Hepatic Imaging with Multidetector CT

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Combining the advantages of a multirow detector array with a fast gantry rotation time, multidetector computed tomographic (CT) scanners can acquire sections at a faster rate than was previously possible. As a result, multidetector CT permits scanning during multiple specific phases of intravenous contrast enhancement and the acquisition of very thin sections over a large area, allowing the creation of multiplanar reconstructions with high z-axis resolution. The authors present an imaging strategy for the diagnosis and staging of hepatic pathologic conditions that emphasizes the role of multidetector CT. Users must master several scanning parameters to obtain the best image quality. For hepatic CT, it is practical to use relatively narrow collimation, increasing the pitch as needed to cover the entire liver. The choice of reconstruction interval is dependent on the problem for which the study is being performed. Water is recommended as an oral contrast agent for non-axial reconstructions, since high-attenuation oral contrast agents might degrade them. Appropriate scanning delays for hepatic CT are dependent on the contrast-agent injection strategy used. A triple-pass technique, highlighting the arterial, parenchymal, and portal venous phases of enhancement, is recommended.

Index terms: Computed tomography (CT), technology, 761.12119 • Computed tomography (CT), thin-section, 761.12119 • Liver, CT, 761.12114, 761.12119


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Introduction
Multidetector computed tomography (CT) represents an advance in CT technology that involves use of a multiple-row detector array instead of the traditional single-row detector array used in spiral CT. This innovation allows scanning four to eight times faster than scanning with spiral CT (1). Because of this faster scanning ability, multidetector CT permits many new scanning techniques that were not possible with single-row helical CT (2,3). Applying multidetector CT to hepatic imaging promises both improved clinical utility of CT and a challenge for radiologists.

In this review, we present an imaging strategy that emphasizes the role of multidetector CT in the diagnosis and staging of hepatic pathologic conditions.

Parameters for Acquisition of Hepatic Images
The best-attainable image quality of any given CT system is determined by many system-inherent factors. The degree to which this potential is actually reached in clinical practice, however, is determined by a number of scanning parameters that the user can modify: (a) collimation, (b) pitch, (c) reconstruction interval, (d) contrast media, and (e) timing of scanning. Optimizing these parameters to achieve the best possible image quality for a specific multidetector CT examination requires a thorough understanding of their interrelationships.

Collimation
The practical considerations with regard to choice of collimation include spatial resolution, image noise, and length of coverage. Collimation should be tailored to the purpose of the study (ie, the specific structures being imaged). Spatial resolution may be increased by means of a decrease in the collimator width, but decreased collimator width also results in increased image noise and decreased length of coverage (Fig 1) (4).

The reduced coverage encountered with narrow collimation, however, can potentially be overcome with an increase in pitch. Thus, several factors must be balanced to achieve the best result for a particular imaging problem.

Pitch
In helical CT, pitch is defined as the table feed during a 360° rotation of the tube-detector apparatus divided by the collimator width. For multidetector CT, there are two distinct versions of pitch, depending on whether the entire beam collimation is considered or the “detector” collimation (ie, beam/4) is used. For example, if 10-mm
beam collimation with a 10-mm table feed per rotation is used in a four-detector-row scanner (ie, “detector” collimation to four 2.5-mm channels), the pitch would be 1 if beam collimation is considered or 4 if detector collimation is considered. The selection of pitch for multidetector CT is affected by such factors as the required length of coverage, reconstructed section thickness, and image noise (5,6).

For a given duration of scanning, minimization of collimation (thus, an increase in pitch) will allow a narrow reconstructed section thickness and potentially improve spatial resolution, particularly in nonaxial planes. However, maximization of pitch may also result in a decrease in contrast resolution. Thus, the most appropriate choice of scanning parameters is dependent on the imaging problem under consideration. For example, because CT angiography allows imaging of structures with very high attenuation against a background of much lower attenuation (ie, high inherent contrast), the loss of contrast resolution caused by maximization of pitch can be disregarded. For CT of the liver, however, the potential loss of contrast resolution with maximal pitch must be taken into consideration. For hepatic CT, because both good spatial resolution and good contrast resolution are required, a practical approach is to use relatively narrow collimation, increasing the pitch as needed to cover the entire liver.

**Reconstruction Interval**

The choice of reconstruction interval is dependent on the clinical problem for which the study is being performed. The smaller the reconstruction interval, the greater the longitudinal (z-axis) resolution, with a resultant loss in z-axis coverage (7). If it is expected that multiplanar reconstructions will be required, a small reconstruction interval with overlapping sections is advantageous (Fig 2). Another consideration is the detection of small lesions, as overlapping reconstructions have been shown to improve the detection of hepatic metastases. In most cases, if nonaxial reconstructions are not anticipated, contiguous reconstructions usually are adequate.

A practical trade-off for improved resolution is slower processing of data, the need for more data storage, and increased time for interpretation of studies (8). These issues have become less problematic with improvements in computing speed and the increasing use of soft-copy interpretation.

**Contrast Media**

Several studies have shown that the volume of contrast medium used to enhance the thoracic vascular structures during helical CT can be as little as one-half that used for dynamic incremental CT (9,10). For abdominal CT, however, the

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**Figure 2.** Hepatocellular carcinoma. (a) Coronal reconstruction image, generated from 5-mm axial sections with a 5-mm reconstruction interval, shows a heterogeneous-attenuation mass in the tip of the right lobe with portal vein thrombosis (arrowhead). (b) Sagittal multiplanar reconstruction image shows rippling artifact on the liver surface as well as destruction of a lumbar spinal body by metastasis (arrow).
issue of reduction in contrast medium has not been resolved. This issue must be revisited with multidetector CT because of its further increase in scanning speed. For liver imaging, the most important patient-related factor that affects the magnitude of hepatic contrast enhancement is body weight (11). The use of oral contrast medium may change with multidetector CT because of the increased use of nonaxial reconstructions and the potential for high-attenuation oral contrast medium to degrade the reconstructions. In these situations, water is recommended as an oral contrast agent.

**Timing of Scanning**

The appropriate scanning delays for hepatic CT are dependent on the strategy used for injecting the contrast medium. The timing of peak aortic and hepatic contrast enhancement is primarily dependent on the rate of injection (12,13). Rapid or low-volume (shorter-duration) injections produce earlier peak enhancement, whereas slow or high-volume (longer-duration) injections result in later peak enhancement. These factors must be taken into account before a fixed scanning delay is instituted.

A preliminary minibolus (5 mL/sec for 4 seconds), with scanning every 2 seconds beginning 10 seconds after the injection is started, can be used. The time to peak aortic enhancement is determined from the resultant time attenuation curve and is used to calculate the scanning delay. The scanning delay can also be accurately timed with a bolus tracking software program (14).

With the triple-pass technique, multidetector CT can be used to image during three distinct hepatic circulatory phases (15–17). The first pass provides an image of the arterial phase, which exquisitely displays the hepatic arterial system, though it may be too early to see some hypervascular neoplasms (Fig 3). The second pass corresponds in timing to initial opacification of the portal venous system and is labeled the parenchymal or portal vein inflow phase. The enhancement of hypervascular neoplasms is maximized during this phase. In both primary and metastatic hypervascular neoplasms (eg, hepatocellular carcinoma, islet cell tumor, carcinoid, sarcoma), approximately 30% more lesions are detectable during this phase than during the later portal venous phase (Fig 4) (17–21). During the third imaging pass, conventionally labeled the portal venous phase but also known as the hepatic venous phase, the hepatic veins are enhanced, having been unenhanced during both the early arterial and parenchymal phases. During this phase, enhancement of background hepatic parenchyma is maximized. Tumors that are hyperattenuating on the arterial-phase and parenchymal-phase images may appear iso- or hypotattenuating on the hepatic venous-phase image (Fig 5) (16–19).

Though all three phases are often useful in the initial detection and characterization of liver lesions, CT arteriography is usually not necessary in patients who are undergoing posttherapeutic care, and only the second and third imaging passes may be performed.

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**Figures 3, 4.** (3) Hepatic hemangioma. Triphasic contrast enhancement with multidetector CT shows sequential enhancement of hepatic vessels and tumor tissue. (a) Axial image obtained during the arterial phase of enhancement shows early eccentric enhancement of the focal hepatic lesion. Portal veins are not enhanced. (b) Image obtained during the parenchymal phase shows further enhancement of the lesion. Portal veins are enhanced, but hepatic veins are not. (c) Image obtained during the hepatic venous phase shows enhancement of hepatic veins and maximal enhancement of the hepatic parenchyma. This phase of enhancement is also known as the portal venous phase. (4) Multiple metastases in a 59-year-old woman. (a) Arterial-phase image shows indistinct, low-attenuation, atypical metastatic carcinoid tumors. (b) Image obtained during the late parenchymal phase allows clearer identification of multifocal, low-attenuation masses in both hepatic lobes. (c) Image obtained during the hepatic venous phase shows maximal parenchymal enhancement. Demarcation of the tumors is less distinct than that on the parenchymal-phase image.
Sample Protocol for
Four-Detector-Row CT of the Liver
For multipass hepatic imaging in our department, 30% nonionic contrast material (30 g iodine) is administered at a rate of 4 mL/sec for 25 seconds. Three passes are performed, one each during the arterial phase (20 seconds after injection of contrast medium), parenchymal phase (35 seconds after the initiation of injection), and hepatic venous phase (60 seconds after the start of injection). Collimation is 2.5 mm. The thickness of reconstructed sections is 5 mm in all cases, with a 60% overlap used during the arterial phase. In all cases, a table speed of 15 mm/sec is used (Table). 

Clinical Utility of Multidetector CT
Improved Detection of Lesions
The shorter imaging times of multidetector CT allow imaging during periods of more intense enhancement, as well as more precise imaging during specific phases of enhancement (Figs 6, 7). In
**Protocols for Multidetector CT of the Liver**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Basic*</th>
<th>Hypervascular Liver Lesion†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contrast medium</td>
<td>C+</td>
<td>H₂O</td>
</tr>
<tr>
<td>Rate of injection (mL/sec)</td>
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<td>4</td>
</tr>
<tr>
<td>Volume of contrast material (mL)</td>
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<td>100</td>
</tr>
<tr>
<td>Scanning delays (sec) per anatomic region</td>
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<td></td>
</tr>
<tr>
<td>Collimation (mm)</td>
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<td>2.5</td>
</tr>
<tr>
<td>Table feed (mm/sec)</td>
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<td>15</td>
</tr>
<tr>
<td>Reconstruction thickness (mm)/interval (mm)</td>
<td>5/5</td>
<td>5/3</td>
</tr>
</tbody>
</table>

Note.—A-P = abdomen to pelvis, C+ = 2.1% solution of barium sulfate.

*Basic protocol is used when liver metastasis is suspected.

†Hypervascular protocol is used when a hypervascular metastasis (such as that from hepatocellular carcinoma, focal nodular hyperplasia, or hemangioma) is suspected.

**Figure 6.** Metastatic melanoma. (a) Multidetector CT scan obtained before administration of contrast medium shows a large, low-attenuation mass in the liver. (b) Scan obtained during the late arterial phase shows partial enhancement of the mass. (c) Scan obtained during the hepatic venous phase shows the mass with homogeneously low attenuation.
addition, with multidetector CT there may be less respiratory misregistration and greater z-axis resolution. The speed of coverage of four-detector-row CT is up to four times faster than that with a single-detector-row scanner. Thus, CT of the liver can be performed routinely with very thin collimation, yielding greater conspicuity of small lesions for better detection of lesions (Fig 1). Use of 2.5-mm-thick sections has been shown to result in a 46% increase in lesion detection compared with the use of 10-mm-thick sections and an 18% increase in detection compared with the use of 5-mm-thick sections (22).

Figure 7. Hepatic perfusion abnormality in a 44-year-old man. (a) Multidetector CT scan obtained during the arterial phase shows transient focal enhancement (arrow). (b, c) Scans obtained sequentially during the parenchymal (b) and hepatic venous (c) phases show no mass. This case shows unusual masslike nodular enhancement. Localized, transient enhancement is common with triphasic scanning. The most common underlying causes are arterial-portal fistulas and minor portal venous variants.

Figure 8. Liver at three-dimensional imaging. (a) Three-dimensional volume-rendered image shows a hemangioma in the right lobe of the liver and the adjacent vasculature. (b) Volumetric reconstruction image from CT angiography displays the hepatic and abdominal vessels and their interrelation. A large eccentric aortic aneurysm is seen near the origin of the right renal artery.
Three-dimensional Imaging
With the rapid scanning ability of multidetector CT, it is feasible to obtain a three-dimensional data set of the entire liver during a single breath hold. With reconstruction of these data, high-quality three-dimensional images may be obtained. We have found that image quality in reconstructed sagittal, coronal, or curved planes is excellent in most cases. The use of curved multiplanar reconstruction along a dilated biliary tree or along vessels may more clearly elucidate the anatomic and pathologic characteristics than the reading of axial images alone. Such unique imaging approaches may ultimately improve lesion detection, characterization, and surgical planning (Fig 8) (23,24).

In addition, multidetector CT permits dynamic subtraction CT of the liver during a single breath hold. Not only is this method an elegant means to quantitate vascularity, it may correlate with the biologic activity of tumors (25).

Limitations of Multidetector CT
The practical result of multidetector CT is the generation of many more narrowly collimated sections than are routinely obtained with single-detector-row CT. For certain examinations such as CT angiography, the image files may be extraordinarily large, with more than 1,000 images. As this number of images is impractical to view on film, soft-copy viewing at a workstation is the most efficient way to review these large data sets (8).

Timing of scanning becomes more critical as the increased speed of multidetector CT narrows the “temporal window” for desirable phase of enhancement. Without proper timing for abdominal studies, it is possible to scan too early and miss the intended phase. The distinct hepatic circulatory phases can be successfully imaged only through adjustment of the acquisition time to the circulation time of the individual patient.

Another potential drawback of multidetector CT may be an increased radiation dose, due to both the high milliampere-second levels used in many thin-section acquisitions to maintain image quality and the increased prevalence of multipass scanning. It behooves radiologists to make an effort to minimize radiation dose when possible. Although cone-beam artifacts are theoretically a potential problem of multidetector CT, they have not caused significant image degradation to date.

Conclusions
Multidetector CT allows highly precise imaging during three (or more) distinct phases of hepatic enhancement. Optimal acquisition timing, in combination with thinner collimation, permits improved lesion detection and will also probably improve characterization of lesions. With the advances in rapid volume rendering and other three-dimensional techniques, a new era of CT-based three-dimensional imaging of the abdominal viscera is becoming a reality.

References


