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Clinical value of CT/MR-US fusion imaging for radiofrequency ablation of hepatic nodules

Jae Young Lee[a,b,*], Byung Ihn Choi[a,b], Yong Eun Chung[c], Min Wook Kim[a,b], Se Hyung Kim[a,b], Joon Koo Han[a,b]

[a] Department of Radiology, Seoul National University Hospital, Seoul, Republic of Korea
[b] Institute of Radiation Medicine, Seoul National University Hospital, Seoul, Republic of Korea
[c] Department of Radiology, Research Institute of Radiological Science, Severance Hospital, Yonsei University College of Medicine, Seoul, Republic of Korea

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ABSTRACT

Objective: The aim of this study was to determine the registration error of an ultrasound (US) fusion imaging system during an ex vivo study and its clinical value for percutaneous radiofrequency ablation (pRFA) during an in vivo study.
Materials and methods: An ex vivo study was performed using 4 bovine livers and 66 sonographically invisible lead pellets. Real-time CT-US fusion imaging was applied to assist the targeting of pellets with needles in each liver; the 4 sessions were performed by either an experienced radiologist (R1, 3 sessions) or an inexperienced resident (R2, 1 session). The distance between the pellet target and needle was measured. An in vivo study was retrospectively performed with 51 nodules (42 HCCs and 9 metastases; mean diameter, 16 mm) of 37 patients. Fusion imaging was used to create a sufficient safety margin (>5 mm) during pRFA in 24 nodules (group 1), accurately target 21 nodules obscured in the US images (group 2) and precisely identify 6 nodules surrounded by similar looking nodules (group 3). Image fusion was achieved using MR and CT images in 16 and 21 patients, respectively. The reablation rate, 1-year local recurrence rate and complications were assessed.
Results: In the ex vivo study, the mean target–needle distances were 2.7 mm ± 1.9 mm (R1) and 3.1 ± 3.3 mm (R2) ($p > 0.05$). In the in vivo study, the reablation rates in groups 1–3 were 13%, 19% and 0%, respectively. At 1 year, the local recurrence rate was 11.8% (6/51). In our assessment of complications, one bile duct injury was observed.
Conclusion: US fusion imaging system has an acceptable registration error and can be an efficacious tool for overcoming the major limitations of US-guided pRFA.

1. Introduction

Ultrasound (US) is the most commonly applied imaging modality during percutaneous radiofrequency ablation (pRFA) of hepatic nodules due to its ability to provide real-time guidance for the placement of electrodes. However, US guidance has weaknesses that limit the applications and indications of pRFA. First, US does not provide information on the size of the safety margin during pRFA because air-bubbles produced during pRFA prevent visualization of the tumor itself. Second, US-guided pRFA is difficult or even impossible when a target lesion is sonographically obscure. Third, when there are confounding nodules around a target lesion, e.g., when there are regenerating or dysplastic nodules around a small HCC within a cirrhotic liver, incorrect targeting can occur using US guidance due to the similarity in appearance of these nearby nodules on US images.

To overcome these limitations of US guidance, several alternatives such as CT guidance or MR guidance have been used. However, both imaging modalities have their own weaknesses: CT guidance has more time requirements, the presence of radiation exposure and difficulty in targeting lesions that require pathways with complex angles or narrow windows [1,2], while MR guidance involves interference between MR scanners and RF systems, the need for MR compatible electrodes and the challenging requirement of open MR systems for near real-time imaging during electrode placement [3–5]. Contrast-enhanced US is another alternative; however, the enhancement effect of commercially available US contrast agents is not of sufficient duration to clearly visualize an obscure target lesion throughout a pRFA procedure.

Recently, several US fusion imaging systems have been introduced in clinical practice. US fusion imaging provides CT or MR cross-sectional multiplanar images that correspond to the acquired

* Corresponding author at: Department of Radiology, Seoul National University Hospital, 101 Daehang-no, Jongno-gu, Seoul 110-744, Republic of Korea.
Tel.: +82 2 2072 3073; fax: +82 2 743 6385.
E-mail address: leejy4u@snu.ac.kr (J.Y. Lee).

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US images, and all images can be displayed simultaneously and in real-time according to the angle of the US transducer. This fusion imaging is attracting the attention of operators who perform pRFA for the treatment of liver tumors because this real-time, multimodality comparison can increase monitoring and targeting confidence during the procedure [2,6–11].

This study was performed to determine the registration error of an US fusion imaging system using a dual sensor positioning system in ex vivo tissue samples. An in vivo study of patients was also performed to assess the clinical value of this method in the presence of the aforementioned challenges of US (safety margin issue, obscure nodule issue, and confounding nodule issue).

2. Materials and methods

2.1. Ex vivo study

Sixty-six 2-mm lead pellets that were invisible on conventional US images but were clearly seen as a high attenuating material on CT images were used as radiopaque targets. The lead pellets were inserted in the periphery of four extracted bovine livers using a 16 G or 18 G introducer (liver 1, 16 lead pellets; liver 2, 17 lead pellets; liver 3, 16 lead pellets; liver 4, 17 lead pellets) (Fig. 1a). The use of four livers enabled us to evaluate the targeting accuracy of three sessions performed by an experienced radiologist and to compare it to one session performed by a radiologist with a different level of experience with US-guided intervention. Six 18 G intravenous cannula piercing needles were inserted in one side of each bovine liver in random patterns to be used as reference (reference needles) for registration of CT and US images (Fig. 1a).

A 16-slice MDCT scan (Sensation 16; Siemens Medical Solutions, Forchheim, Germany) of the bovine liver was performed with a 1-mm collimation and a reconstruction interval of 0.7 mm. The CT DICOM data were pulled onto the fusion imaging system from a Picture Archiving and Communicating system.

An US machine (LOGIQ E9; GE, Milwaukee, WI, USA) equipped with a dual sensor positioning navigation system was used with a 1–5 MHz curvilinear probe. For the fusion of CT and US images, the tip or crossing points of the reference needles were identified on US and correlated with the corresponding points of the needles on CT. Only three of these points made by the tips or crossings of six registration needles were used for this registration (position correlation) to better simulate the clinical environment.

Real-time US imaging was performed by Radiologist 1 (R1) with 7 years of experience in abdominal ultrasound. By observing the US images and corresponding CT images side by side on a monitor, the radiologist targeted the lead pellets that were visible only on the CT images using polyteflon-coated 21-gauge Chiba needles (M.I. Tech, Seoul, Korea) (Fig. 1b). The needles were intended to pass through the target (lead pellet). CT scanning was then performed to assess the accuracy of targeting using the same CT machine and CT protocol that were used to acquire the CT images for fusion. The shortest distance between the Chiba needle and targeted lead pellet was measured on multiplanar reconstructed images (Fig. 1d). In the first session, all 16 lead pellets in liver 1 were targeted. In the second and third sessions, all 17 and 16 lead pellets in livers 2 and 3 were targeted, respectively.

Following these sessions, a medical resident (R2) with no experience in US intervention targeted 17 lead pellets in liver 4 after the US and CT images were registered by the experienced radiologist (R1). CT scanning was also performed to assess the targeting accuracy using the same protocol, as described above. The shortest distance between the Chiba needle and targeted lead pellet was measured on multiplanar reconstructed images.

2.2. In vivo study

The institutional review board of our hospital approved this study and informed consent was waived due to the retrospective nature of the study.

2.2.1. Patients

From February to August 2009, 51 nodules in 37 patients (M:F = 31:6, mean age, 55.8) were treated with pRFA using CT/MR-US fusion imaging (42 HCCs of 33 patients; 9 metastases of 4 patients). All HCCs were according to the American Association for the Study of Liver Disease (AASLD) 2005 recommendations [12]. According to these recommendations, nodules with a size of 1–2 cm in patients with hepatitis B or cirrhosis of other etiology are diagnosed as HCCs when a typical enhancement pattern (hypervascularity in the arterial phase and washout in the portal/venous phase) appears in two imaging techniques. Nodules larger than 2 cm in patients with hepatitis B or cirrhosis of other etiology were diagnosed as HCCs when a typical vascular pattern appears in a dynamic imaging technique or the AFP is >200 ng/ml. A diagnosis of a metastasis was made using both the clinical history and imaging findings: all 4 patients diagnosed with metastases had a prior medical history of colon cancer surgery and an occurrence of hepatic nodules during the follow-up, and all hepatic nodules were associated with imaging findings consistent with a metastasis on CT, MR, and PET-CT images.

The mean diameter of the 42 HCCs and 9 metastases was 18 mm (range, 8–49) and 13 mm (range, 5–25), respectively. All cases were categorized into three groups according to the specific US challenge that necessitated the use of fusion imaging. In group 1 (also called safety margin issue group), fusion imaging was performed to determine if a sufficient safety margin was created around a target lesion. In group 2 (obscure nodule issue group), fusion imaging was conducted to target nodules that were obscured on US images alone. In group 3 (confounding nodule issue group), fusion imaging was carried out for proper targeting of the lesions confounded by adjacent similarly appearing nodules. Groups 1–3 consisted of 24 nodules (19 HCCs, 5 metastases from colon cancers), 21 nodules (17 HCCs, 4 metastases from colon cancers), and 6 nodules (all HCCs), respectively.

2.2.2. Technique

For CT/MR-US fusion imaging, one radiologist with 16 years of experience in abdominal US used the same US machine used in the ex vivo study with a 1–5 MHz curvilinear probe. Dynamic phase CT or MR volume datasets that clearly displayed both the target lesion and hepatic vessels were used as a counterpart to US imaging. As a result, arterial, portal, or hepatobiliary phase images of Gd-EOB-DTPA-enhanced MRI images in 16 patients or arterial or portal phase images of contrast-enhanced CT in 21 patients were used for fusion.

Registration between real-time US and pre-acquired CT/MR volume datasets was achieved by plane registration followed by three point registrations. Generally, the coronal plane was used for plane registration. The branching areas of the portal veins or hepatic veins in the liver were chosen for the point registrations. In the presence of right hepatic lobe lesions, an intercostal scanning was usually used for the point registration and pRFA because it provides good acoustic window regardless of respiration. In cases with left hepatic lobe lesions, a subcostal scanning was usually used because intercostal scanning is nearly impossible in most cases. To enhance the accuracy of the correlation, three point registrations were carried out during the comfortable expiratory phase. The last of three point registrations was achieved near the target lesions.

In group 1 (safety margin issue group), the margin (3, 6, 9, and 12 o'clock) and the center of a targeted tumor were marked using