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Renate M. Hammerstingl
Thomas J. Vogl

Abdominal MDCT: protocols and contrast considerations

R.M. Hammerstingl (✉), T.J. Vogl
Department of Diagnostic and Interventional Radiology
University of Frankfurt am Main
Theodor Stern Kai 7
60590 Frankfurt am Main
Germany
E-mail: hammerstingl@em.uni-frankfurt.de
Tel: +49-69-6301-5167
Fax: +49-6301-83683

Abstract Multidetector computed tomography (MDCT), is the latest breakthrough in CT technology. Thin sections can now be acquired a routine basis in a single-breathhold with 3D-isotropic reconstructions. This results in improved lesion detection of benign as well as malignant abdominal tumours. The ability to scan through the entire abdomen in seconds allows multiphasic acquisitions. Therefore precise timing and optimized contrast is of great importance.
Hypervascularized solid abdominal tumours are best depicted within the time generally regarded as the arterial dominant phase in MDCT, conversely hypovascular lesions are best depicted during venous phase imaging. The acquisition of an early arterial phase provides precise documentation of the arterial vascular system and should be obtained in preoperative abdominal imaging. Three clear separate circulatory phases enable best results in the pretherapeutic work-up of abdominal patients. Regarding follow-up oncologic work-up in colorectal metastatic disease a venous dominant phase might be the optimal protocol.
Regarding contrast optimization, the traditional concept of imaging, where the injection duration equals the scanning duration cannot be used without modifications. To ensure adequate vessel opacification as well as soft tissue imaging with fast MDCT acquisitions, the iodine administration rate needs to be increased. This can be achieved either by an increase of injection flow rate or -more conveniently- by using a higher iodine concentration of the contrast medium. Especially for hypervascular tumours, e.g. HCC, a considerably to far higher contrasts can be achieved using higher concentrated contrast material. The overall improvement in precise timing and better visibility enable a comprehensive approach to abdominal imaging in MDCT.

Keywords Abdominal imaging · MDCT · high iodine · contrast considerations · hepatobiliary system

Introduction

Computed tomography (CT) remains one of the main techniques for imaging of the abdomen. It is still the most commonly used modality for evaluation of the liver, the pancreas and the colon. With the increasing use of MDCT, diagnostic accuracy has been dramatically enhanced resulting in detection rates of up to 95% for focal liver lesions [1]. MDCT scanning of the pancreas is most commonly performed to image inflammatory pancreatic disease with its associated complications and to detect and characterise benign versus malignant pancreatic tumours. The clinical value of MDCT is also focused on imaging of colorectal carcinoma and has proven to be a reliable examination technique for staging of colorectal diseases [2].

Table 1 Diagnostic advantages of MDCT in abdominal imaging

Scan time: shorter scan duration
Improved scanning of soft tissue organs:
- well defined phase of enhancement and perfusion imaging
Scan length: longer scan ranges
Imaging of the vascular system : CT-Angiography
- abdominal aorta, branches of aorta, hepatic arteries and veins, portal vein, mesenteric vessels
Slice thickness: thinner sections
Near isotropic imaging: Postprocessing techniques
- MPR, MIP, VRT, 3D rendering

An overview on protocols and contrast considerations in abdominal MDCT will be given with a focus on the hepatobiliary system.

Abdominal imaging in MDCT

Since its clinical introduction in 1991, volumetric CT scanning has evolutionized diagnostic imaging. Spiral CT has improved over recent years with faster gantry rotation, more powerful X-ray tubes and improved interpolation algorithms, but the greatest advance has been the recent introduction of multi–detector computed tomography (MDCT). Currently capable of acquiring 64 channels of helical data simultaneously, MDCT scanners have achieved the greatest incremental gain in scan speed [3]. Fundamental advantages include substantially shorter acquisition times, creation of thin sections on a routine basis in a single-breathhold, retrospective calculation of thinner or thicker sections from the same raw data, and improved 3D postprocessing (Table 1).

MDCT is adapted to abdominal imaging to produce, under appropriate clinical circumstances, a multipass multiplanar study obtained during defined circulatory phases so as to best outline the vasculature and to image soft tissue tumours (Tables 2 and 3).

This results in improved detection and depiction of tumorous tissue, in terms of tumour size and to tumour/surrounding tissue contrast ratio. Enhancement characteristics described with multiphasic scanning and thinner reconstructed sections allow improved diagnosis in MDCT imaging of the abdomen [4].

Table 2 Scanning protocol in MDCT of the abdomen (4-slice scanner)

Scan	Unenhanced phase	Late arterial phase	Portal venous phase
Collimation	4 x 2.5 mm	4 x 1 mm	4 x 2.5 mm
Normalised pitch	1	1.5	1
Table feed/gantry rotation	10 mm	6 mm	10 mm
kV	120	120	120
Tube current (effective mAs)	150–180	150–180	50–180
Time of rotation (sec)	0.5	0.5	0.5
Scan duration (sec)	10	15	10
Scan delay:	CB (120 HU threshold)		
(post cm injection start)		~30 s	~70 s
Contrast concentration (mg I/ml)	370-400		
Contrast material (Volume in ml)	80		40
Injection rate (ml/s)	4.0		3.0
Saline flush (Volume in ml)	20-50		
MPR:			
Reconstruction (mm)	3	2	3
Increment (mm)	2	1	2

Scanner: Siemens Volume Zoom

Table 3 Scanning protocol in MDCT of the abdomen (16-slice scanner)

Scan	Unenhanced phase	Late arterial phase	Portal venous phase
Collimation	16 x 1.5 mm	16 x 0.75 mm	16 x 1.5 mm
Normalised pitch	1	1	1
Table feed/gantry rotation	24 mm	12 mm	24 mm
kV	120	120	120
Tube current (effective mAs)	150–180	150–180	50–180
Time of rotation (sec)	0.5	0.5	0.5
Scan duration (sec)	5	10	5
Scan delay: (post cm injection start)	CB (140 HU threshold)	~35 s	~70 s
Contrast concentration (mgl/ml)	370-400		
Contrast material (Volume in ml)	70		30
Injection rate (ml/s)	4.5		2.5
Saline flush (Volume in ml)	20-50		
MPR:			
Reconstruction (mm)	2	1	2
Increment (mm)	1	0.5	1

Scanner: Siemens Sensation 16

Protocols in MDCT of the abdomen

Detection of lesions of the abdomen is determined by conspicuity and is related to the degree of tumour to tissue contrast. As tumour characterization is mainly based on lesion contrast uptake in the different enhancement phases, scanning in sufficient phases is absolutely mandatory [5].

During the *early arterial phase* (20 s post start of injection) there is avid enhancement in the arterial vessels but relatively little enhancement of the parenchyma or hypervascular lesions. Accurate CT-angiography with optimal vessel opacification can be performed in presurgical evaluation [6, 7] (Fig. 1).

In the *late arterial phase* or portal vein *inflow phase*, which occurs approximately at 30-35 s post injection, solid neoplasms will be maximally enhanced, whereas the parenchyma will be only minimally enhanced due to predominantly portal venous supply. Therefore this phase is optimal for detection of hypervascular primary liver tumours (Fig. 2) and metastatic infiltration. The *pancreatic parenchymal phase* begins at 40-45 s post injection and provides the highest rates of enhancement of the pancreas.

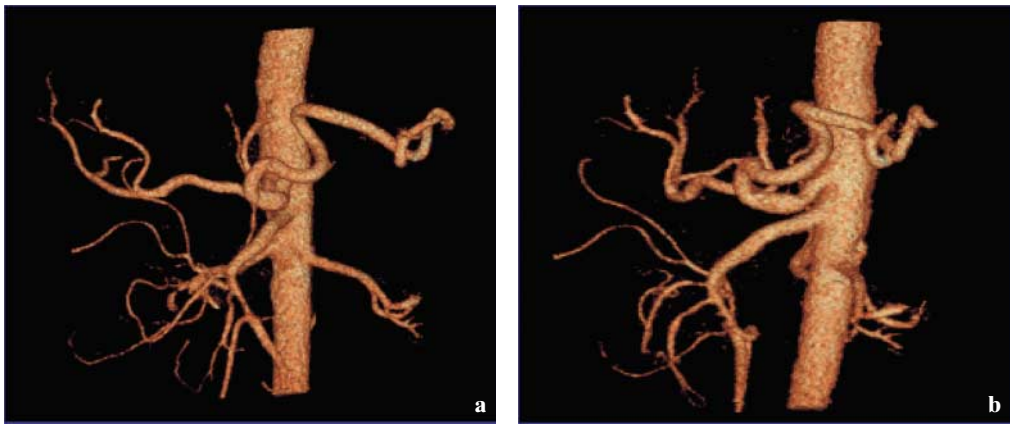

Fig. 1 a, b CT-angiography of the upper abdomen. Documentation of normal arterial vascular anatomy using early arterial imaging and a VRT reconstruction mode (**a**, **b**)

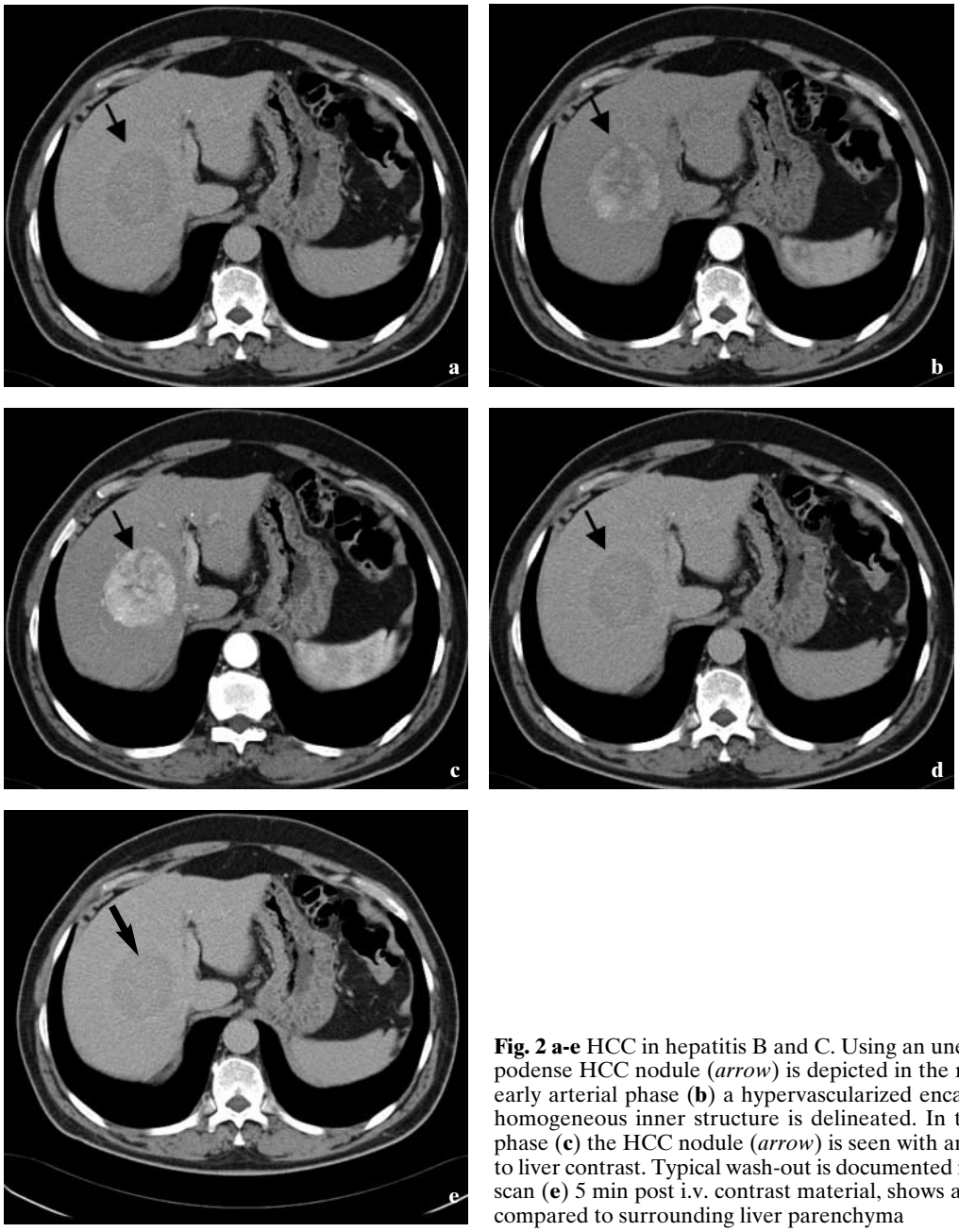

Fig. 2 a-e HCC in hepatitis B and C. Using an unenhanced (**a**) CT scan a large hypodense HCC nodule (*arrow*) is depicted in the right liver lobe segment 8. In the early arterial phase (**b**) a hypervascularized encapsulated lesion (*arrow*) with inhomogeneous inner structure is delineated. In the late arterial phase or inflow phase (**c**) the HCC nodule (*arrow*) is seen with an increasing flush and best lesion to liver contrast. Typical wash-out is documented in venous imaging (**d**). A delayed scan (**e**) 5 min post i.v. contrast material, shows again a hypodense lesion (*arrow*) compared to surrounding liver parenchyma

The phase of portal venous dominante, the *hepatic venous phase* or *portal venous phase or hepatic parenchymal phase* occurs 60-70 s post start of injection with maximum enhancement of the hepatic and still high values in the pancreatic parenchyma. The detection of relatively hypovascular tumours, such as colorectal metastases or adenocarcinoma of the pancreas, is favoured, which may be unsuspected and in some cases poorly imaged during the other two phases.

For an elective diagnosis of the *colon*, cleansing, distension, endoluminal contrast and spasmolytics are mandatory. A very thin-sliced protocol starting approximately 60 s post injection with medium flow velocity, is the optimal imaging protocol. The colon can subsequently be assessed in 3D by using multiplanar reconstruction combined with endoscopic views.

Multiphasic contrast-enhanced MDCT imaging of the liver

The major clinical aspects in liver imaging are detection and characterization of lesions. Moreover the depiction of parenchymal changes and secondary findings are also important (Table 4).

Optimal delineation of hypervascular liver lesions compared to surrounding liver parenchyma is established in the arterial phase of MDCT. Murakami et al. [8] reported an increased detection rate (sensitivity: 86%; positive predictive value: 92%) of HCC nodules using double-arterial imaging, a combination of early and late arterial phase imaging. Further studies, from Ichikawa et al. [9] and Laghi et al. [10] found no significant improvement of double-arterial phase imaging compared to single late arterial-phase imaging (Fig. 3). In a recently published study, Zhao et al. [11] highlighted these results. Their study revealed no statistically significant difference between a double compared to a single arterial protocol regarding the detection rate of HCC nodules (Fig. 4).

Hypovascular liver lesions, e.g. liver metastases are best depicted using venous phase imaging (Fig. 5).

Table 4 Clinical aspects in liver imaging

- Detection of focal liver lesions:
  - Conspicuity
    - size of tumour
    - contrast of tumour to liver parenchyma
    - delineation of boundary
- Characterization of focal liver lesions:
  - Contrast uptake
    - Different phases of contrast uptake
    - Precise timing of scanning phases
      evaluation of vascularity
      evaluation of morphology
- Documentation of parenchymal changes:
  - Regenerative change
  - Nodularity of liver surface
  - Alteration of vascular anatomy
  - Lobar or segmental changes of hepatic morphology
- Documentation of secondary findings:
  - Ascites
  - Splenomegaly
  - Enlargement of extrahepatic portal venous system
  - Gallbladder/small bowel edema

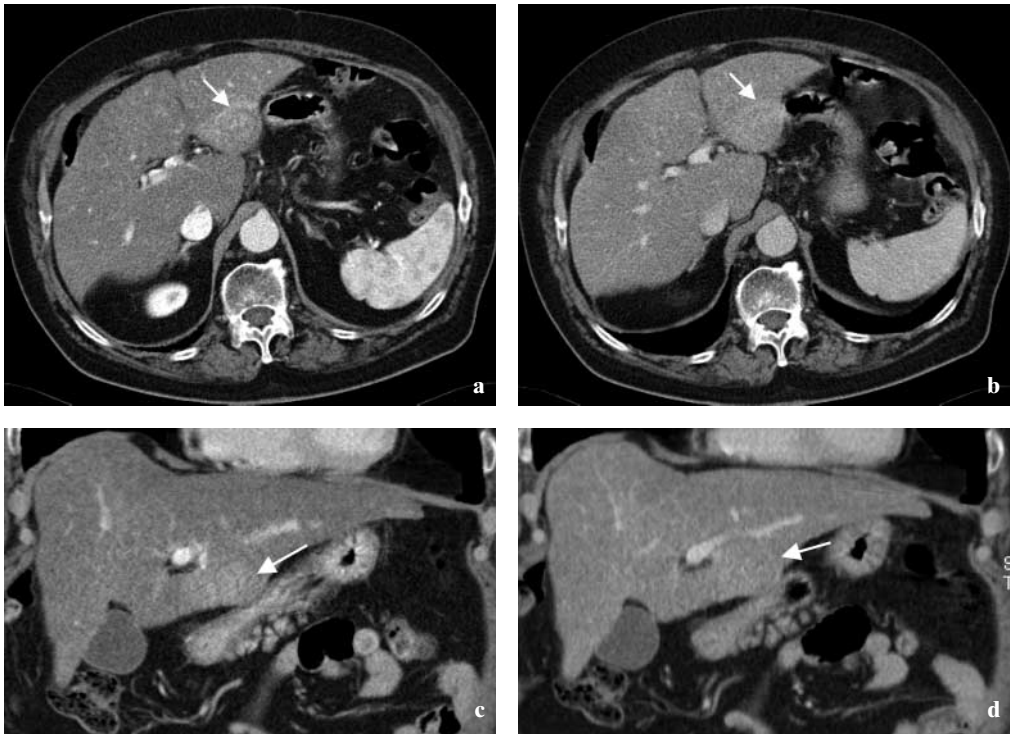

Fig. 3 a-d HCC in liver cirrhosis. Advanced depiction of HCC nodule (*arrow*) in the late arterial phase (**a**) compared to the venous phase (**b**) of scanning in MDCT of the liver. Excellent visualization of the moderate hypervascularized HCC using coronal MPR imaging in the inflow phase (**c**). The reconstructed coronal image in the venous phase (**d**) depicts the capsular appearance of the HCC nodule

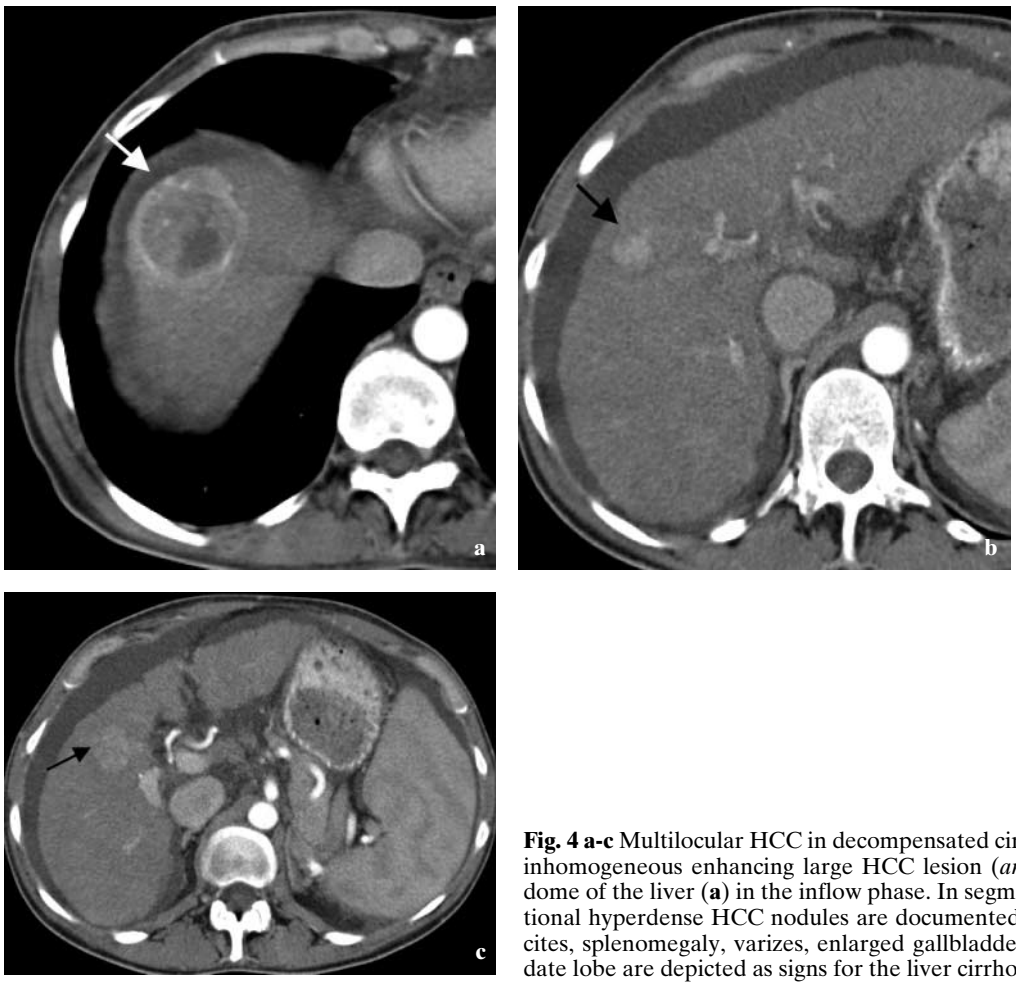

Fig. 4 a-c Multilocular HCC in decompensated cirrhosis. A nodular, encapsulated, inhomogeneous enhancing large HCC lesion (*arrow*) is delineated in the upper dome of the liver (**a**) in the inflow phase. In segment 8 (**b**) and segment 5 (**c**) additional hyperdense HCC nodules are documented in the a late arterial phase. Ascites, splenomegaly, varizes, enlarged gallbladder fossa, hypertrophy of the caudate lobe are depicted as signs for the liver cirrhosis

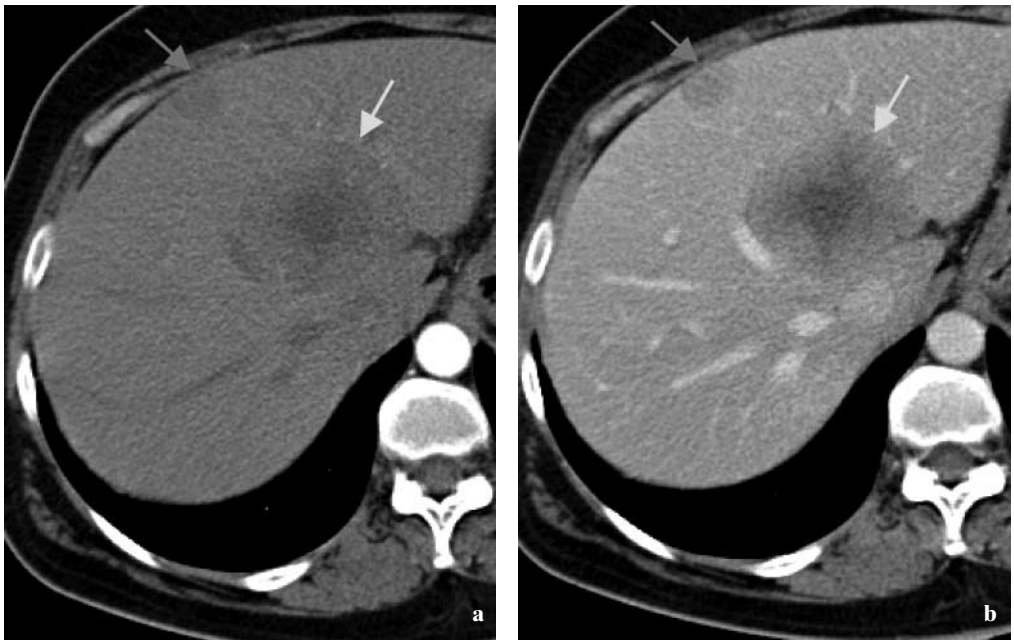

Fig. 5 a, b Liver metastases in colorectal cancer. A large liver metastasis (*arrow*) in the center of the right liver lobe compressing the hepatic veins as well as the portal venous system is best seen in a venous (**b**) phase compared to arterial phase scanning due to the hypovascular nature of the metastasis. A secdondary small metastasis (*small arrow*) is documented in the periphery of segment 4A

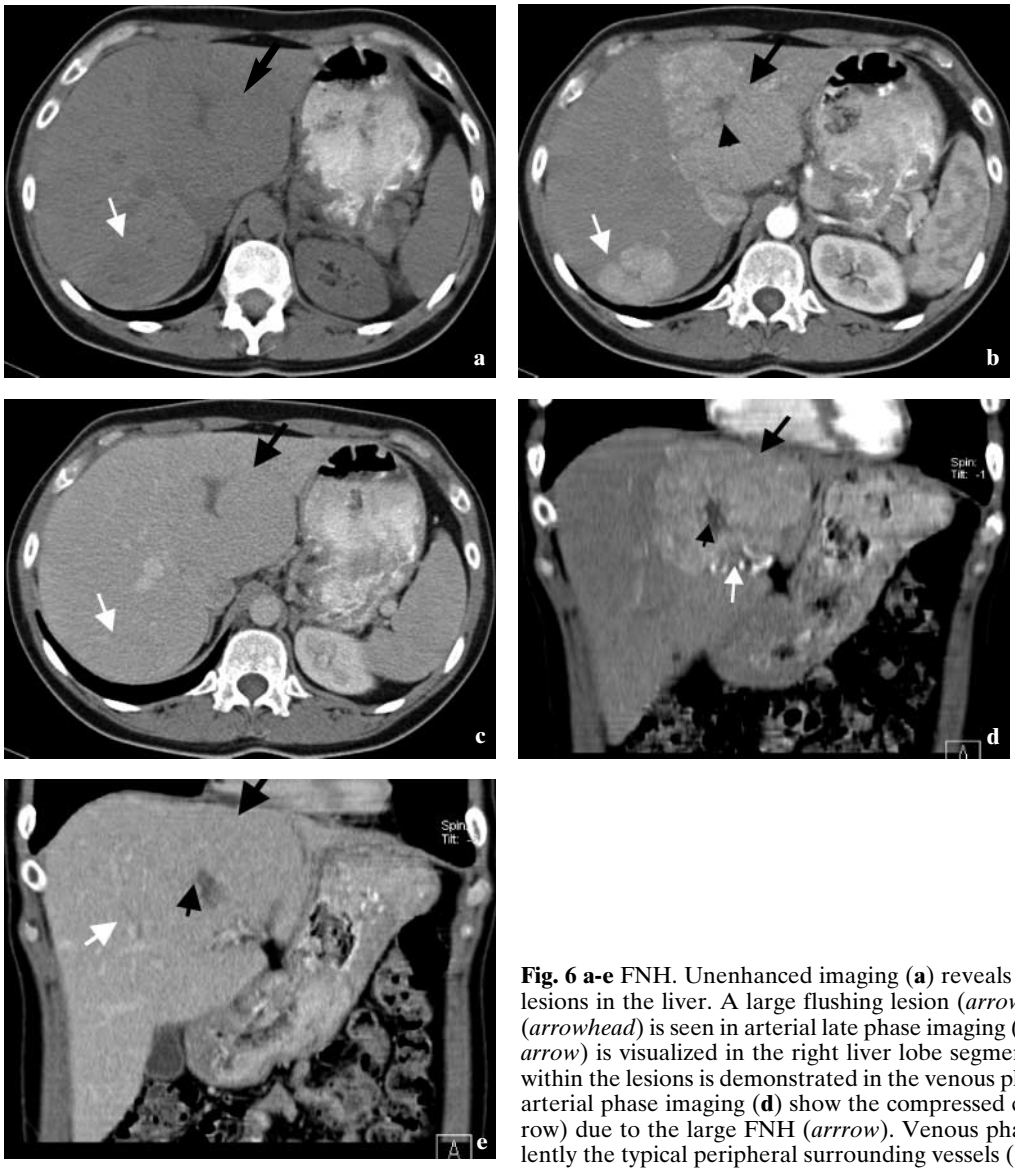

Fig. 6 a-e FNH. Unenhanced imaging (**a**) reveals two moderate hypo- to isodense lesions in the liver. A large flushing lesion (*arrow*) with a central hypodense scar (*arrowhead*) is seen in arterial late phase imaging (**b**). A second FNH nodule (*white arrow*) is visualized in the right liver lobe segment 7. Typical decrease of density within the lesions is demonstrated in the venous phase (**c**). Coronal MPR images in arterial phase imaging (**d**) show the compressed central arterial vessels (white arrow) due to the large FNH (*arrrow*). Venous phase imaging (**e**) delineates excellently the typical peripheral surrounding vessels (*white arrow*)

For characterization of focal liver lesions enhancement patterns such as homogeneous fill-in, abnormal internal vessels, peripheral puddles, and a complete ring help to diagnose more precisely. According to Nino-Murcia and coworkers [12], abnormal internal vessels are associated with HCC, peripheral puddles with hemangioma, and a complete ring with metastasis, in arterial phase imaging. Early flushing of lesions with central scar and decrease of density over time is typical for focal nodular hyperplasia (FNH) (Fig. 6).

According to Lim and coworkers [13] delayed phase imaging helps the diagnosis of HCC, especially for hypovascular tumours. Loyer et al. [14] documented an increased tumour attenuation of CCC on delayed images compared to HCC.

A suitable scanning protocol for MDCT of the liver on a 16-slice scanner is shown in Table 5.

Multiphasic contrast-enhanced MDCT imaging of the pancreas

The clinical aspects in pancreatic imaging are identifying complications of acute pancreatitis, such as exsudates (Fig. 7), obstuction in chronic pancreatitis (Fig. 8), pseudocysts (Fig. 9), necrosis (Fig. 10) and abscesses [15, 16].

Another major topic is tumour imaging. The detection of tumorous tissue and visualization of organ and vessel infiltration is important so as to determine whether a tumour is resectable or not [17]. For visualization of organ infiltration (Figs 11 and 12) a good contrast-to-noise ratio is mandatory. To diagnose vessel infiltration, the optimal imaging phase must be timed (Table 6).

For staging in case of pancreatic carcinoma a quadruple-phase scanning protocol includes unenhanced, arte-

Table 5 Scanning protocol in MDCT of the liver (16-slice scanner)

Scan	Early arterial phase	Lateral arterial phase	Portal venous phase
Collimation	16 x 0.75 mm	16 x 1.5 mm	16 x 1.5 mm
Normalised pitch	1	1	1
Table feed/gantry rotation	12 mm	24 mm	24 mm
kV	120	120	120
Tube current (effective mAs)	150–180	150–180	50–180
Time of rotation (sec)	0.5	0.5	0.5
Scan duration (sec)	10	5	5
Scan delay:	CB (140 HU threshold)		
(post cm injection start)	~20 s	~35 s	~70 s
Contrast concentration (mg l/ml)	400		
Contrast material (Volume in ml)	70		30
Injection rate (ml/s)	4.5		2.5
Saline flush (Volume in ml)	20-50		
MPR:			
Reconstruction (mm)	1	2	2
Increment (mm)	0.5	1	1

Scanner: Siemens Sensation 16

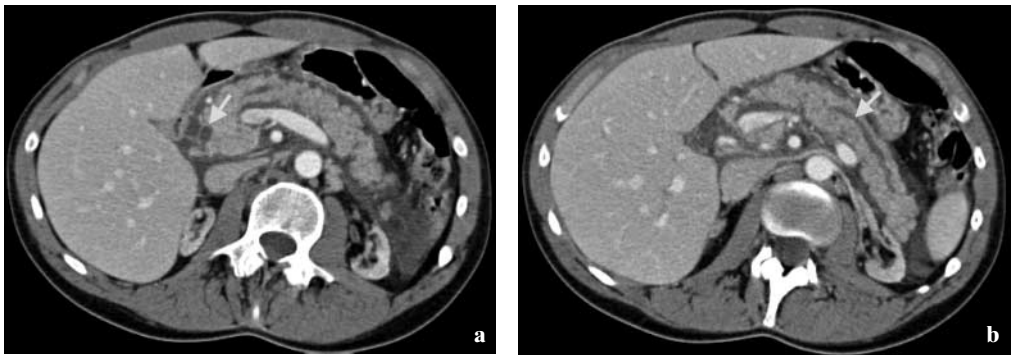

Fig. 7 a, b Acute pancreatitis. Documentation of a dilated common bile duct (*arrow*) in venous phase imaging (**a**, **b**) as well as a dilatation of the pancreatic duct in the distal parts of the pancreas. Exsudates are seen around the pancreatic panrenchyma

rial, pancreatic parenchymal, and portal venous phase imaging. For depiction of large carcinomas, the depiction of the pancreatic parenchymal phase is necessary. According to Raptopoulous et al. [18] arterial phase scanning is more optimal for the detection of small pancreatic adenocarcinomas due to the delay of tumor enhancement compared to pancreatic parenchymal enhancement. This was more often documented in smaller tumours than in larger ones.

According to Fishman and coworkers [19], a combination of CTA techniques and three-dimensional volume rendering allows one to create unique displays for evaluating pancreatic cancer and for accurate staging in these patients.

A suitable scanning protocol for MDCT of the pancreas on a 16-slice scanner is shown in Table 7.

Table 6 Clinical aspects in pancreatic imaging

- Identifying the complications of acute pancreatitis:
  - exudates, pseudocysts, necrosis, abscess
- Tumour imaging:
  - tumour signs of the pancreatic tissue
    - loss of lobular textur
    - ductal cutoff: interrupted duct sign
    - dilatation of pancreatic duct and bile duct
    - hypodense lesion
    - mass effect
    - deforming contour
    - atrophic distal parenchyma
  - visualization of peripancreatic infiltration
    - duodenum, bile duct
  - visualization of infiltration of the surrounding:
    - stomach, spleen, large bowel
  - vessel infiltration
    - celiac trunc
    - superior mesenteric artery and vein

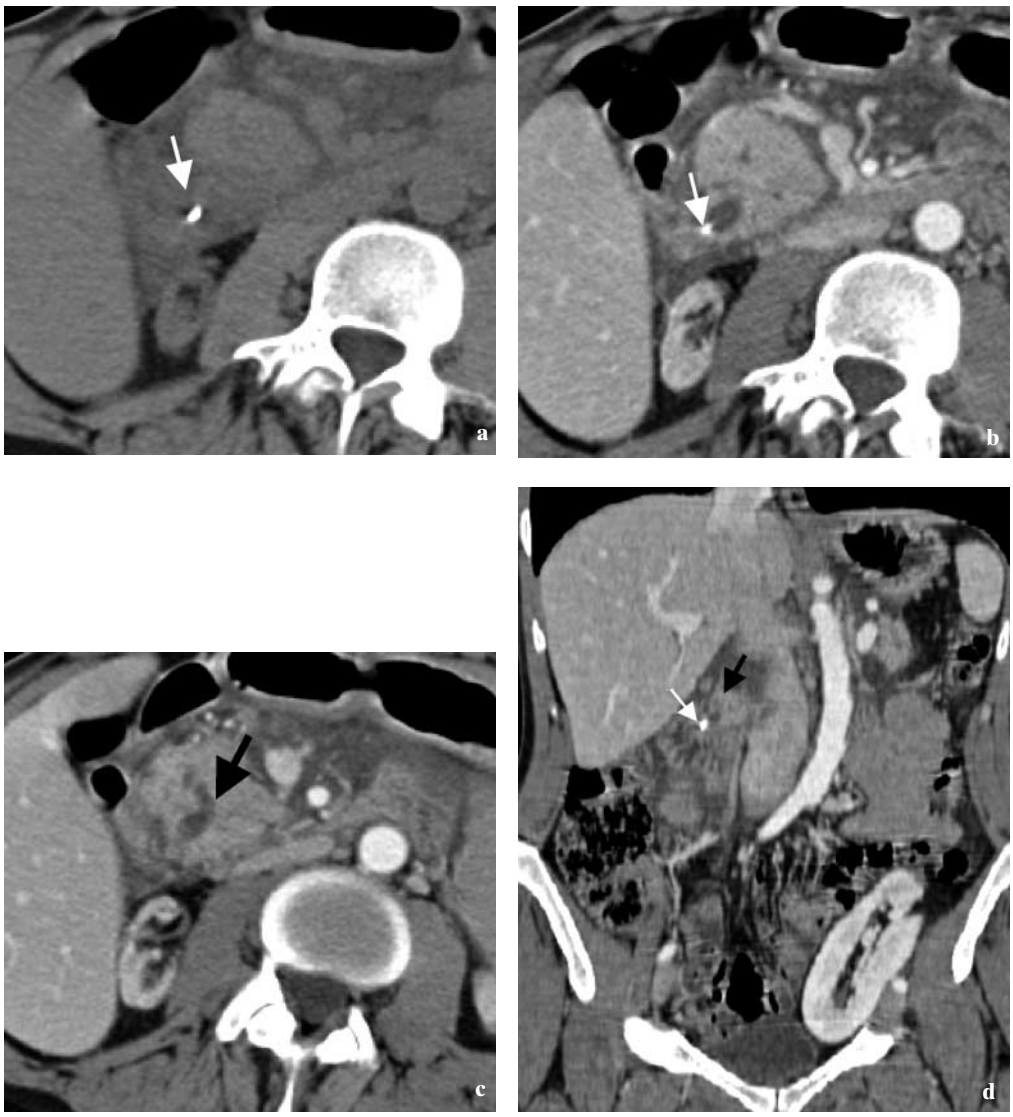

Fig. 8 a-d Obstruction in chronic pancreatitis. Unenhanced imaging (**a**) as well as venous phase imaging (**b**) depicts well a stone (*arrow*) in the proximal parts of the pancreatic duct impinging the common bile duct. Dilation of the distal duct parts post the obstruction (*black arrow*) are well demonstrasted in a venous scan (**c**). Best overview is obtained using a 3D-reconstruction in coronal plane (**d**). The concrement (*arrow*) as well as the dilated pancreatic duct structure (*black arrow*) are excellently visualized. Exsudates are seen around the pancreatic panrenchyma

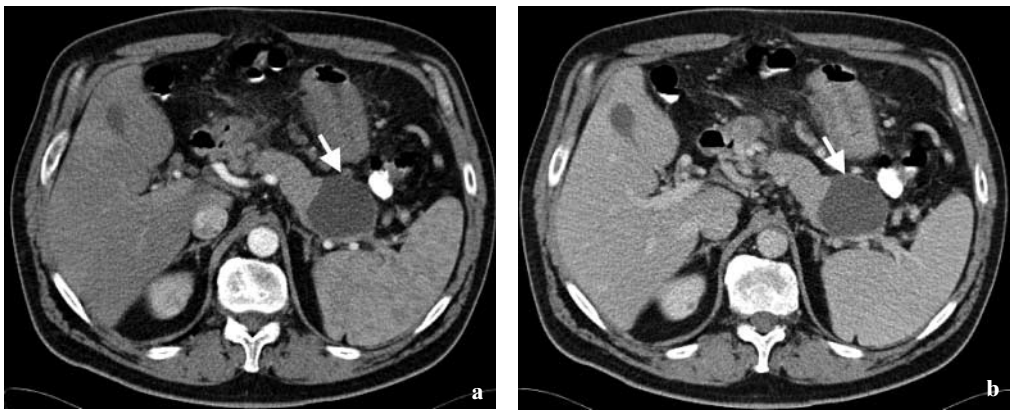

Fig. 9 a, b Pseudocysts in pancreatitis. A large pseudocycst (*arrow*) is demonstrated in the distal parts of the pancreas in arterial (**a**) and venous phase imaging (**b**) of MDCT

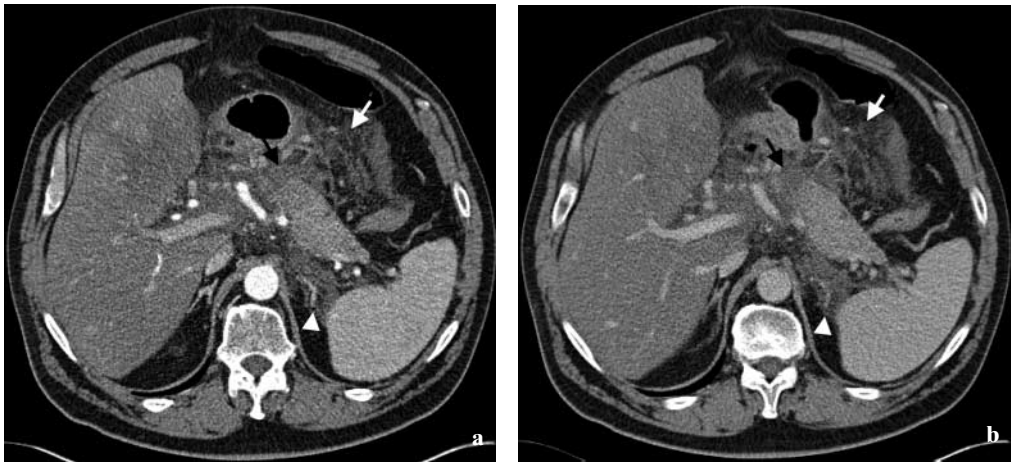

Fig. 10 a, b Necrotic areas in pancreatitis. In a pancreatic parenchymal phase (**a**) and venous phase (**b**) imaging necrotic areas (*black arrow*) of pancreatic parenchyma are delineated. Additionally infiltration of the fatty tissue (*white arrow*) and fluid spaces (*arrowhead*) are depicted

Table 7 Scanning protocol in MDCT of the pancreas (16-slice scanner)

Scan	**Unenhanced phase**	**Pancreatic phase**	**Portal venous phase**
Collimation	16 x 1.5 mm	16 x 0.75 mm	16 x 1.5 mm
Normalised pitch	1	1	1
Table feed/gantry rotation	24 mm	12 mm	24 mm
kV	120	120	120
Tube current (effective mAs)	150–180	150–180	50–180
Time of rotation (sec)	0.5	0.5	0.5
Scan duration (sec)	5	10	5
Scan delay:	CB (140 HU threshold)		
(post cm injection start)		~40 s	~70 s
Contrast concentration (mg l/ml)	400		
Contrast material (Volume in ml)	70		30
Injection rate (ml/s)	4.5		2.5
Saline flush (Volume in ml)	20-50		
MPR:			
Reconstruction (mm)	2	1	2
Increment (mm)	1	0.5	1

Scanner: Siemens Sensation 16

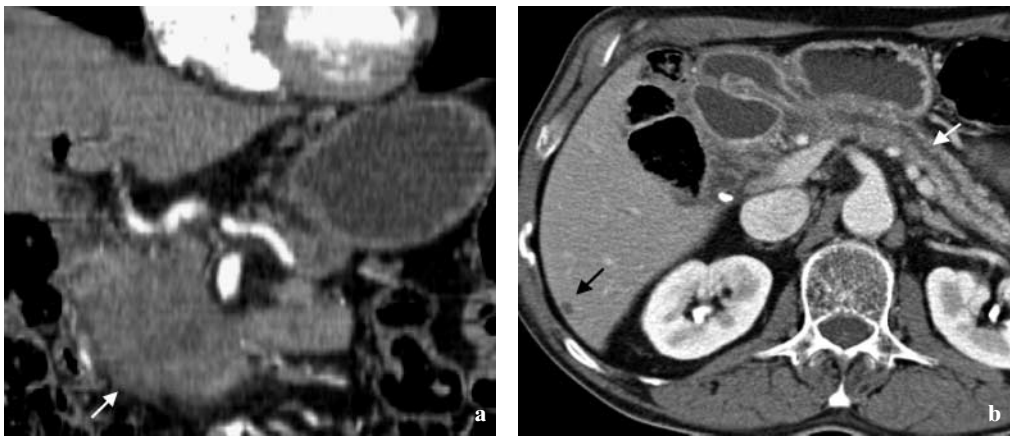

Fig. 11 a, b Pancreatic carcinoma with liver metastasis. 3D-coronal reconstruction depicts accurately the pancreatic carcinoma in the head of the pancreas (*arrow*) of the pancreatic parenchymal phase (**a**). Axial imaging in the venous phase (**b**) demonstrates a liver metastasis (*white arrow*) in the right liver lobe segment 6 and a dilated distal pancreatic duct system (*black arrow*)

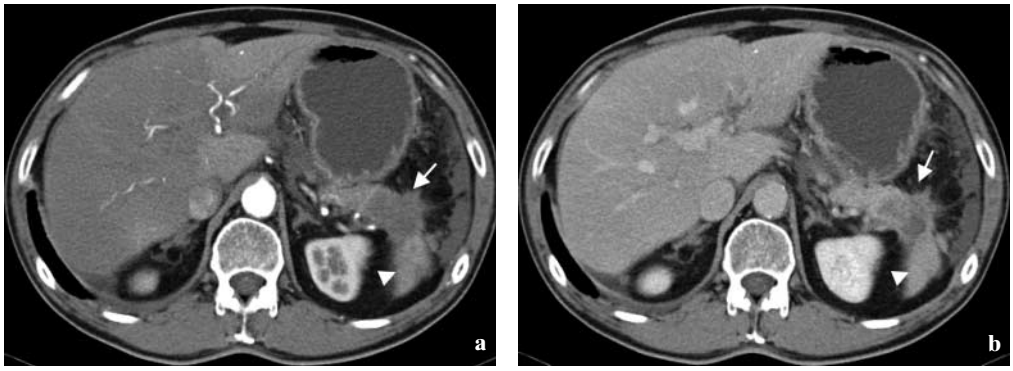

Fig. 12 a, b Pancreatic carcinoma with infiltration to the spleen. Distal parts of the pancreatic tail demonstrate an infiltrating adenocarcinoma (*arrow*) in the pancreatic parenchymal phase (**a**) and portal venous phase (**b**) of imaging. The occlusion of the pancreatic duct system due to tumour infiltration as well as splenic infiltration (*arrowhead*) is well documented

Contrast considerations

When imaging the abdomen, the depiction of parenchymal or soft tissue organs requires a certain amount of total iodine for appropriate scanning. The optimal amount of iodine should be approximately 35-45 g. When considering a median rate of 40 g iodine per imaging, the following volumes should be used: for lower-concentrated contrast agent (300 mgI/ml) an overall volume of 130 ml is necessary for adequate imaging quality; whereas for a concentration of 350 mgI/ml, 115 ml of contrast medium is needed; while for 400 mg I/ml, 100 ml is used.

Using early contrast dynamics as a reference point, it is obvious, that the traditional concept for abdominal imaging, where the injection duration equals the scanning duration, cannot be used without modifications. To ensure adequate vessel opacification as well as soft tissue imaging with fast MDCT acquisitions, the iodine administration rate needs to be increased. This can be achieved either by an increase of injection flow rate or, more conveniently, by using a higher iodine concentration contrast medium [20]. Data obtained from several clinical trials provided higher contrast density values of vascular structures, hepatic and pancreatic tissue as well as hypervascular tumours in arterial phase imaging using a high concentration contrast medium (Table 8).

Determination of the circulation time is of great importance. A test bolus can be used to calculate the circulation time; the use of care bolus technique is more convenient.

After injection of contrast medium, saline flushing should be performed to wash out the residual contrast in the venous system thereby increasing the parenchymal uptake due to the higher amount of iodine.

Table 8 Contrast considerations in MDCT

Modulation of arterial enhancement
Injection rate of contrast medium:
iodine administration rate
- doubling provides twice of enhancement
Injection duration:
time of total administration of volume
- first pass and recirculation effects
- longer injections provide a continuously increase of enhancement
Modulation of soft tissue enhancement
Determination of total contrast medium volume total iodine dose as the key issue
Injection flow rate is not the important factor

Use of high-concentration contrast media: abdominal imaging

According to Hanninen and colleagues [21], a decrease in iodine concentration significantly affects aortic and hepatic contrast enhancement and impairs the delineation of focal liver lesions during biphasic spiral CT. Mean hepatic enhancement and aortic time-attenuation curves were statistically superior using higher-concentrated contrast medium (370 mgI/ml) compared to lower concentrated contrast medium (300 mgI/ml).

In the vascular system of the liver, a greater enhancement in the arterial vessels was documented with 370 mg I/ml versus 300 mg I/ml according to Spielmann and coworkers [22].

Kim et al. [23] researching tumour imaging, found a greater enhancement of HCC using higher-concentrated, 370 mgI/ml in a protocol of 100 ml and a flow rate of 4 ml/s compared to a protocol of 100 ml containing 300 mgI/ml and the same flow rate. Yagyu et al. [24] stated that contrast materials with higher iodine concentration are more effective for depicting hypervascular HCCs on MDCT during the late arterial phase.

In their series of test, Merkle and coworkers [25] documented a statistically significant difference in contrast-enhancement using high-concentration contrast medium (Iomeprol 400 mg I/ml). There was an improvement in the contribution of high-concentration contrast media toward diagnostic value (p=0.02), technical quality (p=0.02) and evaluability of vessels in arterial-phase imaging.

The group of Shinagawa et al. [26] determinated maximum enhancement in the pancreas using CT with high-concentration contrast media in patients with abdominal disease.

We reported our experience in abdominal imaging [27] using a non-ionic high-concentrated contrast medium (Iomeprol) with an iodine concentration of 400 mg/ml compared to lower concentrated samples of 300 mgI/ml and 350 mgI/ml for abdominal imaging. Higher contrast density values of normal liver parenchyma and pancreatic tissue were calculated in the arterial phase for high-concentration contrast medium. For hypervascular tumors, the maximum of absolute contrast to surrounding tissue was increased, permitting a better delineation of vascularity of the lesions.

Conclusion

MDCT scanning times may vary substantially in daily clinical routine depending on the scanner type employed. Therefore acquisition parameters have to be modified. To ensure adequate vessel opacification as well as optimal detection and characterization of depicted abnormal soft tissue with fast MDCT acquisitions, the iodine administration rate needs to be increased. This can be achieved either by an increase of injection flow rate or more conveniently by using a higher iodine concentration of the contrast medium. These agents produce better enhancement of vascular structures and improved overall display of soft tissue tumours.

References

1. Itoh S, Ikeda M, Achiwa M et al (2003) Multiphase contrast-enhanced CT of the liver with multislice CT scanner. Eur Radiol 13:1085-1094
2. Foley WD, Kerimoglu U (2004) Abdominal MDCT: liver, pancreas, and biliary tract (review). Semin Ultrasound CT MR 25:122-144
3. Prokop M (2003) General principles of MDCT. Eur J Radiol 45 [Suppl 1]: 4-10
4. Kopp AF, Heuschmid M, Claussen CD (2002) Multidetector helical CT of the liver for tumor detection and characterization. Eur Radiol 12:745-753
5. Foley WD, Mallisee TA, Hohenwalter MD et al (2000) Multiphasic hepatic CT with a mulitrow detector CT scanner. AJR AM J Roentgenol 175:679-685
6. Sahani D, Saini S, Pena C et al (2002) Using multidetector CT for preoperative vascular evaluation of liver neoplasms: technique and results. AJR AM J Roentgenol 179:53-59
7. Rubin GD (2003) MDCT imaging of the aorta and peripheral vessels (review). Eur J Radiol [Suppl 1]:S42-49
8. Murakami T, Kim T, Takamura M et al (2001) Hypervascular hepatocellular carcinoma: detection with double arterial phase mulit-detector row helical CT. Radiology 218:763-767
9. Ichikawa T, Kitamura T, Nakajima H, Sou H, Tsukamoto T (2002) Hypervascular hepato-cellular carcinoma: can double arterial phase imaging with multidetector CT improve tumor depiction in the cirrhotic liver? Am J Roentgenol 179(3):751–758
10. Laghi A, Iannaccone R, Rossi P et al (2003) Hepatocellular carcinoma:

detection with triple-phase multi-detector row helical CT in patients in chronic hepatitis. Radiology 226: 543–549
11. Zhao H, Yao JL, Han MJ et al (2004) Multiphase hepatic scans with multirow-detector helical CT in detection of hypervascular hepatocellular carcinoma. Hepatobiliary Pancreat Dis Int 3(2):204-208
12. Nino-Murcia M, Olcott EW, Jeffrey RB Jr et al (2000) Focal liver lesions: pattern-based classification scheme for enhancement at arterial phase CT. Radiology 215(3):746-751
13. Lim JH, Choi D, Kim SH et al (2002) Detection of hepatocellular carcinoma: value of adding delayed phase imaging to dual-phase helical CT. AJR Am J Roentgenol 179(1):67-73
14. Loyer EM, Chin H, DuBrow RA et al (1999) Hepatocellular carcinoma and intrahepatic peripheral cholangiocarcinoma: enhancement patterns with quadruple phase helical CT-a comparative study. Radiology 212(3):866-875
15. Balthazar EF (2002) Staging of acute pancreatitis. Radiol Clin N AM 40:1199-1209
16. Kim T, Murakami T, Takamura M et al (2001) Pancreatic mass due to chronic pancreatitis: Correlation of CT and MR imaging features with pathologic findings. AJR AM J Roentgenol 177:367-371
17. Horton KM, Fishman EK (2002) Adenocarcinoma of the pancreas. Radiol Clin N Am 40:1263-1272
18. Raptopoulos VD, Kataaka MD, Brennan DD et al (2005) Early pancreatic phase scanning for detecion of pancreatic adnocarcinoma using 16-row and 64-row MDCT RSNA 2005, Book of abstracts P:502
19. Fishman EK, Horton KM, Urban BA (2000) Multidetector CT angiography in the evaluation of pancreatic carcinoma: preliminary observations. J Comput Assist Tomogr 24(6):849-853
20. Fleischmann D (2003) Use of high-concentration contrast media in multiple-detector-row CT: principles and rationale. Eur Radiol 13 [Suppl 5]:14-20
21. Hanninen EL, Vogl TJ, Felfe R (2000) Detection of focal liver lesions at biphasic spiral CT: randomised double-blind study of the effect of iodine concentration in contrast materials. Radiology 216:403-409
22. Spielmann AL (2003) Liver imaging with MDCT and HCCM. Eur J Radiol 45 [Suppl 1]:50-52
23. Kim KA, Park CM, Lee W et al (2001) Small hepatocellular carcinoma: Three-phase helical CT findings and pathologic correlation. Radiology 221:490 (Abstract book, RSNA)
24. Yagyu Y, Awai K, Inoue M et al (2005) MDCT of hypervascular hepatocellular carcinomas: a prospective study using contrast materials with different iodine concentrations. AJR Am J Roentgenol 184(5):1535-40
25. Merkle EM, Boll DT, Fenchel S (2003) Helical computed tomography of the pancreas: potential impact of higher concentrated contrast agents and multidetector technology. JCAT 27 [Suppl 1]:17-22
26. Shinagawa M, Uchida M, Ishibashi M et al (2003) Assessment of pancreatic CT enhancement using a high concentration of contrast material. Radiat Med 21:74-79
27. Hammerstingl RM, Valette PJ, Regent DM et al (2003) Multidetector CT in abdominal imaging: optimisation of iodine concentration for the diagnosis of abdominal tumors. Radiology [Suppl 1]:41