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ORIGINAL ARTICLE

Acute bowel ischemia: analysis of diagnostic error by overlooked findings at MDCT angiography

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Abstract To retrospectively evaluate the frequency and type of findings that were missed in the original reports of multi-detector CT angiography (MDCTA) in patients with suspected acute bowel ischemia. From January 2007 to March 2011, a series of 35 patients who underwent MDCTA of the abdomen and pelvis and had surgery were included. The reports of the initial CT were retrospectively compared with the discharge diagnosis and surgical reports. Discrepant or missing findings were re-evaluated and divided into relevant or not relevant regarding the diagnosis. In 23 of the 35 patients (66 %), all findings were correctly diagnosed in the initial MDCTA report. In the remaining 12 of the 35 patients (34 %), lesions that were not reported were present at surgery. In 10 of the 12 (83 %) patients, the overlooked findings were relevant and subtle: gas in the portal vein (n=3), gas in the bowel wall (n=3), gas in the portal vein and bowel wall (n=2), thrombotic occlusion of the superior mesenteric artery (n=1), and thrombotic occlusion of the inferior mesenteric artery (n=1). In 2 of the 12 (17 %) patients in whom the MDCTA-overlooked findings were classified as non-relevant, bowel ischemia was found at surgery. With retrospective image interpretation, 83 % of the patients with occlusive mesenteric ischemia at surgery were correctly identified, whereas the remaining 17 % with non-occlusive mesenteric ischemia at surgery showed non-relevant findings at MDCTA. About 33 % of relevant findings of bowel ischemia were overlooked by the initial MDCTA interpretation, most were subtle findings. However, secondary reading revealed most of these findings and can serve to improve diagnostic performance.

Keywords Multi-detector CT angiography · Acute bowel ischemia · Diagnosis · Acute abdomen

Abbreviations
SMA Superior mesenteric artery
IMA Inferior mesenteric artery
SMV Superior mesenteric vein

Introduction

Ischemic bowel disease is a complicated disorder, whose prevalence is increasing all over the world. It represents a broad spectrum of diseases with various clinical and radiological manifestations. Primary causes of insufficient blood supply to the bowel include thromboembolism, non-occlusive causes, bowel obstruction, neoplasms, vasculitis, abdominal inflammatory conditions, trauma, chemotherapy, and radiation. Regardless of the primary cause, CT findings of bowel ischemia are similar [1]. Furthermore, bowel changes can simulate inflammatory or neoplastic conditions. Therefore, a tailored CT examination of the bowel is important in order to avoid delayed diagnosis in the case of

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Table 1 CT findings relevant for the diagnosis of bowel ischemia

CT findings of bowel ischemia		
	Specific	Non-specific
Bowel wall thickening	No	Yes
Decreased wall enhancement	Yes	No
Bowel dilation	No	Yes
Bowel pneumatosis	Yes	No
Gas in portal veins	Yes	No
Gas in the SMV	Yes	No
Free air	Yes	No
Filling defect in the SMA/IMA	Yes	No
Filling defect in a small mesenteric artery	Yes	No
Filling defect in the SMV	Yes	No
Free fluid	No	Yes
Hepatic infarct	Yes	No
Renal infarct	Yes	No
Splenic infarct	Yes	No

ischemia and unnecessary surgery in the other conditions [2]. The purpose of our study was to retrospectively evaluate missed findings in the original reports of multi-detector CT angiography (MDCTA) in patients with surgically proven acute bowel ischemia, with the aim to improve our diagnostic performance.

Materials and methods

Our hospital's institutional review board approved the investigation.

Informed patient consent was not required for our retrospective investigation. We reviewed the electronic medical records of our institution from January 2007 to March 2011 (radiology and pathology reports and discharge summaries) from our database (Hi-tech Software Engineering, Florence, Italy). During this period, we identified 35 consecutive patients (23 males and 12 females; mean age, 68.3 years) with acute abdomen disorders, who underwent MDCTA of the abdomen–pelvis and with surgically proven diagnosis of bowel ischemia. Strangulating obstructions (i.e. closed-loop obstruction) were excluded. All cases of suspected acute bowel ischemia were interpreted at the time of image acquisition and most often by eight board-certified staff emergency

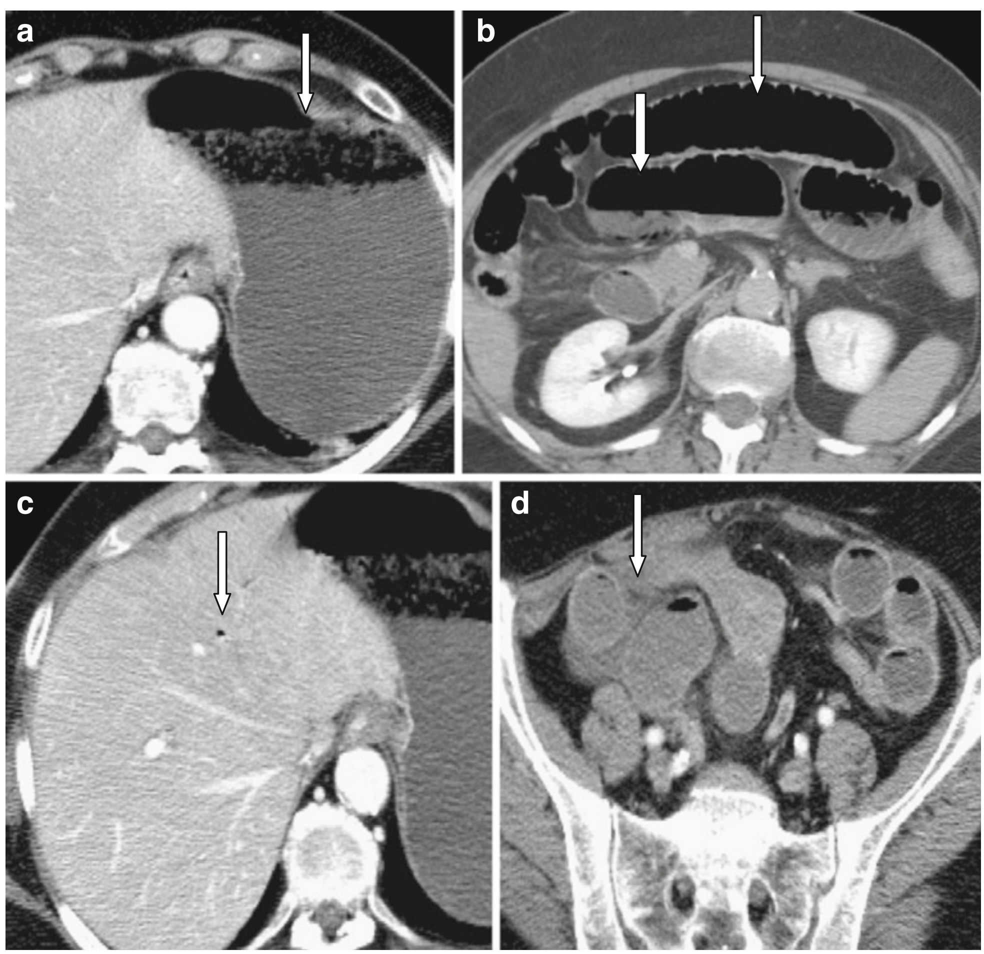

Fig. 1 A 44-year-old female with acute abdomen and clinical suspicion of bowel occlusion. Axial CT shows dilatation of the stomach (*arrow*, **a**) and small bowel dilatation (*arrows*, **b**). At surgery, small bowel infarction was diagnosed. At CT review, missed findings were: a small air bubble in the portal vein (*arrow*, **c**) and lack of bowel wall contrast enhancement, surrounded by free fluid (*arrow*, **d**)

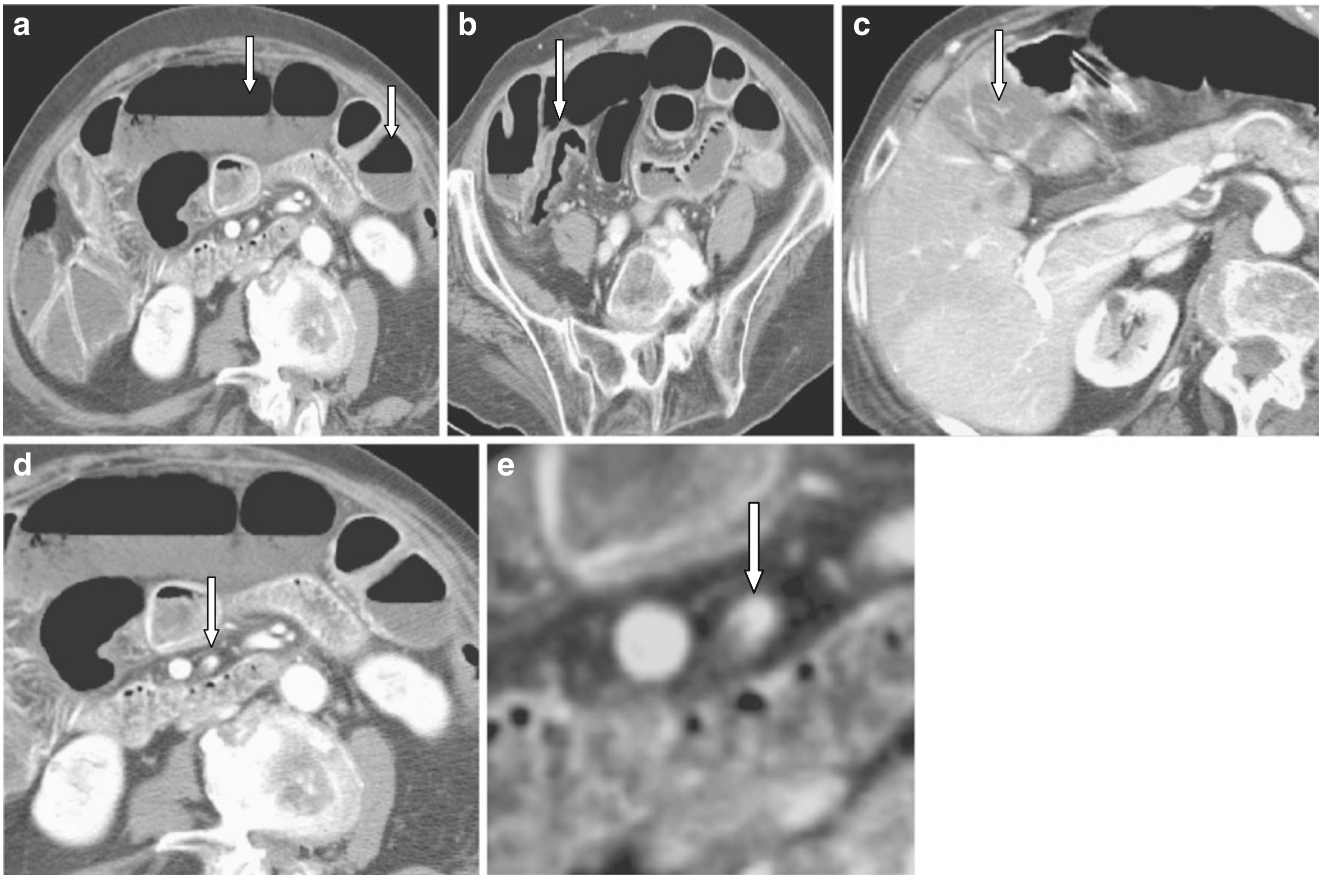

Fig. 2 A 60-year-old man clinically referred for acute abdomen. Axial CT images show air-fluid levels (*arrows*, **a**) and an abrupt change in bowel calibre (*arrow*, **b**), with the initial CT diagnosis of occlusion due to adhesion. At surgery, the final diagnosis was infarction of distal small bowel and right colon. At CT review, missed findings were: diminished small bowel wall enhancement (*arrows*, **a**), perfusion defect of the left lobe of the liver (*arrow*, **c**), and partial thrombosis of the distal SMA (*arrows*, **d**–**e**)

radiologists with 4–24 years post-residency experience, on a random rotating basis. Reports of the initial CT interpretation were retrospectively compared with the surgical reports. In case of discordant MDCTA interpretations, the CT examination was reviewed for overlooked findings.

All relevant CT signs reported in the literature, classified as specific or non-specific for diagnosing bowel ischemia were evaluated [3] (Table 1).

Imaging

All the patients underwent MDCTA using a four-row CT scanner (G.E. Light-Speed, Milwaukee, WI) and received a biphasic power injection of a nonionic intravenous contrast agent through an antecubital vein of 2 mL/kg patient body weight of contrast material at 320 mg/mL iodine concentration (Visipaque, Bracco, Italy), 3 mL/s flow, followed by a saline chaser bolus of 50 mL at equivalent injection rate.

Mesenteric angiography CT protocol included unenhanced and contrast-enhanced scanning of the abdomen and pelvis during the arterial and portal venous phases. Scan delay for the arterial phase was obtained using bolus tracking technique with the region of interest placed in the aorta at the level of the diaphragm, using a predefined 100-HU enhancement threshold level for scan triggering. No oral contrast material was administered. Acquisition parameters were as follows: collimation, 4×2.5 mm; slice thickness, 5 mm; tube voltage, 120–140 kVp, and 200 mAs (effective). Subsequently, images were reconstructed at 2.5 and 1.25 mm of slice thickness.

Evaluation of images and clinical data

Three readers who were blinded to the diagnosis and all clinical information evaluated all of the 35 MDCTA examinations retrospectively, randomly, and individually. The chart review and randomisation of the cases was performed by a surgeon (A.M.). MDCTA readers consisted of reader 1 (P.R.B.), which is the head of the department and had a 2-year abdominal fellowship in a leading US Medical Center and 24 years of work as a senior radiologist focusing

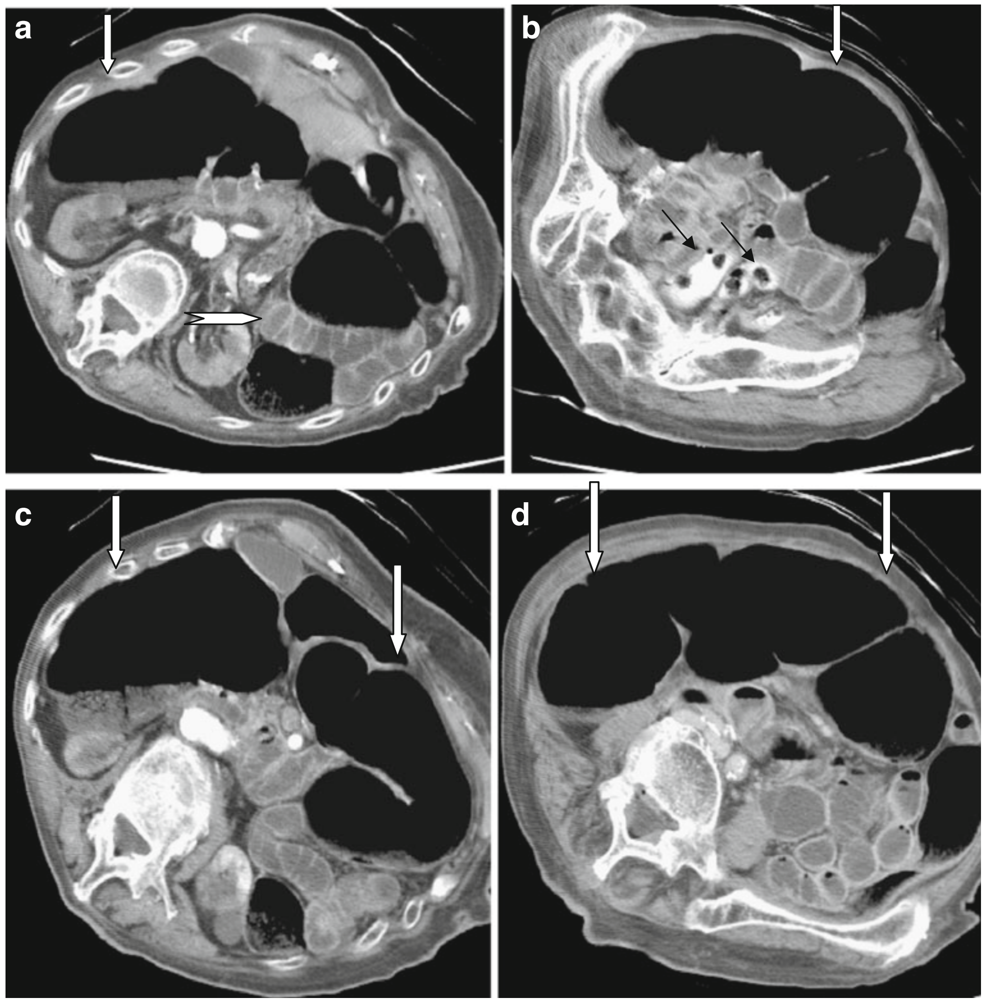

Fig. 3 A 57-year-old male clinically referred for acute abdomen. Axial CT images show (**a**, **b**): marked colonic dilatation by gas (*white arrows*), mild small bowel distention by fluid (*white arrowhead*), and sigmoid diverticula with adjacent fat stranding (*black arrows*). The initial CT diagnosis was colonic diverticulitis. At surgery, the final diagnosis was extended colonic infarction. At CT review, missed findings were: diminished colonic wall enhancement and thin bowel wall (*arrows*, **a**–**d**)

mainly in abdominal radiology. Readers 2 (A.A.L) and 3 (M.C.F.) are both general radiologists with 10 and 4 years post-residence experience respectively, focusing mainly in emergency radiology. All images were reviewed on a picture archiving and communication system workstation (SYNAPSE; Fuji, Tokyo, Japan).

The MDCTA readers were asked to grade their degree of confidence in diagnosing the presence of intestinal ischemia as well as all relevant CT specific signs reported in the literature indicative of intestinal ischemia, in two different session separated from each other by a least 4 weeks. The degree of confidence was graded as "absent" (0) and

Table 2 Distribution areas of bowel ischemia in 35 patients

Distribution areas of bowel ischemia	Number of patients
Ileum	14
Colon and Ileum	6
Colon	8
Jejunum	2
Massive bowel infarction	5

Table 3 Inter-observer agreement of relevant CT findings for the diagnosis of bowel ischemia

Inter-observer agreement		
CT finding	Readers 1 and 2 Kappa value	Readers 1 and 3
Filling defect in a small mesenteric artery[a]	0.61	0.40
Decreased wall enhancement	0.78	0.70
Filling defect in the SMA	0.82	0.84
Filling defect in the SMV	0.83	0.80
Filling defect in a small mesenteric vein	0.68	0.60
Absence of wall enhancement	0.62	0.60
Thin bowel wall	0.60	0.60
Gas in portal vein	0.90	0.61
Gas in the SMV	0.83	0.81
Small bowel pneumatosis	0.83	0.60
Large bowel pneumatosis	0.61	0.41

Inter-observer agreement was calculated using the kappa test, which takes into account possible random agreement

[a] Including the IMA

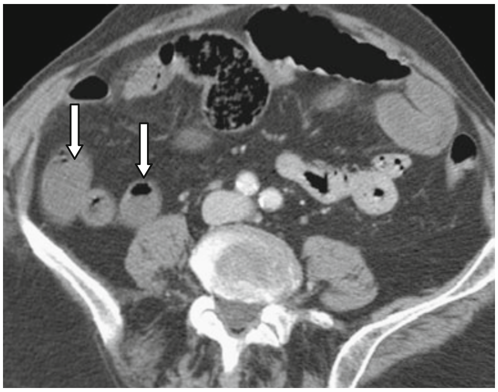

Fig. 4 Axial CT scan shows poor contrast enhancement in the ischemic segment of the bowel (*white arrows*)

"present" (1). The CT findings indicative of intestinal ischemia that were evaluated are given in Table 3.

Statistical evaluation

We evaluated inter-observer agreement between the three readers in recognising CT signs that have been reported to be relevant in diagnosing bowel ischemia by using the Cohen's kappa test. A kappa value of 0.81–1 was considered to represent an almost perfect agreement; a value of 0.61–0.80 was considered substantial agreement, a value of 0.41–0.60 moderate agreement, 0.21–0.40 fair agreement, 0.01–0.20 slight agreement, and a value of 0 was considered poor agreement [4].

Results

Twenty-three out of 35 patients (66 %) were correctly diagnosed on the initial MDCTA report, whereas 12 of the 35 patients (34 %) had surgically proven bowel ischemia,

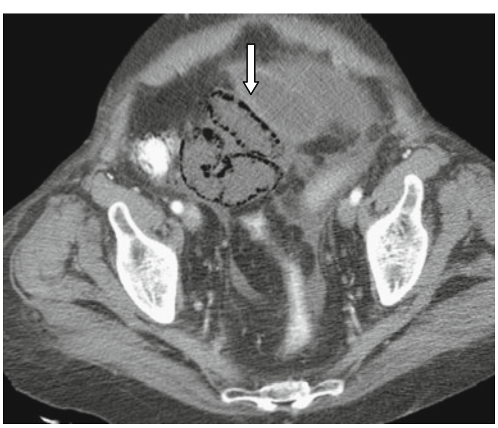

Fig. 5 Axial CT contrast-enhanced scan of a patient with pneumatosis demonstrates gas collection on the dependent side of the bowel wall

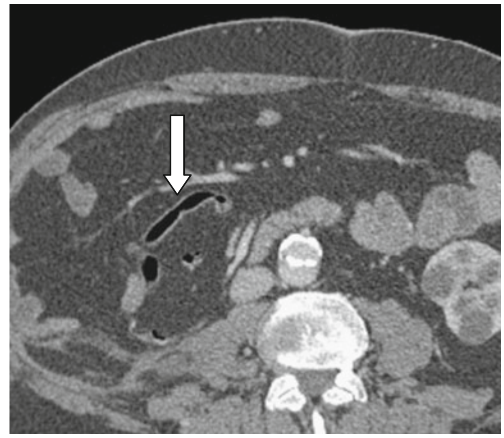

Fig. 6 Axial contrast-enhanced CT scan demonstrates a linear pattern of low attenuation in the mesentery (*arrow*), consisting with gas in a small branch of the mesenteric vein

which was not diagnosed by MDCTA. In 10 of the 12 (83 %) of these "missed diagnoses", specific findings included: portal venous gas in three cases (Fig. 1), gas in the bowel wall in three cases, gas in both the portal vein and bowel wall in two cases, thrombotic occlusion of the distal SMA in one case (Fig. 2), and thrombotic occlusion of the distal IMA in one case.

Two out of the 12 (17 %) patients had overlooked non-specific findings: bowel dilation (Fig. 3) and free fluid. With retrospective image interpretation, 83 % of the patients with occlusive mesenteric ischemia at surgery were correctly identified, whereas the remaining 17 % with non-occlusive mesenteric ischemia at surgery showed non-relevant findings at MDCTA.

Two patients were excluded because they were treated conservatively (one with suspected thrombosis of the SMA and one with mesenteric vasculitis).

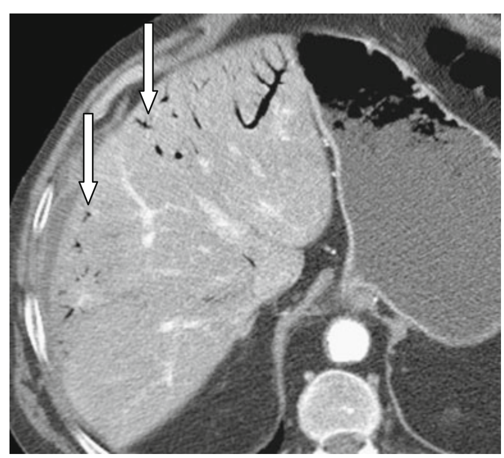

Fig. 7 Axial contrast-enhanced CT scan shows linear and branched pattern of low attenuation in the periphery of the liver (*arrows*), consisting with gas in the portal vein. Perihepatic fluid is also noted

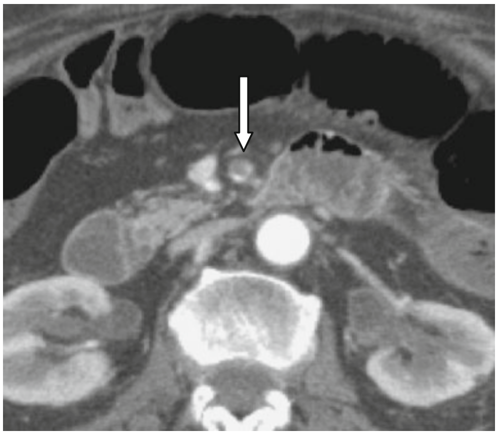

Fig. 8 Axial contrast-enhanced CT scan shows a thrombus in the superior mesenteric artery (*arrow*)

Distribution areas of intestinal ischemia that were detected are given in Table 2.

A substantial inter-observer agreement (kappa test value of 0.81 for readers 1 and 2 and 0.70 % for readers 1 and 3) was achieved in diagnosing the presence of ischemia. Readers 1 and 2 obtained a higher kappa test value than did readers 1 and 3 (close to the limit between almost perfect and substantial agreement).

With regard to relevant specific signs of bowel ischemia, readers 1 and 3 achieved a significant lower *k* test value than did readers 1 and 2 as reported in Table 3, particularly with regard to filling defects in a small mesenteric artery (fair versus substantial agreement), gas in portal vein (substantial versus almost perfect agreement), small bowel wall pneumatosis (moderate versus almost perfect agreement), and large bowel pneumatosis (moderate versus substantial agreement).

The lowest *k* test values (substantial to moderate agreement) were achieved for both groups of readers regarding specific signs of intestinal ischemia such as absence of wall enhancement and thin bowel wall, respectively.

Discussion

Several studies have been published in the literature regarding patients with surgically proven bowel ischemia by using MDCTA findings evaluating the radiologists' performance in the diagnosis of acute bowel ischemia [1–11]. In our experience, CT findings that significantly distinguished bowel ischemia from other bowel conditions were specific signs (absent or decreased bowel wall contrast enhancement, filling defects in the SMA, pneumatosis, and gas in the portal vein and/or superior mesenteric vein).

In our study as well as in studies performed by other investigators [3], the radiologists' experience and expertise had a substantial impact on their performance. The radiologist with fellowship in abdominal imaging, and the radiologist with 10 years post-residence experience achieved a higher agreement in the detection of specific CT signs indicative of intestinal ischemia than did the radiologist with 4 years post-residency experience. We believe that this may be a direct result of level of expertise and experience of the readers. Due to the lower level of expertise and experience, the senior radiologist with the least level of experience was more concern in missing coarse rather than subtle CT signs of intestinal ischemia.

The most specific CT finding that we have encountered was the absent or poor bowel wall contrast enhancement (Fig. 4). There was a less agreement regarding the assessment of bowel wall enhancement (Table 3). We believe that it is not always possible to accurately assess these findings. The bowel is not uncommonly collapsed or is sub-optimally distended, and the opaque enteric contrast used in many routine abdominal examinations precludes optimal visualisation (Fig. 5).

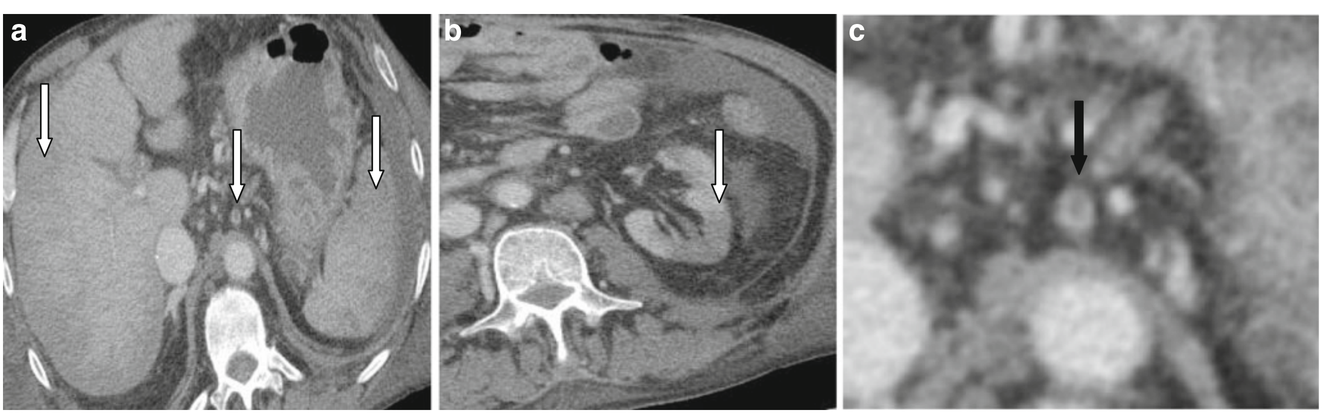

Fig. 9 Axial contrast-enhanced CT scan shows multifocal hepatic (**a**), splenic (**b**), and renal infarcts (**b**), (*white arrows*). A filling defect of the SMA is also present (**a**, **c**; *arrows*)

A relatively low agreement was also achieved in the detection of bowel as well as portal venous gas (Table 3). It is caused by the dissection of luminal gas into the bowel wall across the compromised mucosa. The reported specificities of pneumatosis and portal venous gas for acute intestinal ischemia usually approach 100 % [1]. These signs may also appear in other etiologies and CT findings may be very similar. Therefore, correlation with clinical history, physical examination, and laboratory test results is the best indicator of whether intestinal pneumatosis is due to a benign or life-threatening cause. In cases of intestinal pneumatosis associated with suspected bowel ischemia, detection of hepatic portal or portomesenteric venous gas increases the likelihood of transmural bowel infarction [11–23].

As a general concept, the greater the extent of the pneumatosis more severe is the disease. However, the extent of pneumatosis may also be inversely related to the severity of the disease, as in the case of vasculitis. Mesenteric vasculitis involves a long tract of the bowel, usually jejunum and ileum, small bowel and/or colon, with a non-segmental distribution, whereas thromboembolic ischemia is characterised by a segmental distribution [24].

Mesenteric and portal venous gas is an even less common specific CT sign of bowel ischemia [11–23]. Gas from the intestinal lumen can pass through the bowel wall and travel via the superior mesenteric vein or its branches to the portal vein. Gas in the superior or inferior mesenteric vein can easily be demonstrated with MDCTA. It appears as a linear or branched pattern of low attenuation in the mesenteric border of the bowel (Fig. 6).

Intrahepatic portal vein gas should be differentiated from pneumobilia. Portal vein gas from bowel ischemia usually has a peripheral distribution in the liver (Fig. 7), whereas

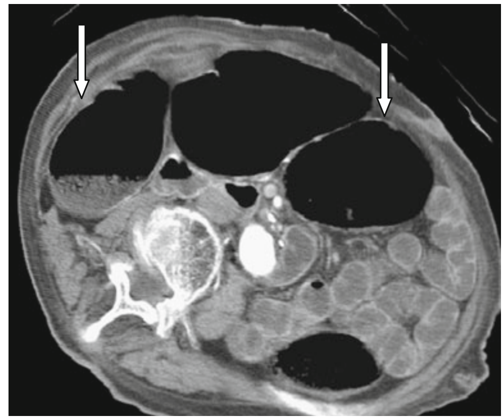

Fig. 11 Axial contrast-enhanced CT scan shows diffuse colon dilation with a thin wall due to the ischemic process (*arrows*)

pneumobilia has a left lobe and common hepatic duct predilection [11–23].

Our results showed that overlooked findings consisting with portal venous gas were due to the presence of a small single "bubble-like" rather than a "linear" pattern of intestinal pneumatosis (Fig. 1). In the remaining cases, intestinal pneumatosis was underestimated because it was considered as a benign (patients were clinically referred for acute abdomen or occlusion) rather than a life-threatening cause of acute bowel ischemia.

Other specific CT signs of acute mesenteric ischemia are vascular occlusion such as mesenteric and/or portal vein thrombosis and infarction of solid organs (Figs. 8 and 9).

There was a less agreement regarding the assessment of vascular occlusions particularly if located in the distal tract of the SMA. Small filling defects may sometimes be difficult to diagnose due to motion artefacts (patients

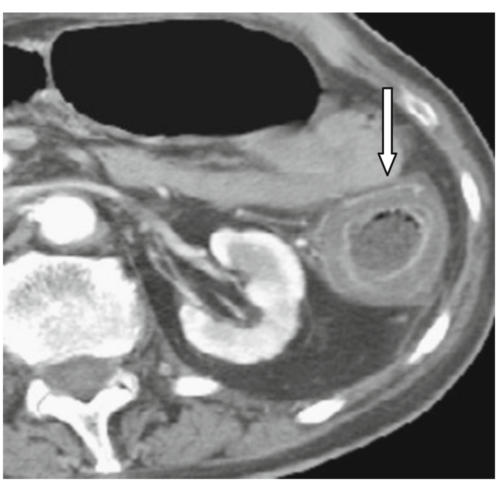

Fig. 10 Axial contrast-enhanced CT scan shows wall thickening of the descending colon, consisting with the target sign (*arrow*)

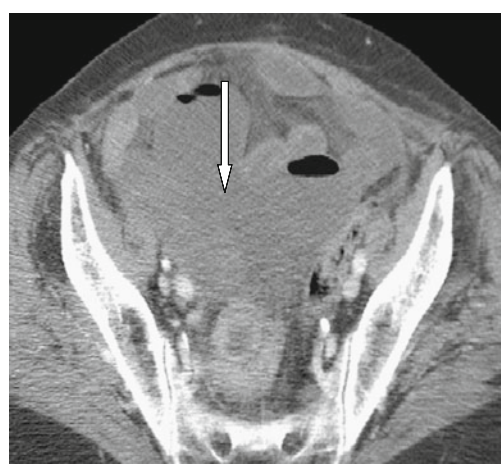

Fig. 12 Axial contrast-enhanced CT scan shows pelvic free fluid (*arrow*). Diminished bowel wall enhancement is also noted

are often old and unable to hold their breath). Motions artefacts and technology-related limitations due to the use of a four-slice CT scanner might also affect the quality of multi-planar reformations (MPR). In addition, a thin bowel wall might be also difficult to assess with low-quality MPR images.

Non-occlusive mesenteric ischemia (NOMI) may be challenging to diagnose. It is a condition where the mesenteric vessels are patent but the blood flow is very low, causing splanchnic vasoconstriction and multiple areas of infarction of solid organs. This can be seen in patients with volume depletion, shock, acute myocardial infection, congestive heart failure, or those secondary to medications such as digitalis, ergot derivatives, norepinephrine, and cocaine. NOMI is often associated with adverse outcomes and high mortality rates reaching up to 58–70 % [11–23].

A non-specific but most common CT sign of acute bowel ischemia is bowel wall thickening, commonly associated with the target sign, in which the alternation of layers of high and low attenuation within the bowel wall are due to submucosal edema or hemorrhage (Fig. 10). However, the ischemic bowel wall may also appear thinner than normal, particularly when it becomes gangrenous [25]. Furthermore, a non-specific CT sign of acute mesenteric ischemia is bowel dilation (Fig. 11), which reflects the interruption of peristaltic activity in ischemic segments. Bowel dilation can produce mucosal disruption that allows intraluminal gas to become intravascular [12–23].

Free peritoneal fluid alone is a common, non-specific CT sign of bowel ischemia (Fig. 12). If associated with mesenteric venous occlusion, the presence of peritoneal fluid indicates a more severe degree of the disease and often requires laparotomy [1–11].

Limitations

Potential limitations of our study are the retrospective nature of its design, incomplete data collection from surgical files, lack of statistical analysis of diagnostic accuracy (no false-positive results were analysed), and technology-related limitations due to the use of a four-slice CT scanner.

Conclusions

The diagnosis of acute mesenteric ischemia is still a challenge for the radiologist. Our results showed that most missed findings were subtle but specific, therefore specific training in abdominal imaging and attention to subtle CT signs are important to improve the radiologists' performance.

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Conflict of interest The authors declare that they have no conflict of interest.

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