Focal Liver Lesions: Characterization with Triphasic Spiral CT

PURPOSE: To assess whether triphasic spiral CT enables characterization of a wide range of focal liver lesions.

MATERIALS AND METHODS: One hundred five patients with suspected focal liver disease underwent triphasic liver CT. After injection of contrast material, the liver was scanned in arterial (scanning delay, 22–27 seconds), portal (scanning delay, 49–73 seconds), and equilibrium (scanning delay, 8–10 minutes) phases. Enhancement of each lesion in each phase was evaluated, and the lesions were tabulated according to one of 11 enhancement patterns.

RESULTS: In 94 patients, 375 liver lesions were detected. The nature of the lesion was confirmed in 326 lesions (87%). Six of 11 enhancement patterns were always due to benign disease and caused by areas with hyper- or hypoperfusion, hemangiomas, cysts, focal nodular hyperplasias, or benign but nonspecified lesions. Two of 11 patterns were always due to malignant disease, and one pattern was due to malignant disease in 38 (97%) of 39 patients with known malignancy elsewhere or with chronic liver disease. The other two patterns were seen in metastases and partly fibrosed hemangiomas.

CONCLUSION: Triphasic liver CT enables characterization of a wide range of focal liver lesions, including the benign liver lesions that occur most frequently.

SPIRAL computed tomography (CT) has rapidly gained acceptance as the preferred CT technique for routine liver evaluation because it provides image acquisition at peak enhancement of the liver parenchyma during a single breath hold (1–4). In addition, the fast data acquisition allows successive scanning of the entire liver at different moments after injection of contrast material, thus creating the possibility of multiphasic liver CT.

Recent studies have reported an improvement in lesion detection if arterial phase imaging is performed in addition to portal venous imaging, especially in the presence of hypervascular neoplasms, such as hepatocellular carcinoma (HCC) (5–8).

In the current study, we evaluated a triphasic spiral CT technique that allows imaging of the entire liver in arterial, portal, and equilibrium phases. The rationale behind the protocol was that the portal phase is the most sensitive phase for lesion detection, whereas the arterial and equilibrium phases can supply additional information on the vascularity of lesions that may help to clarify the nature of lesions. The study was designed to assess whether triphasic spiral liver CT enables characterization of a wide range of liver lesions, also in the presence of multilevel disease and in the coexistence of different pathologic conditions.

MATERIALS AND METHODS

Patients

From February 1993 to July 1994, 105 nonconsecutive patients (45 men, 60 women; age range, 25–84 years; median age, 55 years) were examined with a triphasic liver CT protocol. Patients were included if focal liver disease was suspected clinically or if previous imaging studies depicted hepatic lesions with a nonspecific appearance. Fifty-eight patients were referred with a known primary malignancy: colorectal carcinoma (n = 36), carcinoid (n = 4), breast carcinoma (n = 3), pancreatic endocrine tumors (n = 3), renal carcinoma (n = 3), melanoma (n = 2), leiomyosarcoma (n = 2), and bronchogenic carcinoma, gastric carcinoma, germ cell carcinoma, medullary thyroid carcinoma, and tongue base carcinoma (one each). Among these fifty-eight patients, the reason for referral was suspected metastatic disease or quantification of known metastatic disease. Thirty-one patients without a known primary malignancy were referred because ultrasound (US) or conventional CT demonstrated one or several hepatic lesions that could not be characterized. Eight patients with chronic liver disease were referred because of possible HCC. In three patients, a focal liver mass was suspected at physical examination. In three patients, abnormal liver function test results were the reason for referral. In one patient, a gallbladder carcinoma was suspected at US, and in one patient the reason for referral was unknown.

Index terms: Computed tomography (CT), tissue characterization, 761.91 • Liver, CT, 761.12113, 761.12114, 761.12115 • Liver, cysts, 761.312 • Liver, focal nodular hyperplasia, 761.3198 • Liver neoplasms, 761.30 • Liver neoplasms, secondary, 761.332

Abbreviations: FNH = focal nodular hyperplasia, HCC = hepatocellular carcinoma.

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CT Acquisition

A triphasic liver CT protocol was developed in which we used a spiral CT scanner with a 5.2 mega unit, or MUH, x-ray tube, capable of 50 consecutive 1-second rotations with 225 mAs and 140 kV (model SR 7000, Philips Medical Systems, Best, The Netherlands). Images were reconstructed on a 180° linear interpolation reconstruction algorithm.

With the triphasic liver CT protocol, the entire liver was scanned successively in arterial, portal, and equilibrium phases. After obtaining a digital scout view, an unenhanced scan of the liver was acquired with 10 mm/sec table speed, 10-mm collimation, and 10-mm reconstruction index. On the unenhanced scan, the craniocaudal extent of the liver was measured, and 2 cm was added to this distance to allow for small differences in inspiration. To minimize partial volume effects on the portal phase images, 5-mm collimation and 5 mm/sec table speed were used, with a 2-mm reconstruction index. Because the scanner allowed a maximum of 50 rotations before a waiting period, acquisition in arterial and portal phases together was limited to these 50 rotations. The craniocaudal extent of the liver determined the number of required rotations in portal phase. The remaining number of rotations (50 minus the number of portal phase rotations) were used for the arterial phase, and table speed and collimation were adjusted to cover the entire liver. Depending on the craniocaudal extent of the liver, 5-mm collimation with 10 mm/sec table speed and 5-mm reconstruction index or 10-mm collimation with 20 mm/sec table speed and 10-mm reconstruction index were used in the arterial phase.

The patient was asked to hyperventilate during 30 seconds before arterial scanning. A total of 194 mL of nonionic contrast material (iohexol [Omnipaque]; Nycomed, Princeton, NJ), 350 mg of iodine per milliliter; ioparol [Optiray:] Guerbet, Aulnay-sous-Bois, France], 350 mg of iodine per milliliter; or jopromide [Ultravist; Schering, Kenilworth, NJ]) was injected with a power injector (model CT 9000 Digital In-jection System; Liebel Flarsheim, Cincinnati, Ohio) at 4 mL/sec into an antecubital vein by using an 18-gauge needle. After 22 or 27 seconds (22 seconds in patients younger than 40 years and 27 seconds in patients older than 40 years), the entire liver was scanned in arterial phase.

Twenty seconds after the end of the arterial phase, the liver was scanned in portal phase with 5-mm collimation, 5 mm/sec table speed, and 2-mm reconstruction index. The 20-second interscan delay between the end of the arterial phase and the portal phase acquisition was needed to give the patient a chance to rebreathe and to reposition the scan plane cephalad to the liver. As a result, portal phase acquisition started between 0 and 24 seconds after the end of injection of contrast material.

After reconstruction of arterial phase images (reconstruction time; 8 seconds per section) and saving of the raw data of portal phase sections, a third scan was obtained in the equilibrium phase, 8-10 minutes after injection of contrast material, with 10-mm collimation, 10 mm/sec table speed, and 5-mm reconstruction index. The number of rotations was adjusted to cover the entire liver.

All scans were obtained in the craniocaudal direction and during breath hold. Patients were allowed to breathe slowly during the latter part of the equilibrium acquisition, when the lower abdomen and pelvis were scanned. Total examination time, including reconstruction, filming, and data storage varied between 45 and 50 minutes.

Eight (8%) of 105 examinations were performed with a different protocol, either due to a technical fault or to human error in the implementation of the protocol. All these errors occurred in the first 50 patients. Among these eight examinations, no equilibrium phase of the liver was acquired in six cases. In two cases, the arterial phase was acquired in one examination, and 10-mm collimation instead of 5-mm was used for portal phase imaging in one examination.

Image Interpretation

Initially, images were reviewed as hard copies, with every other image printed on film. Thus, 10-mm arterial and equilibrium phase sections were presented as contiguous images, and 5-mm portal phase sections were presented at 4-mm intervals. During the course of the study, an offline workstation (Easy-vision CT/MR; Philips Medical Systems) became available, which allowed dynamic viewing of all reconstructed images in interactive cine mode. Comparison of the sections at the same anatomic level in the three different phases of contrast enhancement was facilitated by using a proprietary "Compare" function in the workstation.

Each study was interpreted by two radiologists (M.S. and J.N.) in consensus. Most readings were performed in a blinded fashion, but in a number of patients the results of previous imaging studies were known because one of the radiologists had performed the previous study. In all patients but one, the reason for referral was known. First, the enhancement characteristics of the lesions were determined by grading the attenuation of the arterial and portal venous system at the level of the porta hepatis in comparison to liver parenchyma. Second, arterial, portal, and equilibrium phase images were reviewed for the presence of focal liver lesions. The appearance of each lesion in each phase was described in six examinations, noting the attenuation and the homogeneity of the lesion in comparison to surrounding parenchyma in that phase and was expressed as one of five possible states, with an abbreviated name for each state: (a) area of water attenuation, homogeneous: hypo- (cyst), (b) area of soft-tissue attenuation, often slightly inhomogeneous: hyper-, (c) inhomogeneous mixture of hypo- and hyperattenuation, but less hyperattenuating than the arterial system: mixed, (d) area of hyperattenuation, but less hyperattenuating than the arterial system: hyper-, and (e) isoattenuating compared with the arterial system: arterial. Moreover, the presence of a continuous hyperattenuating rim, less hyperattenuating than the arterial system, was noted in the arterial phase, hyper-(rim). After describing the state of each lesion in each phase, the pattern of enhancement over time of each lesion was described as a three-part pattern name that incorporated the appearance of the lesion in each phase (eg, hypo-/hyper-/hypo-). Additional features, defined by typical location, appearance, or size of the lesion, were used to define subtype enhancement patterns.

According to the literature (6,9-23) and previous experience with dynamic liver CT, 11 different enhancement patterns were defined that belonged to one of two general groups, either hypovascular or hypervascular, which demonstrated less contrast enhancement than normal parenchyma during the arterial and portal phases, or hyperattenuating patterns, which demonstrated more contrast enhancement than normal parenchyma during the arterial phase (Table 1). Percentages were rounded off to the nearest whole number.

Standard of Reference

After all studies were interpreted, a standard of reference for each detected lesion was determined. To this purpose, medical history, results of other imaging studies, biopsy findings, and surgical findings were collected. A total of 375 lesions were detected in 94 patients. In 326 lesions (87%), a standard of reference concerning the nature of the lesion was available (Table 2). These 326 lesions were included for further analysis. The following information was accepted as the standard of reference: (a) Findings at surgery and histopathologic examination (n = 74). (b) Findings at percutaneous needle biopsy (n = 137). If, in a patient with multiple lesions, biopsy was performed of one lesion, all lesions with the same appearance at CT as the biopsy lesion were considered to represent the same pathologic finding. (c) Findings at US (n = 32). An anechoic lesion with posterior acoustic enhancement was considered proved if the lesion was found at magnetic resonance (MR) imaging (n = 31). A sharply demarcated lesion with homogeneous high signal intensity on heavily T2-weighted images was considered proved for the presence of a cyst or a hemangioma. (d) Findings at follow-up (n = 52). When a patient with a proved malignancy developed solid lesions in the liver that increased in size over time, the lesions were considered to be metastases of the primary tumor. Conversely, if a lesion did not show any change after a minimum of 1-year follow-up, the lesion was considered to be benign but uncharacterized as to its pathologic nature.
Table 1
Enhancement Patterns

<table>
<thead>
<tr>
<th>Attenuation for Arterial/Portal/Equilibrium Phases</th>
<th>Arterial Phase</th>
<th>Portal Phase</th>
<th>Equilibrium Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypo-/hypo-/hypo-</td>
<td>Hypo- or isooattenuating</td>
<td>Hypoattenuating</td>
<td>Hypo- or isooattenuating, possible hypoattenuating rim</td>
</tr>
<tr>
<td>Hypo-/hypo-(FL)/hypo-</td>
<td>Hypo- or isooattenuating</td>
<td>Hypoattenuating, no mass effect, adjacent to FL</td>
<td>Hypo- or isooattenuating</td>
</tr>
<tr>
<td>Hyper-(rim)/hypo-/hypo-</td>
<td>Hypo- or isooattenuating, hyperattenuating rim</td>
<td>Hypoattenuating</td>
<td>Hypo- or isooattenuating</td>
</tr>
<tr>
<td>Hypo-/hypo-/hyper-</td>
<td>Hypo- or isooattenuating</td>
<td>Hypoattenuating, water attenuation; sharp margin</td>
<td>Hypoattenuating, near water attenuation; sharp margin: ≤5 mm</td>
</tr>
<tr>
<td>Hypo-/hypo-(cyst)/hypo-</td>
<td>Hypo- or isooattenuating</td>
<td>Hypoattenuating</td>
<td>Hypo- or isooattenuating</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Arterial/artrial/artrial</th>
<th>Peripheral nodular enhancement of arterial attenuation or hypoattenuating</th>
<th>Peripheral nodular enhancement of vascular attenuation, progressive in a centropetal fashion</th>
<th>Hyperattenuating with possible central hypoattenuation or isooattenuating (if vascular space is isooattenuating)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyper-/A/A*</td>
<td>Complete enhancement of arterial attenuation or hypoattenuating</td>
<td>Complete enhancement of vascular attenuation</td>
<td>Complete enhancement of vascular attenuation or isooattenuating</td>
</tr>
<tr>
<td>Hyper-/A/A (cleft)***</td>
<td>Hyperattenuating but less hyperattenuating than arterial space</td>
<td>Hyper-, iso-, or hypoattenuating</td>
<td>Iso-or hypoattenuating</td>
</tr>
<tr>
<td>Hyper-(wedge)/iso/iso**</td>
<td>Wedge-shaped area of hyperattenuation, less hyperattenuating than vascular system; no accompanying lesion</td>
<td>Isooattenuating, no lesion</td>
<td>Isooattenuating, no lesion</td>
</tr>
<tr>
<td>Mixed/mixed/mixed</td>
<td>Partly hypoattenuating, partly hyperattenuating</td>
<td>Partly hypoattenuating, partly hyperattenuating</td>
<td>Partly hypoattenuating, partly hyperattenuating</td>
</tr>
</tbody>
</table>

Note.—Hypo-, iso-, and hyperattenuating refer to relative attenuation in comparison to that of the surrounding liver parenchyma.

* Lesions showed less enhancement in the arterial and portal phases than that of liver parenchyma.

1 Subtype of pattern hypo-/hypo-/hypo-FL = falciform ligament.

1 Subtype of pattern hypo-/hypo-(cyst)/hypo-.

5 Lesions showed more enhancement in the arterial phase than that of liver parenchyma.

* This pattern was defined by its appearance in arterial phase only, irrespective of the enhancement in the other phases. A = hypo-, iso-, or hyperattenuating.

** Subtype of hyper-/A/A.

Table 2
Standard of Reference in 326 of the 375 Lesions Detected with Triphasic Liver CT

<table>
<thead>
<tr>
<th>Abnormality</th>
<th>Surgery</th>
<th>Biopsy</th>
<th>MR Imaging</th>
<th>US</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noncolorectal metastases (103 lesions/14 patients)</td>
<td>6/2</td>
<td>87/11</td>
<td></td>
<td>10/1</td>
<td></td>
</tr>
<tr>
<td>Colorectal metastases (62 lesions/25 patients)</td>
<td>33/15</td>
<td>18/5</td>
<td>11/5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCC (18 lesions/5 patients)</td>
<td>2/2</td>
<td>16/3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Hodgkin lymphoma (1 lesion/1 patient)</td>
<td></td>
<td>1/1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemangioma (59 lesions/32 patients)</td>
<td>6/3</td>
<td>3/2</td>
<td>18/6</td>
<td>24/12</td>
<td></td>
</tr>
<tr>
<td>Arterial/arterial/arterial (51 lesions/25 patients)</td>
<td>1/1</td>
<td>2/2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hyper-/hypo-/hyper- (5 lesions/3 patients)</td>
<td>1/1</td>
<td>1/1</td>
<td>1/1</td>
<td>2/2</td>
<td></td>
</tr>
<tr>
<td>hypo-/hypo-/hypo- (5 lesions/5 patients)</td>
<td>6/3</td>
<td>10/1</td>
<td>32/7</td>
<td>3/2</td>
<td></td>
</tr>
<tr>
<td>Cyst (51 lesions/13 patients)</td>
<td>3/3</td>
<td>4/3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FNH (7 lesions/6 patients)</td>
<td></td>
<td>3/2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adenoma (4 lesions/3 patients)</td>
<td>1/1</td>
<td>2/2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focal fat deposit (1 lesion/1 patient)</td>
<td>1/1</td>
<td>2/2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benign, not characterized as to pathologic nature (20 lesions/9 patients)</td>
<td>15/7</td>
<td>5/2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note.—Data are presented as no. of lesions/no. of patients. FNH = focal nodular hyperplasia.

Results

The relative enhancement of the arterial and portal venous systems was visually compared and graded. Arterial phase images were acquired in 104 patients. The arterial system was intensely opacified throughout the entire arterial phase on 98 (94%) of the 104 scans. In this arterial phase, the splenic vein demonstrated variable enhancement depending on the splenic circulation time. As a result, 21 patients (20%) demonstrated enhancement of the intrahepatic portal system slightly less than or equivalent to that of the arterial space. Parenchymal enhancement, however, was always well below the enhancement seen in the portal phase. In the other 83 patients (80%), the intrahepatic portal system was not, or only slightly, enhanced. Apparently, the chosen timing for the arterial scanning delay resulted in a true arterial phase in most patients.

Portal phase images were acquired in all 105 patients. Visually, good enhancement of liver parenchyma was present in all patients. In 53 (50%) of the 105 patients, the enhancement of the portal system at the level of the porta hepatis was more intense com-
pared with that of the arterial system, and in 53 patients (50%) enhancement was equal.

During the equilibrium phase, the vascular spaces and parenchyma could be distinguished in 92 (93%) of the 99 patients in whom equilibrium phase scans were obtained; in seven patients (7%), the vascular structures were isoattenuating compared with liver parenchyma. To assess the utility of triphasic liver CT for characterization of liver lesions, data were analyzed in two formats. First, the 11 patterns of enhancement were compared with the standard of reference to quantify the clinical relevance of each of the 11 patterns. These data and the pathologic counterpart of the 11 enhancement patterns are presented in Table 3.

Second, the abnormalities were compared with their patterns of enhancement to understand the correlation between different pathologic entities and their triphasic liver CT appearance. These findings are presented in Tables 4–7.

**DISCUSSION**

Because of the high frequency of benign focal liver lesions such as cysts, hemangiomas, and FNH (24–27), characterization of these lesions is essential. In addition, in many patients who are referred for liver CT, one does not know what kind of abnormality will be present. Consequently, the preferred liver CT technique should combine a high sensitivity for lesion detection with a good ability for lesion characterization, to differentiate lesions that do need further diagnostic tests or treatment from lesions that do not. To meet these requirements, a triphasic spiral CT technique was developed to image the entire liver in arterial, portal, and equilibrium phases. A monophasic, high-volume (194 mL), high-injection-rate (4 mL/sec) contrast material protocol was used to achieve sufficient arterial opacification during the arterial phase, intense parenchymal opacification in the portal phase, and hyperattenuating vascular space in the equilibrium phase.

**Hypoattenuating Enhancement Patterns**

The characterization of hypoattenuating liver lesions is often difficult, especially when lesions are small (ie, <1.5 cm in diameter). Although such lesions are seldom malignant if found in a patient without a known primary tumor, the chance of malignancy in patients with a known primary tumor is reported to be as high as 34% (27).

The first distinction to be made is between cysts and hypoattenuating solid lesions. All hypo-hypo-(cyst)/hypo-lesions (n = 51) were confirmed to be cysts. Because of their sharper margin and homogeneous hypoattenuation, 5-10-mm hypo-hypo-(cyst)/hypo-lesions (n = 26) could be confidently differentiated from subcentimeter hypo-hypo-lesions (n = 30), greatly reducing the need for confirmatory US or follow-up of these small cysts. The subtype small hypo-hypo-(cyst)/hypo- was used for hypo-hypo-(cyst)/hypo-lesions less than 5 mm in diameter. We defined this subtype...
because we judged that we could not make a certain diagnosis of benignancy in these small lesions. However, all 15 small hypo-/hypo-[FL]/hypo- lesions with a standard-of-reference diagnosis represented benign disease (Fig 1).

Hypoattenuating noncystic lesions were grouped in one of four enhancement patterns, which all demonstrated hypoattenuation in the portal phase, often somewhat inhomogeneous. When these lesions demonstrated no enhancement in other phases (ie, hypo-/hypo-/hypo- pattern), 84 (94%) of 89 lesions were malignant (Table 3).

When an enhancing rim in the arterial phase was observed (ie, hyper-(rim)/hypo-/hypo- pattern), all lesions (29 of 29 lesions) were malignant. The hypervascular rim of hyper-(rim)/hypo-/hypo- lesions has been well described (10,15,16,28,29) and probably represents the well-perfused viable periphery of tumor tissue. These lesions often demonstrated a reversed enhancement pattern in equilibrium phase (ie, a hypoattenuating peripheral rim surrounding a hyperattenuating center) (Fig 2), a phenomenon already known as “the washout sign” (17,30). Others have observed rim enhancement around abscesses (31), which were not present in the current study.

Conversely, if a hypoattenuating lesion in the portal phase demonstrated homogeneous enhancement in the equilibrium phase (ie, hypo-/hypo-/hyper- pattern), only five (62%) of the eight lesions were malignant (Table 3). The remaining 6% of hypo-/hypo-/hypo- lesions and 38% of hypo-/hypo-/hyper- lesions probably represented completely, or partly, fibrosed hemangiomas. Honda et al (15) reported a lack of enhancement during bolus phase in 15% of hemangiomas and hypoattenuation after 6–7 minutes in 5% of hemangiomas. In that study, no explanation was given for these findings. Whereas the central fibrocartilaginous scar in large hemangiomas does not cause diagnostic difficulties, the fibrosis in these smaller lesions gives them a nonspecific hypoattenuating appearance. Four of eight hemangiomas with these nonspecific appearances were found in patients with a history of colorectal tumor, emphasizing the problem of lack of specificity of these enhancement patterns in the studied population.

To avoid confusion between the hyper-(rim)/hypo-/hyper- pattern and the peripheral enhancement in hemangiomas, it is essential to differentiate the fairly homogeneous, continuous rim hyperattenuation with parenchyma but less hyperattenuation than the vascular spaces that characterize hyper-(rim)/hypo-/hypo- lesions (Fig 2) from the globular, peripheral enhancement, isointensification with the arterial system that is the hallmark of hemangiomas (9,12–14) (Fig 3).

A subtype enhancement pattern (ie, hypo-/hypo-[FL]/hypo-) refers to a hypo-/hypo-/hypo- lesion to the right of the falciform ligament, on the anterior surface of the liver, without mass effect. No focal abnormality was found in any of these lesions. The same enhancement pattern has been described as a perfusion defect during CT arterial portography (20,32) or an area of focal fatty infiltration (21,22). Interestingly, in two of 12 hypo-/hypo-(FL)/hypo- lesions observed in total during the study period, the hypoattenuation was also appreciated on unenhanced images and during the arterial and equilibrium phases, while the other 10 hypo-/hypo-(FL)/hypo- lesions were only perceived in the portal phase. Possibly, the persistent hypo-/hypo-(FL)/hypo- lesions were caused by focal fatty infiltration, whereas the lesions only perceived in portal phase may be caused by a variant blood supply (23).

Hyperattenuating Enhancement Patterns

Recent studies have reported an improvement in lesion detection if arterial phase imaging is performed in addition to portal venous scanning, especially for hypervascular lesions (5–8). However, characterization of these lesions as to their clinical importance has so far received little attention.

Hyperattenuation in the arterial phase has to be differentiated in terms of arterial attenuation or less than arterial attenuation. If a lesion demonstrates arterial attenuation, either complete and in all phases or peripheral globular and extending in a centropetal fashion in subsequent phases, the appearance is pathognomonic for hemangioma (9,12–14). Marked differences in perfusion pattern were seen between the hemangiomas that presented as arterial/arterial/arterial lesions. Some hemangiomas may not show any enhancement in the arterial phase and only started to enhance in the portal phase, whereas others demonstrated complete enhancement in both the arterial and portal phases. In the equilibrium phase, 16 (31%) of 51 arterial/arterial/arterial lesions were hyperattenuating compared with the vascular system (Fig 3), a phenomenon already described by Freeny and Marks (9). Apparently, due to slow perfusion, concentration of contrast material in the lesion still exceeded the concentration in the vascular system.

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**Table 4**

<table>
<thead>
<tr>
<th>Pathologic Diagnosis</th>
<th>No. of Lesions</th>
<th>Enhancement Patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorectal metastases (n = 62)</td>
<td>31 (50)</td>
<td>Hypo-/hypo-/hypo-</td>
</tr>
<tr>
<td></td>
<td>24 (39)</td>
<td>Hyper-(rim)/hypo-/hypo-</td>
</tr>
<tr>
<td></td>
<td>5 (8)</td>
<td>Hypo-/hypo-/hyper-</td>
</tr>
<tr>
<td>Noncolorectal metastases (n = 103)*</td>
<td>2 (3)</td>
<td>Mixed-/mixed-/mixed-</td>
</tr>
<tr>
<td></td>
<td>53 (51)</td>
<td>Hypo-/hypo-/hypo-</td>
</tr>
<tr>
<td></td>
<td>26 (25)</td>
<td>Hypo-/mixed/mixed</td>
</tr>
<tr>
<td></td>
<td>20 (19)</td>
<td>Hypo-/A/A</td>
</tr>
<tr>
<td>HCC (n = 18)</td>
<td>4 (4)</td>
<td>Hyper-(rim)/hypo-/hypo-</td>
</tr>
<tr>
<td>Non-Hodgkin lymphoma (n = 1)</td>
<td>18 (100)</td>
<td>Hypo-/A/A</td>
</tr>
<tr>
<td></td>
<td>1 (100)</td>
<td>Hyper-(rim)/hypo-/hypo-</td>
</tr>
</tbody>
</table>

Note—Numbers in parentheses are percentages. Of 14 patients who had more than one colorectal metastasis, eight patients demonstrated different CT appearances of the metastases; two different appearances in five patients and three different appearances in three patients. Likewise, of 12 patients who had more than one noncolorectal metastasis, four patients demonstrated two different CT appearances of the metastases.

* Carcinoid (n = 51), pancreatic endocrine carcinoma (n = 15), breast carcinoma (n = 13), renal carcinoma (n = 13), medullary thyroid carcinoma (n = 10), and leiomyosarcoma (n = 1).

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**Table 5**

<table>
<thead>
<tr>
<th>Pathologic Diagnosis</th>
<th>Size Distribution of Malignant Lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1 cm</td>
</tr>
<tr>
<td>Colorectal metastases (n = 62)</td>
<td>11</td>
</tr>
<tr>
<td>Noncolorectal metastases (n = 103)</td>
<td>33</td>
</tr>
<tr>
<td>HCC (n = 18)</td>
<td>11</td>
</tr>
<tr>
<td>Non-Hodgkin lymphoma (n = 1)</td>
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The combination of all phases allowed us a confident diagnosis of hemangioma in 86% of all hemangiomas present (Table 6). Since 25 (42%) of the 59 hemangiomas were 2 cm or smaller, this is a good result and compares favorably with the findings of a biphasic CT study designed to differentiate hemangiomas from malignant lesions (10). In that study, bolus dynamic phase combined with delayed scanning (5–60 minutes after injection of contrast material) allowed a confident diagnosis in 53.7% of hemangiomas. In addition, the criteria used were not specific, since one pancreatic carcinoma metastasis was erroneously characterized as hemangioma. We believe that the better results in our current study were achieved because the triphasic spiral CT technique allows optimal use of contrast dynamics due to the speed of data acquisition. Overlapping reconstructions allow centering of the plane of reconstruction with respect to lesions and, thus, leads to a higher percentage of typical appearances. More stringent criteria for the “typical hemangioma appearance” were adopted to prevent false-positive diagnoses. The ability of triphasic liver CT to facilitate confident characterization of most hemangiomas, irrespective of their size, potentially can lead to a substantial reduction in confirmatory tests, such as T2-weighted MR imaging, red blood cell scintigraphy, or histologic biopsy, as advocated in patients suspected of having hemangiomas (14).

The second group of lesions with hyperattenuation in the arterial phase demonstrated enhancement less than arterial space attenuation. Hyper-/A/A lesions are nonspecific hypervascular lesions found in malignant and benign disease. Most (84%) hyper-/A/A lesions were malignant and represented metastases from hypervascular tumors or HCC (Table 3, Fig 4). Although 90 (87%) of 103 noncolorectal metastases represented metastases from hypervascular primary tumors, only 44% presented as hyperattenuating lesions in the arterial phase (19% hyper-/A/A and 25% mixed/mixed/mixed); the remainder (51% hypo-/hypo-/hypo- and 4% hyper-(rim)/hypo-/hypo-) were indistinguishable from hypovascular colorectal metastases (Table 4). Whether metastases from hypervascular primary tumors are well depicted on an incremental bolus dynamic scan is a matter of discussion (33–35). If lesion detection is the only issue, portal phase images alone would have allowed detection of all hypervascular metastases. However, 13 (65%) of 20 hypervascular metastases that appeared as hyper-/A/A lesions were better delineated on arterial phase images, while the other seven (35%) hyper-/A/A hypervascular metastases were better delineated on portal phase images owing to a small hypoattenuating rim that surrounded the otherwise isoattenuating lesion (Fig 4).

All 18 HCC lesions presented as hyper-/A/A; three lesions were only visible in the arterial phase, five lesions were hypooptenuating in the portal phase, and 10 lesions (present in one patient) were hyperattenuating in the portal phase and better visualized than in the arterial phase. These findings are in keeping with the well-known hypervascularity of HCC (15,24,36). However, larger studies are needed to confirm if all hyper-/A/A lesions occurring in patients with chronic liver disease truly represent HCC lesions.

Only 16% of hyper-/A/A lesions were benign and represented adenomas, FNHs, or a benign lesion with unknown histologic diagnosis (Table 3). Interpretation of a hyper-/A/A lesion should be done in a clinical context; all malignant hyper-/A/A lesions occurred in patients with chronic liver disease or in patients with a known hypervascular primary malignancy. Conversely, all benign hyper-/A/A lesions occurred in patients without such a history, except one lesion in a patient with a history of melanoma. Consequently, aspiration biopsy was
Figure 2. Colorectal metastasis with hyper-(rim)/hypo-/hypo- appearance. (a) Arterial phase image shows a homogeneously enhanced hyperattenuating rim (arrows). (b) Portal phase image shows that the lesion was homogeneously hypoattenuating. (c) Equilibrium phase image shows that the periphery of the metastasis is hypoattenuating (arrows) relative to the enhanced center of the lesion and the surrounding liver parenchyma.

Figure 3. Triphasic liver CT images at two anatomic levels. (a–c) In the anterior segment of the left lobe, a lesion is present with the appearance of a large arterial/arterial/arterial lesion. (d–f) In the right lobe, a small subcapsular lesion is present (arrow) that showed intense and complete enhancement in the arterial (d) and portal (e) phases, consistent with a small arterial/arterial/arterial lesion. Both lesions demonstrated complete enhancement in the equilibrium phase (c, f [arrow]), hyperattenuating compared with the vascular system. Two hemangiommas were confirmed at laparotomy.
essential for differentiating melanoma metastasis from adenoma or FNH.

Hyper-/A/A(cleft) refers to a subtype pattern wherein a central hypoattenuating cleft is observed in the arterial phase, and the cleft enhances in the equilibrium phase. This cleft may be stellate, round, or linear. In all hyper-/A/A(cleft) lesions with a standard of reference, the diagnosis of FNH was confirmed (Fig 5). Conversely, a hyper-/A/A(cleft) appearance was found in 71% of FNH (Table 6), which compares favorably with angiography, and reported to be characteristic in 73% (11). In view of the associated risk of hemorrhage in adenomas, it is important to differentiate adenomas from FNH. In our limited experience so far, a hyper-/A/A(cleft) lesion excludes the possibility of adenoma, thus potentially limiting the need for further imaging procedures.

In one patient, a wedge-shaped area of hyperattenuation was observed in the arterial phase, in an area where no abnormality was found at surgery. It is important to differentiate such a hyper-(wedge)/iso-/iso- pattern, without any sign of focal disease, from subsegmental areas of contrast enhancement, which may accompany focal liver lesions, probably due to increased arterial supply to the liver region that contains the lesions (7,37).

All mixed/mixed/mixed lesions represent malignant disease, the majority (26 lesions [93%]) being noncolorectal metastases (Table 3). Probably, the combination of enhancing tumor with interspersed areas of necrosis was the cause of this appearance.

Study Limitations

A number of limitations are present in our study. The study was not blinded; the clinical history of all but one patient and the results of other imaging studies in some patients were known. The reported data are only relevant to the studied population, wherein some abnormalities were not represented (eg, infectious disease). Some of the standards of reference used can be criticized. In some patients with multiple lesions, biopsy was performed of only one lesion, and coexisting lesions with the same CT appearance were assumed to represent the same abnormality as the biopsy lesion. Preferably, each lesion would have been correlated with surgery or biopsy, but this would exclude a large amount of lesions from the study and introduce a selection bias. We are unable to quantitate the addition value of arterial and equilibrium phase sections relative to portal phase sections alone for two reasons. First, sections of the three phases were interpreted concurrently, and second, section geometry of the three phases differed. If all three phases would have been acquired with the same section geometry, comparison of the value of the three separate phases would have been meaningful. However, with the scanner used, this could only have been achieved by scanning all phases with 10-mm collimation and 10 mm/sec table speed. Instead, we chose 5-mm collimation and 5 mm/sec table speed for the portal sections to minimize partial volume averaging. Other scanners, and the most recent version of the scanner used, offer the possibility of identical section geometry in all phases, with use of 7- or 8-mm collimation; however, this would still result in an increase in partial volume averaging in portal phase sections.

By strictly defining the 11 CT appearances, an objective characterization system is implied. In our experience, the definitions of the various CT appearances do fit the vast majority of lesions; however, some lesions are difficult to classify because they do not strictly follow the definition of the various CT appearances. In these cases, one has to judge which appearance best fits the lesion under study.

Conclusions

Triphasic spiral liver CT is a standardized CT procedure, designed to enable detection and characterization of a large variety of liver lesions, also in the presence of different pathologic conditions and multilevel disease. The 5-mm portal phase images, reconstructed at 2-mm intervals, acquired at the peak of liver enhancement are the centerpiece of the protocol and are essential for lesion detection. Arterial phase images are helpful in the detection of hypervascular lesions and are essential for the characterization of a large proportion of lesions. Equilibrium phase images further aid
in lesion characterization. Our results demonstrate that characterization of frequently occurring benign focal liver lesions, such as hemangiomata, cyst, and FNH, which represented 117 (36%) of the 326 focal liver lesions with a standard of reference, was satisfactory (51 [86%] of 59 hemangiomata, 51 [100%] of 51 cysts, and five [71%] of seven FNHs). All lesions with a small hypo-/hypo-cyst)/hypo-appearances were almost all benign. Conversely, all hyper-/hypo-appearances were either due to probably fibrosed hemangiomata; the remainder were due to both colocolctal and non-colocolctal metastases.

In clinical practice, one has to decide in which patients to use triphasic liver CT. The liver is scanned four times, with resultant increased radiation exposure. In addition, the procedure takes more time and is more costly than (single-phase) spiral CT because of the large number of images acquired that all have to be reconstructed and interpreted. Therefore, one has to limit its use to patients who are likely to gain from this additional burden.

In our clinic, patients with unclassified lesions at US or monophasic CT, possible resectable colorectal metastases or metastases from hypervascular primary tumors, and suspected HCC constitute the vast majority of those who undergo triphasic liver CT. In these patients, triphasic liver CT, performed as an outpatient procedure, is likely to provide most information needed for clinical management.

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