SHORT COMMUNICATION

Three-dimensional images of liver tumours reconstructed by Gd-EOB-DTPA-enhanced MRI

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ABSTRACT. The purpose of this study was to evaluate three-dimensional images of liver tumours obtained with gadolinium ethoxybenzyl diethylenetriamine penta-acetic acid (Gd-EOB-DTPA)-enhanced MRI (3D-EOB-MRI) in hepatic surgery. We conclude that 3D-EOB-MRI may be an alternative method for depicting liver tumours adjacent to the hepatic veins and portal branches, and may provide additional information for surgical planning.

Received 2 June 2011
Revised 15 November 2011
Accepted 20 December 2011

DOI: 10.1259/bjr/39943503

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Advances in radiological imaging techniques have been crucial in the development of hepatic surgery, and development of three-dimensional (3D) images has been helpful in surgical procedures. Better understanding of 3D appearances of liver structure may improve the outcome of curative surgery, and make more aggressive resection possible. Most 3D images of the liver have been reconstructed using volume data from multidetector row helical CT (MDCT) with multiphasic contrast-enhanced studies [1–4]. Although MDCT images are widely utilised, there may be some cases when a liver tumour can only be determined by MRI, or when a patient cannot undergo contrast-enhanced CT owing to risk of allergic reaction to the contrast medium.

The hepatocyte-specific contrast agent gadolinium ethoxybenzyl diethylenetriamine penta-acetic acid (Gd-EOB-DTPA) was developed to improve the detection and characterisation of focal liver lesions with MRI [5–8]. 3D images of tumours and vascular structures reconstructed from hepatobiliary phase Gd-EOB-DTPA-enhanced MRI (3D-EOB-MRI) have not been previously reported.

In this study, we reconstructed images obtained by 3D-EOB-MRI, and evaluated the efficacy in hepatic surgery.

Methods and materials

Between June 2009 and September 2010, 26 consecutive patients (18 male, 8 female; age range 36–71 years; mean age 55 years) with liver tumours underwent Gd-EOB-DTPA-enhanced MRI at our institution within 3 weeks before surgery. The diagnoses of the liver tumours

were confirmed pathologically after surgery. This study was approved by our institutional ethics review board, and each patient gave informed consent prior to the study.

MRI examination

All MRI was performed with a 1.5-T superconducting MRI scanner (Magnetom® Symphony; Siemens, Erlangen, Germany) with a phased-array multicoil for signal reception. The liver was imaged in the axial planes in the following sequences. Baseline MR images included the respiratory-triggered transverse T_2 weighted turbo spin echo (TSE) sequence and transverse breath-hold T_1 weighted gradient-recalled echo sequence. Respiratory-triggered T_2 weighted imaging was obtained using the following parameters: repetition time (TR), 3300–5500 ms; echo time (TE), 85 ms; echo train length, 5; matrix, 192–256×256; and two signal averages. Breath-hold in-phase and out-of-phase T_1 weighted imaging was obtained using the following parameters: TR, 126 ms; TE, 2.3 (out-of-phase) to 4.6 ms (in-phase); flip angle, 80°; matrix, 162–192×256; one signal average. For each sequence, 5-mm slices with no gap were used, and a field of view of 35–40 cm, depending on the size of the liver.

Dynamic imaging was performed with intravenous bolus injection of Gd-EOB-DTPA (Primovist, Bayer, Germany) as a contrast agent at a dose of 25 $\mu\text{mol kg}^{-1}$ body weight and a flow rate of 1 ml s^{-1} , followed by a 20-ml saline flushing. A power injector (Sonic Shot; Nemoto-Kyorindo, Tokyo, Japan) was used for injection of the contrast agent and saline. Unenhanced arterial phase (20–35 s), portal phase (45–60 s), equilibrium phase (180 s) and hepatobiliary phase (20–25 min) images were obtained using 3D Fourier transform gradient echo

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imaging (volumetric interpolated breath-hold examination, VIBE; Siemens, Erlangen, Germany) using the following parameters: TR, 3.3–4.4 ms; TE 1.4–1.9 ms; flip angle, 9° ; one signal acquired; matrix, 128–192 interpolated to 256×256 ; field of view, 32–35 cm, with 80% rectangular field of view; interpolated section thickness of 2–3 mm; and slab thickness of 16–20 cm to ensure full coverage of the liver.

The data from the hepatobiliary phase were then transferred to a workstation (Zio, Tokyo, Japan). 3D liver images were reconstructed using volume rendering, and multiplanar reformatted images connecting axial and 3D images were also obtained. 3D images of vascular structures and the hepatic surface were reconstructed on the display under the same threshold conditions, then solitary or multiple tumours were reconstructed independently under another threshold condition from the same series of data. These images were fitted to overlap on the same display (Figure 1).

Imaging analysis

Segmental anatomy and location of the tumours were evaluated on the 3D images. The location of the tumours was correlated with post-operative pathological findings. On 3D images, the conspicuity of the right, middle and

left hepatic veins and subsegmental portal branches (P3, P6, P8) was evaluated on a scale of 0–2, where 0 indicates vasculature is not visible; 1 indicates vasculature is visible, but obscure; and 2 indicates vasculature is clearly visible. The 3D images were initially reviewed by two radiologists independently. The workstation allowed the radiologists to adjust the threshold to create optimal 3D images. In cases of disagreement, final decisions were reached by consensus.

Contrast-to-noise ratios (CNRs) for liver tissue, vascular structure and the tumour were calculated. CNR was defined as signal intensity (SI)/noise on axial images. Noise was defined as the standard deviation of the SI measured in ambient air. Differences in CNRs between liver tissue and vascular structures and between liver tissue and tumours on the hepatobiliary phase were compared with those on the portovenous phase by Student's *t*-test.

Results

11 patients were diagnosed with hepatocellular carcinomas (HCCs), 1 patient was diagnosed with intrahepatic cholangiocellular carcinoma, 13 patients were diagnosed with metastatic tumours and 1 patient was diagnosed with inflammatory pseudotumour. The

Figure 1. Colorectal metastatic tumour in a 55-year-old male. Axial gadolinium ethoxybenzyl diethylenetriamine penta-acetic acid (Gd-EOB-DTPA)-enhanced images obtained during the (a) portal venous phase and (b) hepatobiliary phase show the lesion in segment 7/8 of the right lobe of the liver (arrow). On the hepatobiliary phase, both the lesion and vascular structures appear as areas of hypointensity compared with the liver parenchyma. Gd-EOB-DTPA-enhanced MR images on the (c) caudal–cranial plane and (d) right–high anteroposterior plane demonstrate the lesion (white arrow) in segment 7/8 of the liver. Note that both the hepatic veins and the portal branches are clearly visible with the tumour. (e) A multiplanar reformatted image along the right hepatic vein and (f) a three-dimensional (3D) image with selective slab thickness reveal that the tumour is located apart from the right hepatic vein (arrow). In addition, the 3D image reveals that the tumour involved an intrahepatic portal vein (white arrow) that branched posteriorly from the subsegmental portal branch (P8). The tumour was surgically resected with the intrahepatic portal branch, and the right hepatic vein was preserved.

number of the tumours in each patient ranged from one to four (average number of tumours was 1.35 ± 0.81).

The subsegmental locations of the tumours on 3D images matched in all cases with the findings from the post-surgery pathology.

The differences in the CNR of liver tissue and hepatic vein on the portovenous phase and on the hepatobiliary phase were 55.0 ± 35.1 and 176.7 ± 78.2 , respectively. The differences in the CNR of liver tissue and the portal vein on the portovenous phase and on the hepatobiliary phase were 63.5 ± 53.4 and 170.3 ± 73.4 , respectively. The differences in the CNR of liver tissue and the tumours on the portovenous phase and on the hepatobiliary phase were 108.8 ± 61.3 and 187.4 ± 83.9 , respectively. The differences in the CNR of liver tissue and hepatic vein, liver tissue and portal branch, and liver tissue and the tumour were all statistically higher on the hepatobiliary phase than on the portovenous phase ($p < 0.001$).

On 3D images, in the evaluation of the conspicuity of the vascular structure, 22 cases (84.6%) were categorised as 2, but 3 cases (11.5%) were categorised as 1, and 1 case (0.4%) was categorised as 0. The cases categorised as 1 or 0 were HCC cases with liver cirrhosis.

Discussion

Imaging techniques of the liver should provide details of segmental and vascular anatomy to facilitate treatment planning. Reconstructed 3D images have been adopted to increase understanding of major blood vessels and other important structures related to the lesion, and have been very useful in hepatic resection and hepatic transplantation [1–4]. Until recently, 3D images of the liver have been mainly reconstructed by CT data, and these images have been widely utilised in surgical planning [1–4]. Segmental anatomy of the liver is mainly defined by hepatic veins and portal branches, so sliced MR provide all the information on the major vessels and the tumour. Lee et al [9] reported isotropic volumetric interpolated breath-hold examination as a dynamic 3D imaging of the liver, and these techniques can facilitate reconstruction methods such as multiplanar reformatting and angiographic post-processing for definition of vascular and segmental anatomy. In their study, 3D images were reconstructed on arterial and portovenous phase by contrast-enhanced dynamic study using Gd-based non-specific extracellular contrast agent.

The hepatocyte-specific contrast agent Gd-EOB-DTPA was developed to improve the detection and characterisation of focal liver lesions using MRI [5–8]. It is useful for detecting lesions in patients known or suspected to have focal hepatic lesions. However, 3D images reconstructed by Gd-EOB-enhanced MRI on the hepatobiliary phase have not been previously reported. When Gd-EOB-DTPA is injected intravenously as a bolus, its blood pool properties are transient, and early dynamic imaging is possible similar to using Gd-based non-specific extracellular contrast agent. Intense enhancement of the liver can be obtained after 20 min and lasts for at least 120 min after administration of Gd-EOB-DTPA. Major vessels in the liver appear at very low signal intensity, in contrast to liver tissue, and most tumours also appear as areas of very low signal intensity.

In our study, the differences in CNRs between liver tissue and hepatic vein, liver tissue and portal branch, and between liver tissue and the tumour were statistically higher on the hepatobiliary phase than on the portovenous phase. Compared with MRI using other Gd contrast agents, the intensity of portal or hepatic venous enhancement in the portovenous phase on Gd-EOB-enhanced MRI seems to be relatively weak.

The higher contrast between liver parenchyma and the vessels and between liver parenchyma and the tumour is ideal for the reconstruction of 3D images. The optimal phase when the tumour and vascular structure appear most conspicuous is often different in multiphasic contrast-enhanced CT, and 3D CT images have to be reconstructed from more than two series of the study. However, on 3D-EOB-MRI, both the tumours and the vascular structures are well defined on the hepatobiliary phase, so the 3D image can be reconstructed from only one series without a gap on the respiratory-triggered phase. 3D-EOB-MRI is thought to be feasible for different types of tumour with high signal intensity on the hepatobiliary phase, because the 3D images of the tumours can be reconstructed independently under different thresholds from the same series of data.

On the other hand, this study indicates that vascular structures are not well defined in some cases of liver dysfunction. In four patients with liver cirrhosis, vascular structures were not clearly demonstrated owing to the severe liver dysfunction leading to a lower accumulation of Gd-EOB-DTPA in the liver parenchyma.

Thick perivascular fat at the hilum tends to affect the conspicuity of vascular structures and the surface of the liver may obstruct the imaging of the underlying vascular structure. 3D-EOB-MRI is not able to demonstrate hepatic arterial anatomy or tumour invasion of the arteries. We recognise the need for advanced techniques to resolve these problems, and have to consider adaptability to this method. However, the current study indicates that 3D-EOB-MRI may be an alternative method for 3D study of liver tumours, and may provide additional information for surgical planning.

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