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Ultrasound Fusion Imaging of Hepatocellular Carcinoma: A Review of Current Evidence

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Key Words

Hepatocellular carcinoma · Magnetic navigation · Multiplanar reconstruction images · Radiofrequency ablation · Ultrasound fusion imaging

Abstract

With advances in technology, imaging techniques that entail fusion of sonography and CT or MRI have been introduced in clinical practice. Ultrasound fusion imaging provides CT or MRI cross-sectional multiplanar images that correspond to the sonographic images, and fusion imaging of B-mode sonography and CT or MRI can be displayed simultaneously and in real time according to the angle of the transducer. Ultrasound fusion imaging helps us understand the three-dimensional relationship between the liver vasculature and tumors, and can detect small liver tumors with poor conspicuity. This fusion imaging is attracting the attention of operators who perform radiofrequency ablation (RFA) for the treatment of hepatic malignancies because this real-time, multimodality comparison can increase monitoring and targeting confidence during the procedure. When RFA with fusion imaging was performed on small hepatocellular carcinomas (HCCs) with poor conspicuity, it was reported that the rates of technical success and local tumor progression were 94.4–100% and 0–8.3%. However,

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E-Mail karger@karger.com www.karger.com/ddi there have been no studies comparing fusion imaging guidance and contrast-enhanced sonography, CT or MRI guidance in ablation. Fusion imaging-guided RFA has proved to be effective for HCCs that are poorly defined on not only conventional B-mode sonography but also contrast-enhanced sonography. In addition, fusion imaging could be useful to assess the treatment response of RFA because of three-dimensional information. Here, we give an overview of the current status of ultrasound fusion imaging for clinical application in the liver. © 2014 S. Karger AG, Basel

Introduction

Multiplanar reconstruction (MPR) is a method of displaying three-dimensional (3D) datasets and plays an important role in the interpretation of the 3D anatomical location or extent of disease. Multi-detector raw CT or thin-section MRI has facilitated better images with thinner slice thickness, which has allowed more MPR images to be evaluated in greater detail [1, 2]. Additionally, a fast and accurate magnetic position and orientation tracking method has been developed. By integrating special information between ultrasonic transducer and volume data, two-dimensional (2D) MPR images can display simulta-

Masatoshi Kudo, MD, PhD Department of Gastroenterology and Hepatology Kinki University Faculty of Medicine 377-2 Ohno-Higashi, Osaka-Sayama, Osaka 589-8511 (Japan) E-Mail m-kudo@med.kindai.ac.jp neously in the same plane as sonography. Thus, ultrasound fusion imaging known as virtual sonography has emerged in radiology.

Percutaneous radiofrequency ablation (RFA) has been widely implemented in the management of small hepatocellular carcinomas (HCCs) [3-9]. The local efficacy of RFA for small HCCs (i.e. <2 cm) has been shown to be comparable to that of surgical outcomes [10-16]. However, multiple sessions of RFA therapy are required in difficult cases such as small HCCs with poor conspicuity [17-19]. Lee et al. [20] reported that the most common cause of mistargeting was confusion with cirrhotic nodules, followed by poor conspicuity, a poor sonic window, a poor electrode path and/or inaccurate electrode placement. Inconspicuous HCC on B-mode sonography accounted for 5.2-38.8% of the total nodules treated with percutaneous ablation [21-23]. Indeed, the primary success of percutaneous ablation therapies depends on correct targeting via an imaging technique, and local control is optimized by accurate electrode placement. Various techniques to overcome this problem, such as contrastenhanced sonography [24] and ultrasound fusion imaging, are also powerful for the detection of hepatic nodules poorly defined with B-mode sonography. This article summarizes the principles, clinical applications and technique of ultrasound fusion imaging.

Background

The idea of virtual sonography was initiated by Oshio and Shinmoto in 1996 [25]. At that time, single-slice helical CT with a single detector was the only available modality. Obtaining CT images required a long time to scan the whole liver because helical CT allowed only one channel of image information to be recorded for each rotation of the gantry. Although MPR resembled sonographic images after reconstruction, it could not offer adequate CT image quality for clinical use because of low spatial resolution in the z direction. Multi-detector raw CT now offers rapid scanning of large longitudinal volumes and scan volumes over a large range within a short time with thin-slice images. Advances in volumetric image acquisition capabilities and computer graphics have permitted remarkable improvements in spatial resolution and interactive 3D image-processing techniques [26-28]. Crosssectional MPR images of the liver from almost isovoxel volume data allow virtual sonographic visualization, and a powerful personal computer can perform the operations quickly [29-31].

Magnetic tracking techniques are based on accurate mapping of a 3D magnetic field. When using ultrasound fusion imaging, spatial information can be obtained from the relationship between the magnetic field generator and a magnetic sensor attached to a transducer. The low-frequency pulsed direct current fields are unaffected by body tissues and most non-ferrous metals.

Matrix Transformation on Fusion Imaging

The ultrasound fusion imaging system is mainly composed of the sonography machine with a built-in magnetic location detector unit, magnetic field generator and magnetic sensor. The field generator is set up beside the patient, and then the magnetic sensor is attached to the sonographic transducer connected to the magnetic location detector unit [32]. Generally, 3D special coordinates transformation can be calculated by a matrix transform as below:

$$[X' Y' Z' 1] = [X Y Z 1] \times \begin{vmatrix} r11 & r12 & r13 & 0 \\ r21 & r22 & r23 & 0 \\ r31 & r32 & r33 & 0 \\ Dx & Dy & Dz & 1 \end{vmatrix}$$

X, Y, Z represent the coordinate before transformation, X', Y', Z' the coordinate after transformation, r11-r33 the rotating components, and Dx, Dy, Dz the parallel translation components.

The four coordinate systems of the CT volume, magnetic generator, magnetic sensor and ultrasonic transducer are needed to make calculations (fig. 1). In order to reconstruct the ultrasound fusion image, the following transformation matrixes are required: (i) transformation matrix US from the coordinates of the ultrasonic imaging plane to those of the magnetic sensor (US), (ii) transformation matrix SG from the coordinates of the magnetic sensor to those of the field generator (SG), and (iii) transformation matrix GC from the coordinates of the field generator to those of the CT volume data (GC).

The matrix (UC) that transforms the coordinates of the ultrasonography plane into those of the CT volume data can be expressed by the following equation:

$$UC = US \times SG \times GC$$

According to this equation, GC can be expressed as

$$GC = SG^{-1} \times US^{-1} \times UC$$

Ultrasound Fusion Imaging of HCC



Fig. 1. 3D special coordinate transformations in ultrasound fusion imaging. The four coordinate systems of the CT volume (black), magnetic generator (red), magnetic sensor (blue) and ultrasonic probe (green) are shown (colors in online version). Ultrasound fusion imaging between sonography and MPR images are required the transformation matrixes in turn. Therefore, synchronous imaging can be demonstrated for each movement of the transducer.

Therefore, transformation matrix SG can be acquired from the magnetic sensor data, and transformation matrix US can be calculated from the geometrical position. Since the field generator will not be moved during a diagnosis with this system, transformation matrix GC can be treated as a constant matrix. Transformation matrix GC can thus be calculated if transformation matrix UC is evaluated by performing a calibration with a reference point set after the installation of the magnetic generator. Therefore, ultrasound fusion imaging can be synchronized by manually registering the live ultrasound image to the corresponding image area of the CT/MRI data.

Clinical Uses

Ultrasound Training

The training guidelines established by the American College of Radiology (ACR) and the American Institute of Ultrasound in Medicine (AIUM) for physicians who interpret diagnostic sonographic examinations require at least 3 months of sonographic training during the residency program and involvement in a minimum of 300-500 sonographic examinations during the training period. It is essential not only to demonstrate clear 2D images but also to understand the 3D relationship on abdominal sonographic examination. Sonographic images, which depend on the transducer angle and location, can be changed to produce various cross-sectional images according to the aiming of the operator. This is one of the advantages of sonography. Nevertheless, it is not easy to grasp the 3D vascular anatomy of the liver on sonography from contrast CT information with 2D transverse images [33, 34]. However, by using ultrasound fusion imaging, it is easy to compare the MPR images with B-mode images because the sonographic monitor shows them side-by-side. Okamoto et al. [35] reported that the sensitivity of detecting hepatic nodules on fusion imaging increased from 50.7 to 83.57% compared with using conventional B-mode sonography.

Guidance in RFA

Accurate localization and targeting of small HCCs with poor ultrasound conspicuity is critical to successful RFA. However, ultrasound-guided RFA is often difficult when a target lesion is sonographically obscure. Moreover, when there are regenerating or dysplastic nodules around a small HCC within a cirrhotic liver, incorrect targeting can occur when using ultrasound guidance due to the similarity in appearance of these nearby nodules on sonography. To overcome these limitations of ultrasound guidance, several alternatives such as CT or MRI guidance have been used. However, both imaging modalities have their own weaknesses: CT guidance takes longer and exposes the subject to radiation [30, 36], while MRI guidance is complicated by interference between MRI scanners and RFA systems [37, 38]. Contrast-enhanced sonography is another alternative, but the enhancement effect of commercially available ultrasound contrast agents is not of sufficient duration to clearly visualize an obscure target lesion throughout the RFA procedure [24, 39].

Fusion imaging-guided RFA has been used for HCCs with poor conspicuity on conventional sonography (fig. 2). This technique can increase operator confidence, the accuracy of the procedure and technical success. When RFA with fusion imaging was performed on small HCCs with poor conspicuity, the rates of technical success and local tumor progression were 94.4–100% and 0–8.3% [40–



Fig. 2. A 64-year-old man with a 1.7-cm HCC in right hepatic dome. **a** The MPR image (right) corresponding to the sonographic image from intercostal view after synchronization shows a typical HCC nodule (arrow). B-mode sonography (left) shows the radiofrequency electrode needle (arrowheads) inserted into a low-echoic nodule of HCC (dotted circle). **b** During the percutaneous RFA procedure, air bubbles (dotted circle) obscured the HCC nodule on B-mode sonography (left).

44]. No studies have compared fusion imaging guidance and contrast-enhanced sonography guidance in ablation. However, fusion imaging-guided RFA has proved to be effective for HCCs that are poorly defined on not only conventional B-mode sonography but also contrast-enhanced sonography. In addition, it could be used for fusion imaging guidance comparing MPR images and contrast-enhanced sonography. On the other hand, it has been reported that fusion imaging occasionally could not show coincident images. This imaging incompatibility could be attributed to variance in the depth of breathholding at CT and ultrasound examination, and may increase with the distance between the magnetic sensor attached to the ultrasonic transducer and the field generator. However, this imaging incompatibility has been reducing by enhanced performance of magnetic sensors.

Fusion imaging can be considered to have an acceptable registration error and to be an efficacious tool for overcoming the limitations of ultrasound-guided RFA, which include sonographically obscure nodule issues and confounding nodule issues.

Treatment Response Assessment

Axial images of CT/MRI are mainly used in the evaluation of the therapeutic response of HCCs after RFA [45-47]. However, some HCC patients showed local tumor progression a few months after first ablation because of residual tumors that went unnoticed on axial images. It used to be difficult to distinguish between small residual HCCs and hyperemia lesions because they both showed arterial enhancement. The problem of the partial volume effect cannot be resolved by using MPR. However, multiangle images using MPR might be able to show the residual HCC as circular enhancement because the shape of enhanced lesions can help diagnose small residual HCC or hyperemia [48-50]. In addition, multi-angle images might be highly sensitive for assessing the 5-mm safety margin around the whole tumor. Assessment of RFA with 3D information could have higher accuracy than with 2D information [48].

Conclusion

Ultrasound fusion imaging has three important features for clinical application. The first is compatibility. The virtual sonographic images obtained using MPR can easily be compared with B-mode sonographic images because the monitor can show them side-by-side. The second is its swift response. With a powerful computer, the fusion imaging can be displayed smoothly for each movement of the transducer in real time. The third feature is synchronicity. This technique contributes to immediate feedback when identifying small hepatic nodules. Ultrasound fusion imaging can indicate the 3D relationship between the liver vasculature and tumors. Fusion imaging can be an efficacious tool in the management of HCCs that have poor ultrasound conspicuity.

Disclosure Statement

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The authors have no conflicts of interest to disclose.

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