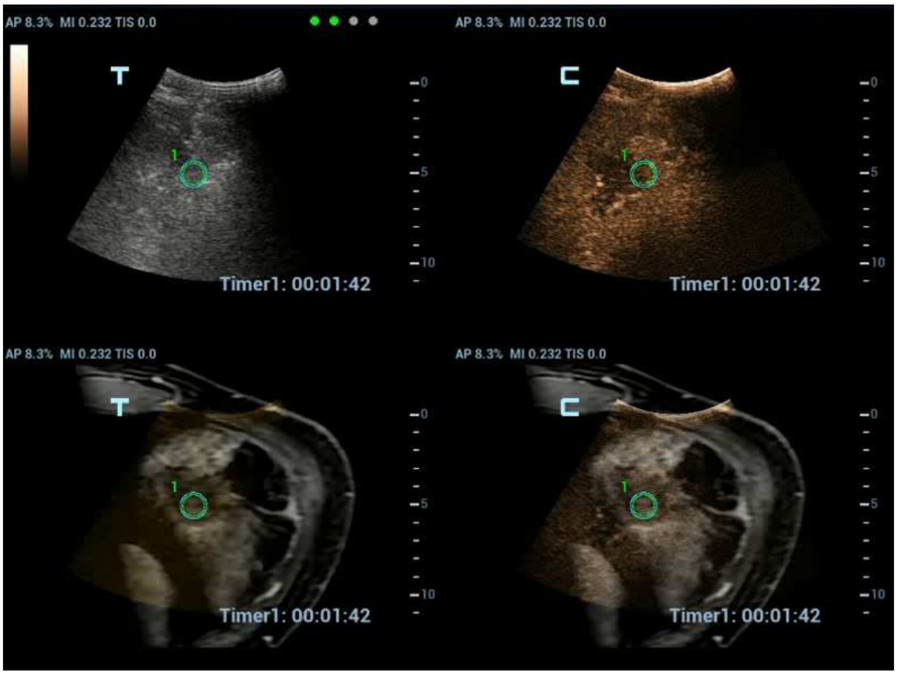

Fig.7 iFusion with CEUS in dual mode

2.3.1 Respiration Gating

The position of the human liver varies with changes in phase of respiration, while the selected ultrasonic plane is acquired in the specific phase of respiration during registration. Therefore, during fusion navigation, the accuracy decreases, and the phase difference increases. This accuracy reduction becomes more apparent if there is a difference between the current phase of respiration and that during registration. The respiration-induced liver fusion error may be up to more than 1 cm. By means of a motion sensor attached to the belly (as illustrated in the left figure below) iFusion can monitor the current phase of respiration (as illustrated in the green curve and the red vertical line of the right picture in Fig.8) and record the phase of respiration during registration (as illustrated in the blue horizontal line of the right figure below) in order to help sonographers grasp the current reliability of fusion effectively. By virtue of this respiration sensor, iFusion can compensate for errors induced by any respiration motion during fusion, as described in *2.3.2*.

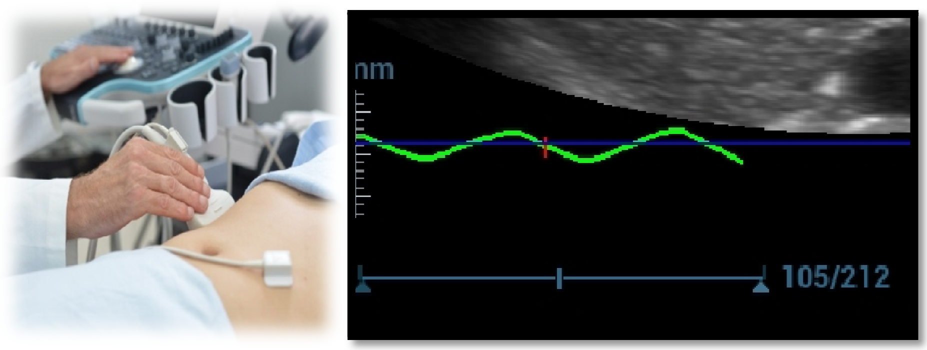

Fig.8 Respiration Gating and Scenario

2.3.2 Respiratory Compensation

Based on our study of four groups of human abdominal CT data under free-breathing conditions, the change in human liver due to respiratory motion was dominated by displacement, while both rotation and deformation were not significant. However, in terms of components in three axial directions of human body coordinates, the displacement along the cephalo-caudal direction was much greater than displacement along the other two directions (Fig.9, Fig.10, Fig.11). Hence, respiration-induced fusion errors can largely be corrected effectively as long as a model of the liver moving along three axial directions can be established accurately.

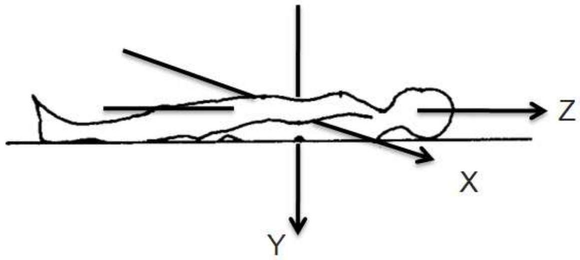

Fig.9 Human body coordinates

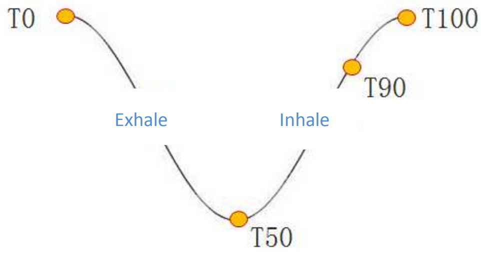

Fig.10 Respiration phase curve

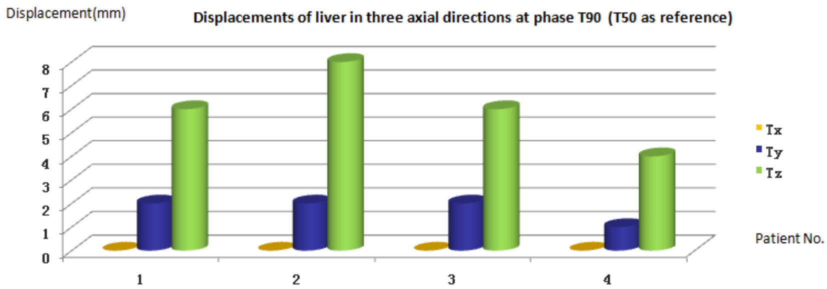

Fig.11 Analysis of human liver movement with respiration

Respiration compensation is Mindray's exclusive and patented technology. Before compensation, a model of liver motion should be established first. The method is described as Fig.12 shows: stabilize the probe in the longitudinal direction as far as possible, acquire liver ultrasound video clips under patient's free-breathing conditions, and select one of those video clips with regular respiration and less probe shaking for motion analysis; then establish a model of liver movement with respiration based on the information of respiration phase changes in this video clip.

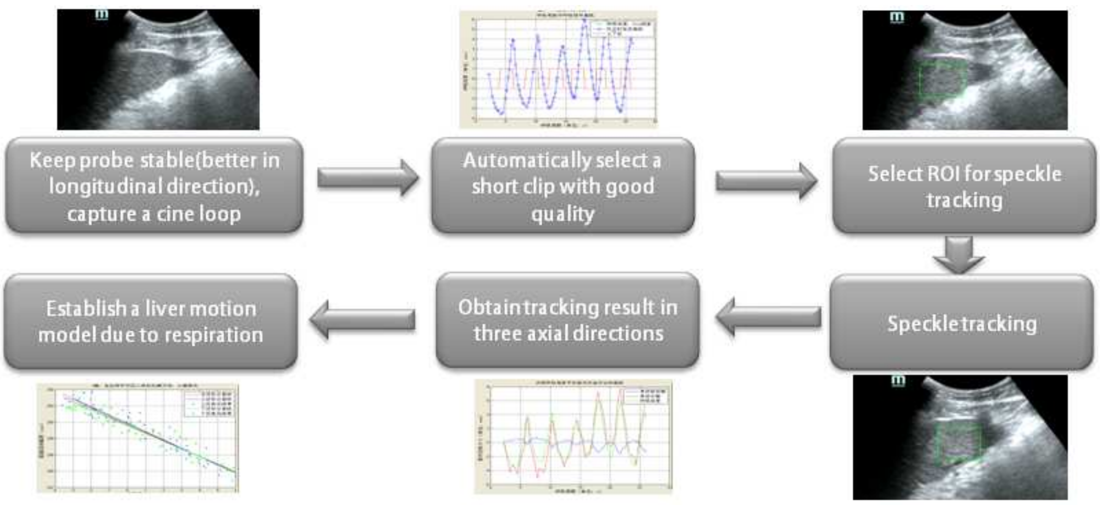

Fig.12 Flowchart of establishment of liver movement model due to respiration

After modeling, the liver displacement between the current respiration phase and that during registration can be obtained in real time and compensated for during fusion navigation. It has been proved in clinical experiments that respiration motion compensation can correct approximately 80% of fusion errors caused by liver movement and markedly improve the fusion accuracy of a full respiration cycle, as Fig.13 shows.

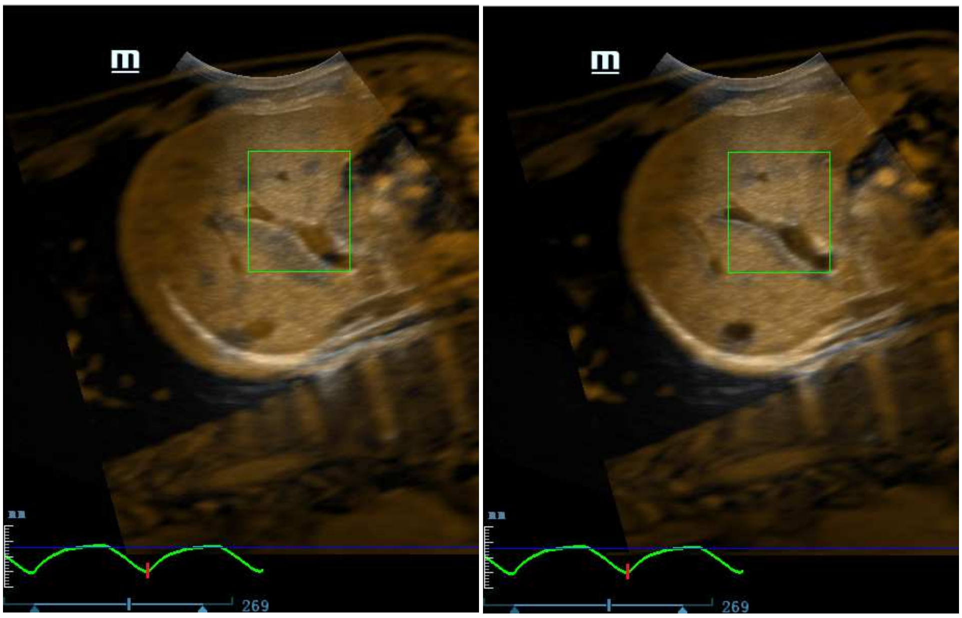

Fig.13 Comparison before and after respiration compensation (the left is pre-compensation and the right is post-compensation)

3. Case Study

Case 1. Liver tumor is suspected. On CT, it is distinctly hypoechoic and ill-defined; on conventional B-mode ultrasonography, it is obscured and iso-echoic. iFusion is performed and the lesion location is tagged, then contrast-enhanced ultrasonography is performed, as Fig.14 shows. The finding displays distinct fast-in and fast-out signs, indicating diagnosis as liver cancer.

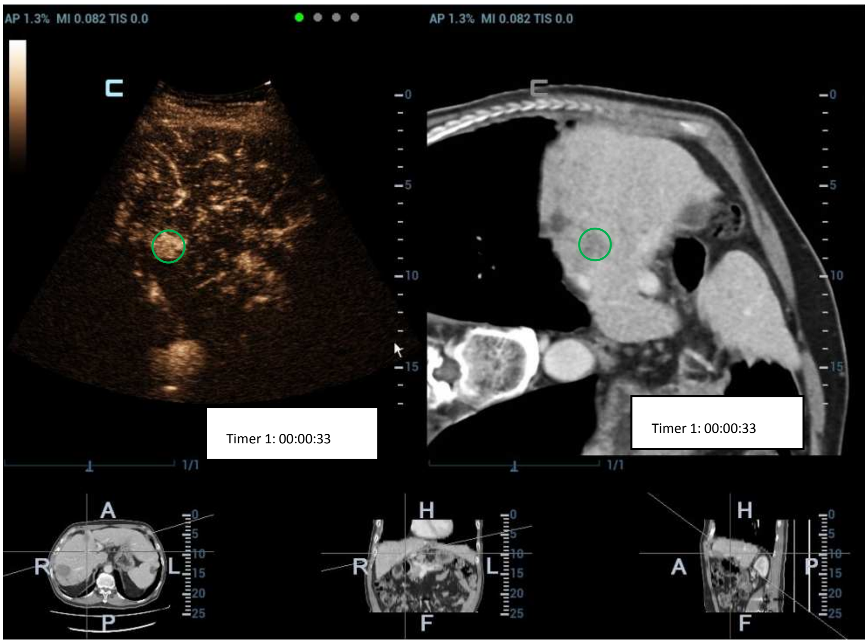

Fig.14 iFusion with CEUS

4. ***Case 2.*** Liver cancer: On MR, the tumor is well-defined, and the ultrasound-guided percutaneous radio-frequency ablation is scheduled to be performed. Pure ultrasound fails to guide insertion of the needle accurately due to small lesions, deep location, and iso-echo, as Fig.15 shows. Performing iFusion and tagging the lesion location with target marker can accurately guide the needle tip to the lesion location.

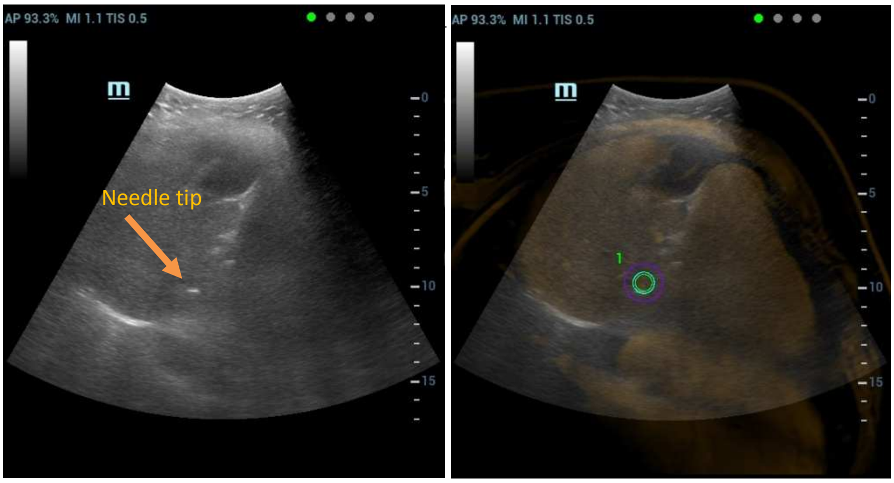

Fig.15 iFusion during intervention procedure

Case 3. Liver cancer: The ultrasound-guided percutaneous radio-frequency ablation is performed. Pre-operatively, iFusion has been performed and the lesion location has been tagged by target marker. A 5 mm safety margin is set up, as Fig.16 shows. Post-operatively, contrast-enhanced ultrasonography is performed immediately for treatment evaluation in the area of ablation including safety margin.

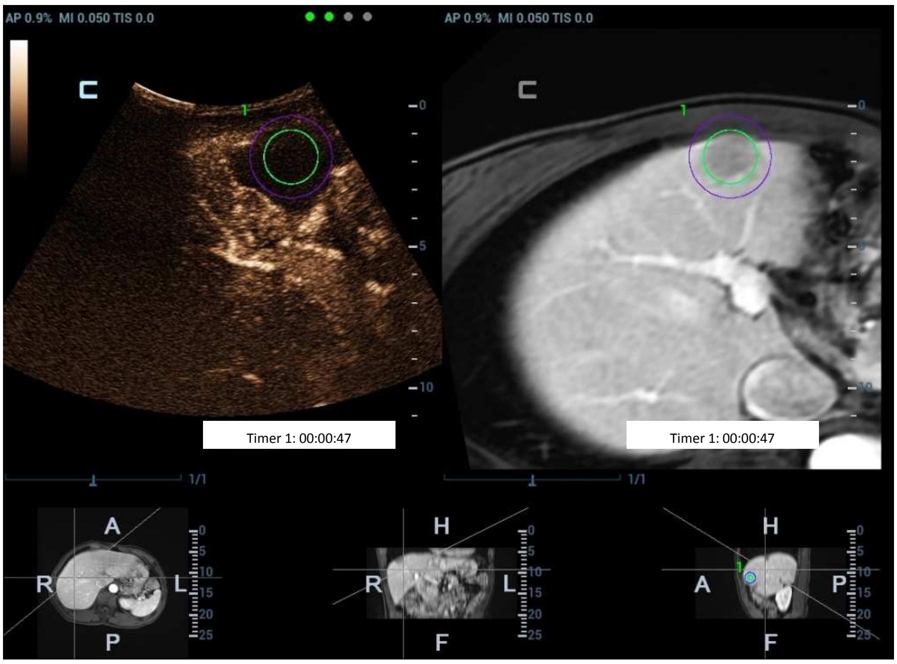

Fig.16 iFusion for treatment evaluation

5. Conclusion

With great clinical values, Resona 7’s iFusion imaging technology can effectively boost confidence in the ultrasound diagnosis of small or difficult to judge liver lesions, and effectively improve the accuracy of ultrasound-guided interventional procedure and the evaluation of the treatment results. Mindray’s exclusive respiration compensation technology can effectively compensate for respiration-induced fusion errors and significantly improve fusion navigation accuracy to a new level.

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