Mapping of hepatic vascular anatomy: dynamic contrast-enhanced parallel MR imaging compared with 64 detector row CT

Heilmaier, C; Sutter, R; Lutz, A M; Seifert, B; Weishaupt, D; Marincek, B; Willmann, J K

Heilmaier, C; Sutter, R; Lutz, A M; Seifert, B; Weishaupt, D; Marincek, B; Willmann, J K (2007). Mapping of hepatic vascular anatomy: dynamic contrast-enhanced parallel MR imaging compared with 64 detector row CT. Radiology, 245(3):872-880.

Postprint available at:
http://www.zora.uzh.ch

Posted at the Zurich Open Repository and Archive, University of Zurich.
http://www.zora.uzh.ch

Originally published at:
Mapping of hepatic vascular anatomy: dynamic contrast-enhanced parallel MR imaging compared with 64 detector row CT

Abstract

The study was approved by the institutional review board, and informed consent was obtained from all patients. The purpose of this study was to retrospectively evaluate the feasibility, reliability, and accuracy of breath-hold dynamic contrast material-enhanced parallel gradient-echo (GRE) magnetic resonance (MR) imaging for mapping the hepatic vascular anatomy, with contrast-enhanced 64-detector row computed tomography (CT) as the reference standard. The parallel GRE MR data sets of 100 patients acquired at 1.5 T were evaluated independently by two blinded readers with respect to (a) image quality for depiction of the hepatic arteries and the portal and hepatic veins and (b) presence of arterial stenosis and variant hepatic vasculature. The readers rated image quality to be good or excellent for 91.1%-100% of the vessels. At parallel GRE MR imaging, the readers diagnosed variant hepatic vessels and arterial stenosis with 94%-100% accuracy. They concluded that parallel GRE MR imaging, as compared with 64-detector row CT, is feasible for hepatic vascular mapping and enables reliable and accurate detection of variant hepatic vasculature and diagnosis of arterial stenosis. Supplemental material: http://radiology.rsajnl.org/cgi/content/full/2453062103/DC1.
The study was approved by the institutional review board, and informed consent was obtained from all patients. The purpose of this study was to retrospectively evaluate the feasibility, reliability, and accuracy of breath-hold dynamic contrast material–enhanced parallel gradient-echo (GRE) magnetic resonance (MR) imaging for mapping the hepatic vascular anatomy, with contrast-enhanced 64–detector row computed tomography (CT) as the reference standard. The parallel GRE MR data sets of 100 patients acquired at 1.5 T were evaluated independently by two blinded readers with respect to (a) image quality for depiction of the hepatic arteries and the portal and hepatic veins and (b) presence of arterial stenosis and variant hepatic vasculature. The readers rated image quality to be good or excellent for 91.1%–100% of the vessels. At parallel GRE MR imaging, the readers diagnosed variant hepatic vessels and arterial stenosis with 94%–100% accuracy. They concluded that parallel GRE MR imaging, as compared with 64–detector row CT, is feasible for hepatic vascular mapping and enables reliable and accurate detection of variant hepatic vasculature and diagnosis of arterial stenosis.
Breath-hold dynamic contrast material–enhanced three-dimensional gradient-echo (GRE) magnetic resonance (MR) imaging is increasingly being used for assessment of the hepatic vascular anatomy (1–4). This technique enables one to combine the advantages of minimal invasiveness with simultaneous assessment of the hepatic parenchymal morphology and detailed analysis of the vascular anatomy. Furthermore, no ionizing radiation is used, and this is particularly important in young patients with compromised respiratory and/or cardiac function, who may not be capable of undergoing repetitive follow-up examinations of the liver (3,5). Breath-hold times exceeding 25–30 seconds, however, are often necessary for standard three-dimensional GRE sequences. This limits the utility of the technique in patients with compromised respiratory function, who may not be capable of the multiple breath holds required for dynamic GRE MR imaging (4).

Several approaches can be used to reduce the breath-hold times in dynamic GRE MR imaging. For example, by decreasing the number or size of the partitions and/or the matrix size, one can substantially reduce breath-hold times—often at the expense of spatial resolution and craniocaudal coverage, however. In another approach, one incorporates recently introduced parallel acquisition techniques that involve the use of the spatial information contained in the sensitivity profiles of multiple elements of a receive coil (4,6–8). With parallel imaging, the k-space is systematically undersampled while data are acquired with all coil elements in parallel. This enables a reduction in the number of spatial-encoding steps and thus a shorter MR image acquisition time while preserving the spatial resolution of the MR image. Henceforth, this imaging technique is referred to as parallel GRE MR imaging.

Investigators in a relatively recent study (4) demonstrated the feasibility of parallel GRE MR imaging for clinical imaging of the liver, including depiction of the portal and hepatic veins, in 20 patients. The authors concluded that parallel GRE MR imaging may be particularly beneficial in patients with limited breath-hold capability, shortening the imaging times compared with the imaging times required for standard GRE MR imaging. However, to our knowledge, in no previous study have investigators evaluated the diagnostic accuracy of dynamic parallel GRE MR imaging, as compared with a reference standard, for comprehensive hepatic vascular mapping, including evaluation of the hepatic arteries and the portal and hepatic veins. Thus, the purpose of our study was to retrospectively evaluate the feasibility, reliability, and accuracy of breath-hold dynamic contrast-enhanced parallel GRE MR imaging for mapping of the hepatic vascular anatomy, with contrast-enhanced 64-detector row computed tomography (CT) as the noninvasive reference standard.

**Materials and Methods**

**Patients**

This study was approved by the institutional review board of University Hospital Zurich. Informed consent was obtained from all patients. We cross-referenced our institutional medical database with our imaging database to identify all patients who from September 2004 through December 2005 underwent both dynamic parallel GRE MR imaging of the liver and contrast-enhanced dual-phase 64-detector row CT of the abdomen within a 90-day period (mean, 37 days; median, 32 days; range, 2–89 days). One hundred seventy-five patients underwent MR imaging of the liver. One hundred twenty-one of these patients also underwent contrast-enhanced dual-phase 64-detector row CT of the abdomen. Twenty-one patients were excluded because informed consent could not be obtained owing to the following reasons: Ten (48%) patients died, six (29%) did not want to provide written informed consent, and five (24%) could not be contacted owing to a change of address. Thus, the data of 100 patients—58 men with a mean age of 56 years (range, 27–80 years) and 42 women with a mean age of 53 years (range, 26–77 years)—were included in this study (Fig 1). In five (5%) of the 100

---

**Advances in Knowledge**

- Dynamic contrast-enhanced gradient-echo (GRE) MR imaging of the hepatic vasculature accelerated by a parallel acquisition technique is feasible, with good to excellent overall image quality for depiction of the hepatic arteries and the portal and hepatic veins.
- Parallel GRE MR imaging, as compared with 64-detector row CT as the reference standard, enables reliable and accurate detection of anatomic variants of the hepatic arteries and the portal and hepatic veins, as well as reliable and accurate diagnosis of arterial stenosis.

---

**Implication for Patient Care**

- Parallel gradient-echo MR imaging enables mapping of the hepatic vascular anatomy within breath-hold times shorter than 20 seconds.

---

**Abbreviations:**

- CI = confidence interval
- CNR = contrast-to-noise ratio
- GRE = gradient echo
- MPV = main portal vein
- SNR = signal-to-noise ratio

**Author contributions:**

Guarantors of integrity of entire study, C.H., J.K.W.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; manuscript final version approval, all authors; literature research, C.H., J.K.W.; clinical studies, C.H., A.M.L., J.K.W.; statistical analysis, B.S., J.K.W.; and manuscript editing, C.H., A.M.L., J.K.W.

Authors stated no financial relationship to disclose.
patients, a minor contrast material reaction (rash) was documented after multi-detector row CT. No contrast material reaction was noted after MR imaging. Multi-detector row CT was performed before MR imaging in 73 (73%) of the 100 patients.

Liver cirrhosis was present in 65 (65%) of the 100 patients. The underlying cause of the liver cirrhosis was alcohol abuse in 21 (32%) of these 65 patients, chronic hepatitis C infection in 20 (31%), hepatitis B in 12 (18%), a combination of alcohol abuse and chronic hepatitis C infection in nine (14%), hemochromatosis in two (3%), and primary biliary cirrhosis in one (2%). Liver cirrhosis was histologically confirmed in all patients. Cirrhosis was clinically classified as Child-Pugh class A in three (5%) of the 65 patients, Child-Pugh class B in 29 (45%), and Child-Pugh class C in 33 (51%). The following focal liver lesions were diagnosed in the patients: hepatocellular carcinoma in 42, metastasis in 18, hemangioma in 14, and hilar cholangiocarcinoma in three. Five (5%) of the 100 patients underwent orthotopic liver transplantation before their inclusion in the study.

MR Imaging

In all patients, MR imaging was performed by using a 1.5-T MR system (Signa Excite HD; GE Healthcare, Milwaukee, Wis) equipped with high-performance gradients: an amplitude of 33 mT/m and a slew rate of 120 mT/(m s msec). For signal reception, an anteroposterior eight-element phased-array surface coil covering the entire liver was placed around the patient. Before imaging, a 20–22-gauge intravenous catheter was placed in an antecubital vein and was attached to an MR-compatible power injector (Spectris; Medrad, Indianola, Pa). All patients were positioned supine and feet first on the imaging table.

For dynamic MR imaging, a parallel three-dimensional spoiled GRE sequence (LAVA [Liver Acquisition with Volume Acceleration], version 12.0M4; GE Healthcare) was performed in the transverse plane by using the following parameters: 3.1/1.4 (repetition time msec/echo time msec), a 15° excitation angle, a receiver bandwidth of ±83.3 kHz, a nominal measured voxel dimension of 1.5 × 1.5 × 4.0 mm in acquisition along the frequency-encoding times phase-encoding times section-encoding direction, an interpolated reconstructed voxel dimension of 0.75 × 0.75 × 2.0 mm, a fat suppression inversion-recovery time of 7.0 msec, 35–55 sections (depending on the patient size), 0.73 signal acquired and a nominal acquisition matrix of 384 × 224. Half-Fourier techniques were applied along the frequency-encoding and phase-encoding directions, and a linear phase-encoded ordering scheme was used. The parallel three-dimensional spoiled GRE sequence facilitated acceleration by a factor of two by reducing the number of phase-encoding steps acquired along the anteroposterior direction. The coil sensitivity profiles required for the sensitivity-encoding image reconstruction (9) were derived from a separate single-breath-hold calibration acquisition that preceded dynamic parallel MR imaging. The repeated application of frequency-selective fat magnetization inversion pulses during the imaging sequence induced repeated zero crossings of the fat signal. The flip angle was optimized so that one such zero crossing temporally coincided with the acquisition of the center of k-space, optimizing the fat signal suppression.

Gadobutrol (Gadovist; Schering, Berlin, Germany) was injected intravenously at a dose of 0.1 mmol per kilogram of body weight and at a flow rate of 2 mL/sec, and parallel GRE MR imaging was timed to capture the arterial, portal venous (60 seconds after gadobutrol administration), and equilibrium (240 seconds after gadobutrol administration) phases (2,10). To determine the optimal delay time for the arterial phase in each patient, a test bolus of 1 mL of gadobutrol was administered and the time required for the bolus to reach the celiac trunk was measured by using a multiphase sagittal single-section GRE sequence (5/1, 60° flip angle). After the contrast material bolus, a 20-mL saline flush was administered at the same flow rate. The mean time for acquisition of the parallel GRE MR data sets obtained during each contrast enhancement phase was 16 seconds (range, 15–17 seconds). All parallel GRE MR examinations were performed during a breath hold at the end of inspiration.

64-Detector Row CT

In all 100 patients, multi-detector row CT images of the abdomen were obtained by using a 64-detector row CT scanner (Sensation 64; Siemens, Forchheim, Germany). All patients underwent dual-phase multi-detector row CT of the abdomen during the arterial and portal venous phases of contrast enhancement.

Before scanning, a 20–22-gauge catheter was placed in an antecubital vein and was attached to an automated in-
A bolus-tracking technique (CARE-Bolus; Sensation Navigator, Siemens) was used to define the optimal time delay after administration of the contrast medium that would facilitate optimal intraluminal contrast enhancement during the arterial phase. This technique involved a single nonenhanced low-dose (10-mAs) examination at the level of the celiac trunk, where a 15–20-mm² region of interest had been placed by a technologist. The region of interest served as a reference for the dynamic measurements of contrast enhancement. Subsequently, 120 mL of nonionic iodinated contrast medium (iodixanol, Visipaque; Amersham Health, Buckinghamshire, England) (270 mg of iodine per milliliter) was administered at a flow rate of 4 mL/sec and followed by a 20-mL saline flush that was injected at the same flow rate. Ten seconds after the start of the contrast medium injection, repetitive low-dose monitoring CT examinations (120 kV, 10 mAs, 0.5-second scanning

### Table 1

<table>
<thead>
<tr>
<th>Vessel</th>
<th>SNR</th>
<th>CNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arteries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrarenal aorta</td>
<td>94.6 ± 35.2</td>
<td>78.9 ± 33.4</td>
</tr>
<tr>
<td>Celiac trunk</td>
<td>77.9 ± 35.0</td>
<td>61.6 ± 33.3</td>
</tr>
<tr>
<td>Splenic artery</td>
<td>73.5 ± 31.2</td>
<td>65.4 ± 23.8</td>
</tr>
<tr>
<td>Left gastric artery</td>
<td>54.2 ± 24.7</td>
<td>41.9 ± 20.3</td>
</tr>
<tr>
<td>Common hepatic artery</td>
<td>68.7 ± 26.5</td>
<td>53.1 ± 25.4</td>
</tr>
<tr>
<td>Gastroduodenal artery</td>
<td>57.7 ± 29.8</td>
<td>39.4 ± 20.1</td>
</tr>
<tr>
<td>Proper hepatic artery</td>
<td>63.4 ± 22.2</td>
<td>53.6 ± 20.9</td>
</tr>
<tr>
<td>Right hepatic artery</td>
<td>57.2 ± 23.3</td>
<td>47.8 ± 22.8</td>
</tr>
<tr>
<td>Left hepatic artery</td>
<td>56.2 ± 19.7</td>
<td>46.3 ± 32.8</td>
</tr>
<tr>
<td>Superior mesenteric artery</td>
<td>80.7 ± 30.5</td>
<td>71.1 ± 32.9</td>
</tr>
<tr>
<td>All arteries</td>
<td>68.4 ± 27.8</td>
<td>55.9 ± 26.6</td>
</tr>
<tr>
<td>Portal veins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPV</td>
<td>58.6 ± 51.4</td>
<td>43.7 ± 28.0</td>
</tr>
<tr>
<td>Right portal vein</td>
<td>55.1 ± 51.0</td>
<td>43.4 ± 20.9</td>
</tr>
<tr>
<td>Left portal vein</td>
<td>53.0 ± 51.9</td>
<td>42.3 ± 16.7</td>
</tr>
<tr>
<td>All portal veins</td>
<td>55.6 ± 51.4</td>
<td>43.1 ± 21.9</td>
</tr>
<tr>
<td>Hepatic veins</td>
<td>50.3 ± 44.3</td>
<td>43.8 ± 16.7</td>
</tr>
</tbody>
</table>

Note.—Numbers are mean values ± standard deviations for 100 patients.

### Table 2

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Image Quality Grade</th>
<th>Reader 1</th>
<th>Reader 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Arteries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrarenal aorta</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Celiac trunk</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Splenic artery</td>
<td>0</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>Left gastric artery</td>
<td>0</td>
<td>1</td>
<td>29</td>
</tr>
<tr>
<td>Common hepatic artery</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Gastroduodenal artery</td>
<td>7</td>
<td>12</td>
<td>35</td>
</tr>
<tr>
<td>Proper hepatic artery</td>
<td>4</td>
<td>12</td>
<td>43</td>
</tr>
<tr>
<td>Right hepatic artery</td>
<td>5</td>
<td>22</td>
<td>36</td>
</tr>
<tr>
<td>Left hepatic artery</td>
<td>5</td>
<td>21</td>
<td>41</td>
</tr>
<tr>
<td>Superior mesenteric artery</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>68</td>
<td>223</td>
</tr>
<tr>
<td>Portal veins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPV</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Right portal vein</td>
<td>0</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Left portal vein</td>
<td>0</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>0</td>
<td>36</td>
</tr>
<tr>
<td>Hepatic veins</td>
<td>0</td>
<td>4</td>
<td>25</td>
</tr>
</tbody>
</table>

Note.—Data are numbers of vessels, in a total of 100 patients. Grade 1 = poor visibility (nondiagnostic image quality, low signal intensity, and severe blurring artifacts). Grade 2 = moderate visibility (low signal intensity and moderate blurring artifacts). Grade 3 = good visibility (high signal intensity and slight blurring artifacts). Grade 4 = excellent visibility (high signal intensity and no blurring artifacts).
time, 1-second interscan delay) were performed until the preset contrast enhancement level of 120 HU was reached. This resulted in the automatic initiation of the first multi-detector row CT examination, 2 seconds after the preset level was reached. After the first examination, a second multi-detector row CT examination was performed during the portal venous phase (60 seconds after the start of the contrast medium injection).

The scanning settings for the arterial and portal venous phases were as follows: a section thickness of 0.6 mm, a table feed of 46 mm per rotation, and a gantry rotation time of 0.5 second (pitch, 1.2). The x-ray tube voltage setting was 120 kV at a mean tube current of 150 mA. Transverse section reconstructions were performed by using a nominal section thickness of 1.0 mm at an interval of 0.4 mm for both contrast enhancement phases (11,12). The reconstruction field of view was set according to the patient’s size and ranged from 25 to 45 cm at a matrix size of 512 × 512.

Quantitative Analysis of MR Imaging

Quantitative and qualitative analyses of the images were performed at an interactive workstation (Advantage Windows Workstation 4.2; GE Healthcare, Buc, France). For quantitative analysis, one author (C.H., 3 years experience in abdominal MR imaging) who was blinded to all clinical data but was aware of the purpose of the study performed signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) measurements in all 100 patients. SNR and CNR were measured in the following 14 vessels: infrarenal aorta, celiac trunk, splenic artery, left gastric artery, common hepatic artery, proper hepatic artery, left and right hepatic arteries, gastroduodenal artery, superior mesenteric artery, main portal vein (MPV), left portal vein, right portal vein, and the largest of the three hepatic veins (ie, right, middle, or left hepatic vein). Regions of interest were placed in the respective vessel in the adjacent liver parenchyma or the retroperitoneal fat tissue, and in an image region in the air adjacent to the body within the coil. The regions of interest were drawn such that they covered the maximal area of each vessel (mean, 39 mm²; range, 8–102 mm²). In the hepatic veins, the regions of interest were placed 1 cm proximal to the inferior vena cava. SNR and CNR were calculated as follows: SNR = SIv/SDb, where SIv is the mean signal intensity in the vessel and SDb is the standard deviation of the mean signal intensity of the magnitude background outside the body within the coil (air). CNR = (SIv – SIb,f)/SDb, where SIb,f is the mean signal intensity in the adjacent liver parenchyma or retroperitoneal fat tissue.

Figure 2

(a) On image from parallel GRE MR data set (3.1/1.4), both readers noted branching of the common hepatic artery (large arrow in a and b) directly from the abdominal aorta. This represents a type XI variant (any arterial variant not included in Michels types I–X). Both readers graded the image quality for the common hepatic artery and the splenic artery (small arrow in a and b) as excellent (grade 4: high signal intensity, no blurring artifacts). (b) The type XI variant hepatic artery anatomy was confirmed on the corresponding image from the 64-detector row CT angiography data set.

Figure 3

(a) On image from parallel GRE MR data set (3.1/1.4), both readers noted trifurcation of the MPV (large arrow in a and b) into the left portal vein (small arrow in a and b) and into the right anterior (large arrowhead in a and b) and right posterior (small arrowhead in a and b) branches. The image quality for the MPV and its branches was graded as excellent by both readers. (b) The presence of portal vein trifurcation was confirmed on the corresponding image from the 64-detector row CT data set. Note the bilateral posterior transpedicular screw fixation in the thoracic vertebra.
**Qualitative Analysis of MR Data**

**Subjective image quality.**—Two radiologists (J.K.W. [reader 1] and C.H. [reader 2], 7 and 3 years experience in abdominal MR imaging, respectively) in independent readings rated the subjective MR image quality for depiction of the 14 vessels assessed in all 100 patients. Both readers were blinded to all clinical data, and the patient cases were assessed in random order. Neither reader was blinded to the purpose of the study. The image quality for each vessel was graded by using a four-point Likert scale: Grade 1 indicated poor visibility (nondiagnostic image quality, low signal intensity, and severe blurring artifacts); grade 2, moderate visibility (low signal intensity and moderate blurring artifacts); grade 3, good visibility (high signal intensity and slight blurring artifacts); and grade 4, excellent visibility (high signal intensity and no blurring artifacts).

**Variant hepatic vasculature.**—The two readers independently assessed the dynamic parallel GRE MR images for the presence of surgically important anatomic variants of the hepatic vasculature. Both readers were blinded to the multi–detector row CT results, and patient cases were presented in random order. The readers were allowed to adjust the window centers and level settings to their individual preferences and to use transverse or oblique maximum intensity projections of the MR data set if these were considered beneficial. A cine mode was available for rapid interactive interpretation. Both readers were asked to classify the hepatic artery anatomy into one of 10 categories according to the Michels classification system or into an 11th category that included other variants not included in the Michels classification (13).

Standard portal vein anatomy was considered a bifurcation of the MPV into the right and left portal veins, with the left portal vein branching from the MPV more proximally than the right portal vein and with the right portal vein splitting into the right anterior and right posterior branches. A trifurcation of the MPV or a right portal vein branching from the MPV more proximally than the left portal vein was considered an anatomic variant (14–16).

Three hepatic veins with the common hepatic trunk of the main and left hepatic veins draining into the inferior vena cava and a single right hepatic vein draining into the inferior vena cava were considered the standard anatomy of the hepatic veins. Special attention was given to the presence of large (>3 mm) accessory right hepatic veins draining liver segments V–VIII directly into either the inferior vena cava or the main hepatic vein and to the presence of supernumerary left hepatic veins (1,16,17). Moreover, the presence of separate drainage of the main and left hepatic veins into the inferior vena cava was noted.

**Arterial stenosis and portal venous thrombosis.**—Both readers (J.K.W., C.H.) were asked to independently note the presence of arterial stenosis in all arteries being evaluated. For this purpose, each reader was allowed to adjust the window centers and level settings to his or her preference and to use transverse or oblique maximum intensity projections of the MR data set. Grading of arterial stenosis was performed with an electronic caliper by using a four-point Likert scale: Grade 1 meant normal vessel or mild vessel irregularities (<10% luminal narrowing); grade 2, moderate arterial stenosis (10%–49% luminal narrowing); grade 3, severe arterial stenosis (50%–99% luminal narrowing); and grade 4, occlusion. Grade 3 or 4 arterial stenosis was considered hemodynamically significant (18). In addition, readers 1 and 2 independently noted the presence of a thrombus in the MPV, right portal vein, or left portal vein.

**Analysis of Multi–Detector Row CT Data**

A consensus panel that consisted of two readers (R.S., A.M.L.) evaluated all multi–detector row CT images on the basis of the transverse multi–detector row CT source data available at the interactive workstation (Advantage Windows Workstation 4.2). The readers were allowed to adjust the window centers and level settings to their individual preferences and to make use of transverse or oblique maximum intensity projections of the multi–detector row CT data sets if these were considered useful. Both readers were blinded to all clinical data and MR imaging results. Assessment of variant hepatic vasculature, grading of arterial stenosis, and detection of portal venous thrombosis were performed by using the same classification scheme used to evaluate the parallel GRE MR data.

**Statistical Analyses**

SNR and CNR are reported as mean values ± standard deviations. To assess interobserver agreement between readers 1 and 2 for detection of variant hepatic vasculature and arterial stenosis, κ values and corresponding 95% confidence intervals (CIs) were determined: A κ value of 0 indicated poor agreement; 0.01–0.20, slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, good agreement; and 0.81–1.00, excellent agreement (19).

The sensitivity, specificity, positive predictive value, negative predictive value, and accuracy (and corresponding 95% CIs) of parallel GRE MR imaging, as compared with multi–detector row CT, for the detection of hepatic arterial, portal venous, and hepatic venous variants and hemodynamically significant hepatic arterial stenosis were calculated for each reader. Since there was a maximum of one hemodynamically signifi-
Discussion

In our study, overall image quality for depiction of most of the hepatic vessels was rated as high with use of the parallel GRE MR technique described. All portal and hepatic veins were visible for diagnostic purposes, and both readers considered image quality to be nondiagnostic in only 2.1% of the hepatic arteries. The good to excellent image quality for depiction of most of the hepatic vessels in our study was mirrored by relatively high mean SNRs and CNRs. The values in our study are comparable to or even higher than those reported for GRE MR imaging with use of the same definitions for calculations of SNR and CNR (3,20). However, because noise is not spatially uniform on images obtained by using parallel imaging reconstruction, comparisons with the SNRs and CNRs derived in other studies may have reduced value. Compared with conventional MR imaging, parallel imaging generally is limited owing to decreased SNR and CNR. These decreases are inversely proportional to the square root of the acceleration factor. For an acceleration factor of two, the SNR in parallel imaging has been estimated to be reduced by about 30%–35% compared with the SNR in conventional MR imaging (6,9,21,22).

Several factors could have contributed to the high SNRs and CNRs in our study. The eight-element phased-array coil facilitated arterial stenosis in all patients, permitting analysis of arterial stenosis in all patients. The mapping of hepatic vascular anatomy involved comparison of parallel GRE MR images in two (2%) of the 100 patients; the thrombus was confirmed at multi-detector row CT.

Table 3

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variant Hepatic Artery Anatomy</th>
<th>Variant Portal Vein Anatomy</th>
<th>Variant Hepatic Vein Anatomy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reader 1</td>
<td>Reader 2</td>
<td>Reader 1</td>
</tr>
<tr>
<td>No. of true-positive findings</td>
<td>23</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>No. of true-negative findings</td>
<td>75</td>
<td>77</td>
<td>82</td>
</tr>
<tr>
<td>No. of false-positive findings</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No. of false-negative findings</td>
<td>2</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Sensitivity (%)*</td>
<td>92 (74, 99)</td>
<td>80 (59, 93)</td>
<td>100 (83, 100)</td>
</tr>
<tr>
<td>Specificity (%)*</td>
<td>100 (95, 100)</td>
<td>100 (95, 100)</td>
<td>100 (96, 100)</td>
</tr>
<tr>
<td>Positive predictive value (%)*</td>
<td>100 (85, 100)</td>
<td>100 (83, 100)</td>
<td>100 (83, 100)</td>
</tr>
<tr>
<td>Negative predictive value (%)*</td>
<td>97 (91, 100)</td>
<td>94 (86, 98)</td>
<td>100 (96, 100)</td>
</tr>
<tr>
<td>Accuracy (%)*</td>
<td>98 (83, 100)</td>
<td>95 (89, 98)</td>
<td>100 (96, 100)</td>
</tr>
</tbody>
</table>

* Numbers in parentheses are 95% CIs.

Table 3 presents the reader assessment of parallel GRE MR imaging, as compared with 64-detector row CT, for detection of anatomic variants of hepatic arteries and portal and hepatic veins in 100 patients. The eight-element phased-array coil facilitated arterial stenosis in all patients, permitting analysis of arterial stenosis in all patients. The mapping of hepatic vascular anatomy involved comparison of parallel GRE MR images in two (2%) of the 100 patients; the thrombus was confirmed at multi-detector row CT.


cant arterial stenosis in all patients, per-patient analysis was performed.

Results

In terms of quantitative image analysis, mean SNRs ranged between 50.3 and 94.6 and mean CNRs ranged between 39.4 and 78.9 (Table 1).

Qualitative Analysis of Image Quality

Readers 1 and 2 graded the image quality as good or excellent for 91.1% and 91.3% of the hepatic arteries, respectively, and for 100% of the portal veins (Table 2, Figs 2–4). Image quality was graded as good or excellent for 96% of the hepatic veins by reader 1 and for 97% of the hepatic veins by reader 2. Both readers reported nondiagnostic image quality for 21 (2.1%) of the 1000 arteries, which included the gastroduodenal arteries and the proper, right, and left hepatic arteries. Both readers graded the image quality for all portal and hepatic veins as diagnostic.

Qualitative Analysis of Variant Hepatic Vasculature

There was excellent agreement between readers 1 and 2 (κ = 0.95; 95% CI: 0.83, 1.00) in the detection of all hepatic artery variants (Fig 2, Table E1; http://radiology.rsna.org/cgi/content/full/2453062103/DC1). Both readers identified a portal vein trifurcation in 10 (10%) of the 100 patients (Fig 3) and early branching of the right portal vein in nine (9%) (κ = 1.00; 95% CI: 0.88, 1.00). There was excellent agreement between the two readers in the identification of all variant hepatic veins as well (κ = 0.98; 95% CI: 0.78, 1.00) (Fig 4). The accuracy of parallel GRE MR imaging in the identification of variant hepatic vasculature reached 95% (95% CI: 89%, 98%) or higher for both readers (Table 3).

Qualitative Analysis of Arterial Stenosis and Portal Venous Thrombosis

Overall, there was excellent agreement between readers 1 and 2 in the detection of arterial stenosis (κ = 0.98; 95% CI: 0.82, 1.00) (Table E2, http://radiology.rsna.org/cgi/content/full/2453062103/DC1). Hemodynamically significant arterial stenosis was present in the celiac trunk and superior mesenteric artery. The accuracy of parallel GRE MR imaging, as compared with multi–detector row CT, in the diagnosis of hemodynamically significant arterial stenosis was 97% (95% CI: 91%, 99%) for reader 1 and 94% (95% CI: 87%, 98%) for reader 2 (Table 4). Both readers identified thrombosis in the MPV on the parallel GRE MR images in two (2%) of the 100 patients; the thrombus was confirmed at multi–detector row CT. There was no thrombus that was not depicted at parallel GRE MR imaging.

In our study, overall image quality for depiction of most of the hepatic vessels was rated as high with use of the parallel GRE MR technique described. All portal and hepatic veins were visible for diagnostic purposes, and both readers considered image quality to be nondiagnostic in only 2.1% of the hepatic arteries. The good to excellent image quality for depiction of most of the hepatic vessels in our study was mirrored by relatively high mean SNRs and CNRs. The values in our study are comparable to or even higher than those reported for GRE MR imaging with use of the same definitions for calculations of SNR and CNR (3,20). However, because noise is not spatially uniform on images obtained by using parallel imaging reconstruction, comparisons with the SNRs and CNRs derived in other studies may have reduced value. Compared with conventional MR imaging, parallel imaging generally is limited owing to decreased SNR and CNR. These decreases are inversely proportional to the square root of the acceleration factor. For an acceleration factor of two, the SNR in parallel imaging has been estimated to be reduced by about 30%–35% compared with the SNR in conventional MR imaging (6,9,21,22). Several factors could have contributed to the high SNRs and CNRs in our study. The eight-element phased-ar-
Ray surface coil used contained integrated preamplifiers for signal amplification as close as possible to signal generation, before additional noise is picked up. In addition, the geometric arrangement of the coil elements was optimized to keep the noise-enhancing geometry factor—which is used to determine the local noise variations in parallel imaging—as low as possible throughout the imaging volume. Furthermore, we used a 1 mol/L gadolinium chelate as the intravenous contrast agent, which has been shown to improve the SNR and CNR in vascular imaging (23).

The overall good to excellent image quality for depiction of the hepatic vessels in our study also translated into high sensitivities and specificities for parallel GRE MR imaging in hepatic vascular mapping. Hepatic artery variants were detected by readers 1 and 2 with sensitivities of 92% and 80%, respectively, and with a specificity of 100%. Portal vein variants were diagnosed with sensitivities and specificities of 100%. Hepatic vein variants were diagnosed by readers 1 and 2 with sensitivities of 98% and 99%, respectively, and with specificities of 95% and 92%, respectively. The performance of parallel GRE MR imaging in our study was comparable to the performance of conventional GRE MR imaging in hepatic vascular mapping in previous studies (5,24). In one study, both the sensitivity and the specificity of conventional GRE MR imaging, as compared with digital subtraction angiography, were 100% for the detection of hepatic artery variants in 23 patients (3). In another study, digital subtraction angiography findings confirmed the findings of conventional GRE MR imaging of the hepatic artery anatomy in 12 (92%) of 13 patients (24). In the same study, the preoperative findings of conventional GRE MR imaging of the normal portal vein anatomy and normal right hepatic vein anatomy in nine living liver donor candidates were confirmed at surgery.

The use of a parallel GRE MR sequence in clinical practice may be a further step toward a simplified preoperative “all-in-one” work-up of liver surgery candidates (23). In addition to liver parenchymal imaging, parallel GRE MR imaging enables accurate preoperative mapping of the hepatic vasculature for dedicated evaluation of the hepatic vessels—without the need for additional imaging such as multi-detector row CT or catheter-based angiography. Apart from concerns regarding radiation exposure, a major advantage of MR imaging, as compared with multi-detector row CT or catheter-based angiography, is the smaller risk of renal function impairment or anaphylactic reactions following contrast medium administration. This may be advantageous, particularly in patients in whom repetitive follow-up examinations of the liver are indicated.

Our study had limitations: The retrospective design and the need for retrospective informed consent for inclusion of the patients’ data may have led to selection bias in favor of patients in better health who were able to give informed consent at the time of the study. Therefore, patients in poor health, including those with dyspnea or tachypnea, may have been systematically excluded from the study, and this may have led to results that were falsely in favor of parallel GRE MR imaging. In addition, since the retrospective design did not allow a systematic comparison of the image quality and accuracy of parallel GRE MR imaging between the patients with and those without compromised respiratory function, the true improvements in clinical imaging achieved with parallel GRE MR imaging and the shorter acquisition times in patients who have difficulty holding their breath cannot be quantified by using the results of our study. A prospective study with large numbers of patients with and patients without compromised respiratory function is needed to overcome this limitation.

The overall low prevalence of hemodynamically significant arterial stenosis, which was present in the celiac trunk and superior mesenteric artery only, may have limited the statistics calculated for the detection of arterial stenosis on parallel GRE MR images. In addition, the results of parallel GRE MR imaging for mapping the hepatic vasculature were not compared with intraoperative findings or digital subtraction angiography findings, which are established reference standards. Multi-detector row CT may not be a perfect reference standard for this purpose. However, in a growing body of studies, multi-detector row CT, with its high spatial resolution, is being recommended as a noninvasive imaging modality for hepatic vasculature mapping (12,25–27).

In conclusion, our study findings demonstrate that three-dimensional GRE MR imaging accelerated by a parallel acquisition technique is feasible and reliable for hepatic vascular mapping. Compared with 64–detector row CT as the noninvasive reference standard, parallel GRE MR imaging enables accurate mapping of the hepatic vascular anatomy.

Table 4

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reader 1</th>
<th>Reader 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of true-positive findings</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>No. of true-negative findings</td>
<td>87</td>
<td>85</td>
</tr>
<tr>
<td>No. of false-positive findings</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>No. of false-negative findings</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Sensitivity (%)*</td>
<td>100 (70, 100)</td>
<td>90 (56, 100)</td>
</tr>
<tr>
<td>Specificity (%)*</td>
<td>97 (91, 99)</td>
<td>94 (88, 98)</td>
</tr>
<tr>
<td>Positive predictive value (%)*</td>
<td>77 (46, 96)</td>
<td>64 (35, 88)</td>
</tr>
<tr>
<td>Negative predictive value (%)*</td>
<td>100 (96, 100)</td>
<td>99 (94, 100)</td>
</tr>
<tr>
<td>Accuracy (%)*</td>
<td>97 (91, 99)</td>
<td>94 (87, 98)</td>
</tr>
</tbody>
</table>

* Numbers in parentheses are 95% CIs.
References


# Radiology 2007

This is your reprint order form or pro forma invoice

(Please keep a copy of this document for your records.)

---

Reprint order forms and purchase orders or prepayments must be received 72 hours after receipt of form either by mail or by fax at 410-820-9765. It is the policy of Cadmus Reprints to issue one invoice per order. Please print clearly.

---

### Author Information

- **Author Name**: ___________________________________________________________________________________________
- **Title of Article**: __________________________________________________________________________________________
- **Issue of Journal**: ___________________________ Reprint # _____________ Publication Date ________________
- **Number of Pages**: ___________________________  
  **KB #**: _____________  
  Symbol: Radiology
- **Color in Article?**: Yes / No (Please Circle)

Please include the journal name and reprint number or manuscript number on your purchase order or other correspondence.

### Order and Shipping Information

**Reprint Costs** (Please see page 2 of 2 for reprint costs/fees.)

- _______ Number of reprints ordered $_________
- _______ Number of color reprints ordered $_________
- _______ Number of covers ordered $_________
  **Subtotal** $_________
- Taxes $_________

*(Add appropriate sales tax for Virginia, Maryland, Pennsylvania, and the District of Columbia or Canadian GST to the reprints if your order is to be shipped to these locations.)*

**Shipping Address** (cannot ship to a P.O. Box) Please Print Clearly

- **Name**: ___________________________________________________________________________________________
- **Institution**: ___________________________________________________________________________________________
- **Street**: ___________________________________________________________________________________________
- **City**: ____________________ State _____ Zip ___________
- **Country**: __________________________ _________________
- **Quantity**: _____________  
  **Fax**: __________________________ _________________
  **Phone**: Day ________________ Evening ________________
  **E-mail Address**: __________________________ _________________

**Additional Shipping Address** (cannot ship to a P.O. Box)

- **Name**: ___________________________________________________________________________________________
- **Institution**: ___________________________________________________________________________________________
- **Street**: ___________________________________________________________________________________________
- **City**: ____________________ State _____ Zip ___________
- **Country**: __________________________ _________________
- **Quantity**: _____________  
  **Fax**: __________________________ _________________
  **Phone**: Day ________________ Evening ________________
  **E-mail Address**: __________________________ _________________

* Add $32 for each additional shipping address

### Payment and Credit Card Details

**Enclosed**: Personal Check ________  
Credit Card Payment Details ________

Checks must be paid in U.S. dollars and drawn on a U.S. Bank.

- Credit Card: __ VISA  __ Am. Exp.  __ MasterCard  
- Card Number ______________________________________
- Expiration Date ____________________________________
- Signature: _______________________________________

Please send your order form and prepayment made payable to:

**Cadmus Reprints**  
P.O. Box 751903  
Charlotte, NC  28275-1903

*Note: Do not send express packages to this location, PO Box.*

**FEIN #:**541274108

---

**Invoice or Credit Card Information**

**Invoice Address** Please Print Clearly

Please complete Invoice address as it appears on credit card statement

- **Name**: ___________________________________________________________________________________________
- **Institution**: ___________________________________________________________________________________________
- **Department**: ___________________________________________________________________________________________
- **Street**: ___________________________________________________________________________________________
- **City**: ____________________ State _____ Zip ___________
- **Country**: __________________________ _________________
- **Phone**: _____________  
  **Fax**: ________  
  **E-mail Address**: _____________

Cadmus will process credit cards and **Cadmus Journal Services** will appear on the credit card statement.

*If you don’t mail your order form, you may fax it to 410-820-9765 with your credit card information.*

---

Signature ___________________________ Date ___________________________

Signature is required. By signing this form, the author agrees to accept the responsibility for the payment of reprints and/or all charges described in this document.
**Black and White Reprint Prices**

<table>
<thead>
<tr>
<th># of Pages</th>
<th>Domestic (USA only)</th>
<th>International (includes Canada and Mexico)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>1-4</td>
<td>$213</td>
<td>$228</td>
</tr>
<tr>
<td>5-8</td>
<td>$338</td>
<td>$373</td>
</tr>
<tr>
<td>9-12</td>
<td>$450</td>
<td>$500</td>
</tr>
<tr>
<td>13-16</td>
<td>$555</td>
<td>$623</td>
</tr>
<tr>
<td>17-20</td>
<td>$673</td>
<td>$753</td>
</tr>
<tr>
<td>21-24</td>
<td>$785</td>
<td>$880</td>
</tr>
<tr>
<td>25-28</td>
<td>$895</td>
<td>$1,010</td>
</tr>
<tr>
<td>29-32</td>
<td>$1,008</td>
<td>$1,143</td>
</tr>
<tr>
<td>Covers</td>
<td>$95</td>
<td>$118</td>
</tr>
</tbody>
</table>

Minimum order is 50 copies. For orders larger than 500 copies, please consult Cadmus Reprints at 800-407-9190.

**Reprint Cover**
Cover prices are listed above. The cover will include the publication title, article title, and author name in black.

**Shipping**
Shipping costs are included in the reprint prices. Domestic orders are shipped via UPS Ground service. Foreign orders are shipped via a proof of delivery air service.

**Multiple Shipments**
Orders can be shipped to more than one location. Please be aware that it will cost $32 for each additional location.

**Delivery**
Your order will be shipped within 2 weeks of the journal print date. Allow extra time for delivery.

**Color Reprint Prices**

<table>
<thead>
<tr>
<th># of Pages</th>
<th>Domestic (USA only)</th>
<th>International (includes Canada and Mexico)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>1-4</td>
<td>$218</td>
<td>$233</td>
</tr>
<tr>
<td>5-8</td>
<td>$343</td>
<td>$388</td>
</tr>
<tr>
<td>9-12</td>
<td>$471</td>
<td>$503</td>
</tr>
<tr>
<td>13-16</td>
<td>$601</td>
<td>$633</td>
</tr>
<tr>
<td>17-20</td>
<td>$738</td>
<td>$767</td>
</tr>
<tr>
<td>21-24</td>
<td>$872</td>
<td>$899</td>
</tr>
<tr>
<td>25-28</td>
<td>$1,004</td>
<td>$1,035</td>
</tr>
<tr>
<td>29-32</td>
<td>$1,140</td>
<td>$1,173</td>
</tr>
<tr>
<td>Covers</td>
<td>$95</td>
<td>$118</td>
</tr>
</tbody>
</table>

Minimum order is 50 copies. For orders larger than 500 copies, please consult Cadmus Reprints at 800-407-9190.

**Reprint Cover**
Cover prices are listed above. The cover will include the publication title, article title, and author name in black.

**Shipping**
Shipping costs are included in the reprint prices. Domestic orders are shipped via UPS Ground service. Foreign orders are shipped via a proof of delivery air service.

**Multiple Shipments**
Orders can be shipped to more than one location. Please be aware that it will cost $32 for each additional location.

**Delivery**
Your order will be shipped within 2 weeks of the journal print date. Allow extra time for delivery.

**Tax Due**
Residents of Virginia, Maryland, Pennsylvania, and the District of Columbia are required to add the appropriate sales tax to each reprint order. For orders shipped to Canada, please add 7% Canadian GST unless exemption is claimed.

**Ordering**
Reprint order forms and purchase order or prepayment is required to process your order. Please reference journal name and reprint number or manuscript number on any correspondence. You may use the reverse side of this form as a proforma invoice. Please return your order form and prepayment to:

**Cadmus Reprints**
P.O. Box 751903  
Charlotte, NC  28275-1903

**Note:** Do not send express packages to this location, PO Box.
**FEIN #: 541274108**

Please direct all inquiries to:

**Rose A. Baynard**
800-407-9190 (toll free number)  
410-819-3966 (direct number)  
410-820-9765 (FAX number)  
baynardr@cadmus.com (e-mail)