Eur Radiol
DOI 10.1007/s00330-016-4712-9

EMERGENCY RADIOLOGY

Emergency assessment of patients with acute abdominal pain using low-dose CT with iterative reconstruction: a comparative study

Pierre-Alexandre Poletti [1] · **Minerva Becker** [1] · **Christoph D. Becker** [1] · **Alice Halfon Poletti** [2] · **Olivier T. Rutschmann** [2] · **Habib Zaidi** [1] · **Thomas Perneger** [3] · **Alexandra Platon** [1]

Received: 5 October 2016 / Accepted: 15 December 2016

Abstract
Objectives To determine if radiation dose delivered by contrast-enhanced CT (CECT) for acute abdominal pain can be reduced to the dose administered in abdominal radiography (<2.5 mSv) using low-dose CT (LDCT) with iterative reconstruction algorithms.
Methods One hundred and fifty-one consecutive patients requiring CECT for acute abdominal pain were included, and their body mass index (BMI) was calculated. CECT was immediately followed by LDCT. LDCT series was processed using 1) 40% iterative reconstruction algorithm blended with filtered back projection (LDCT-IR-FBP) and 2) model-based iterative reconstruction algorithm (LDCT-MBIR). LDCT-IR-FBP and LDCT-MBIR images were reviewed independently by two board-certified radiologists (Raters 1 and 2).
Results Abdominal pathology was revealed on CECT in 120 (79%) patients. In those with BMI <30, accuracies for correct diagnosis by Rater 1 with LDCT-IR-FBP and LDCT-MBIR, when compared to CECT, were 95.4% (104/109) and 99% (108/109), respectively, and 92.7% (101/109) and 100% (109/109) for Rater 2. In patients with BMI ≥30, accuracies with LDCT-IR-FBP and LDCT-MBIR were 88.1% (37/42) and 90.5% (38/42) for Rater 1 and 78.6% (33/42) and 92.9% (39/42) for Rater 2.
Conclusions The radiation dose delivered by CT to non-obese patients with acute abdominal pain can be safely reduced to levels close to standard radiography using LDCT-MBIR.
Key Points
• *LDCT-MBIR (<2.5 mSv) can be used to assess acute abdominal pain.*
• *LDCT-MBIR (<2.5 mSv) cannot safely assess acute abdominal pain in obese patients.*
• *LDCT-IR-FBP (<2.5 mSv) cannot safely assess patients with acute abdominal pain.*

Keywords CT · Acute abdomen · Radiation dose · Iterative reconstruction · Emergencies

Abbreviations and acronyms

CECT	Contrast-enhanced CT
LDCT	Low-dose CT
BMI	Body mass index
IR	Iterative reconstruction
FBP	Filtered back projection
MBIR	Model-based iterative reconstruction
DLP	Dose-length product

✉ Pierre-Alexandre Poletti
pierre-alexandre.poletti@hcuge.ch

[1] Department of Radiology, University Hospital of Geneva, 4 rue Gabrielle Perret-Gentil, 1211 Geneva, Switzerland

[2] Department of Community, Primary Care and Emergency Medicine, University Hospital of Geneva, Geneva, Switzerland

[3] Division of Clinical Epidemiology, University Hospital of Geneva, Geneva, Switzerland

Introduction

Reducing radiation doses by abdominal computed tomography (CT) has become a significant challenge in emergency radiology for three reasons. Firstly, CT use has significantly increased in emergency medicine

Published online: 12 January 2017

compared to other imaging techniques [1]. Secondly, over the last decade, abdominal pain has become the first indication for scanning patients in emergency medicine [2]. Finally, the alleged risk for CT-induced cancer is estimated to be higher when involving the abdomen than other anatomical regions [3]. This concern does not appear limited to young people, but could also affect middle-aged patients [4].

Abdominal low-dose CT (LDCT) protocols deliver an effective radiation dose (<2.5 mSv) close to that of two abdominal radiographs (2 × 1.3 mSv) [5–7] by means of a charge tube current <50 mAs and filtered back projection (FBP) algorithm. These protocols are used to replace standard CT (8-10 mSv) in certain acute abdominal conditions, such as renal colic [8–10] and appendicitis [11–13], combined with well-defined algorithms. However, LDCT quality is limited by increased noise and beam-hardening artefacts [14–16]. For this reason, no series has yet demonstrated their value for diagnosing patients with acute abdominal pain other than renal colic, appendicitis, and diverticulitis [8–13, 17]. Recent iterative reconstruction algorithms, such as ASIR (adaptive statistical iterative reconstruction, GE healthcare, Milwaukee, WI, USA), IRIS (iterative reconstruction in image space, Siemens Healthcare, Forchheim, Germany), SAFIRE (sinogram affirmed iterative reconstruction, Siemens Healthcare, Forchheim, Germany), and ADMIRE (advanced modelled iterative reconstruction, Siemens Healthcare, Forchheim, Germany), were shown to improve CT image quality by reducing noise [16, 18, 19]. As these algorithms alter image texture, creating a smooth appearance [19], they must be blended with FBP to obtain the best trade-off between noise reduction and image-quality impairment due to smoothing. Recently, new generations of iterative reconstruction algorithms have been developed, such as MBIR (model-based iterative reconstruction, Veo^{R}, GE Healthcare, Milwaukee, WI), using a full iterative reconstruction [16, 19, 20]. In addition to suppressing noise, this technology improves spatial resolution and reduces image artefacts, maintaining a good contrast-noise ratio while preserving image texture [21–23]. However, unlike prior generations, this complex modelling technique requires a central processing unit, involving relatively long reconstruction times (0.2-0.5 images/s) [24, 25].

This study sought to determine whether the radiation dose delivered to patients undergoing contrast-enhanced CT (CECT) for acute abdominal pain can safely be reduced to the dose close to that administered in two abdominal radiography examinations (<2.5 mSv) by applying iterative reconstruction algorithms to low-dose CT protocols (LDCT).

Materials and methods

This study was approved by the institutional review board (CER 13-121), with written informed consent obtained from all patients.

Patient population

The study was targeted on adult patients (>18 years old) admitted with acute abdominal pain, clinically not suspected of renal colic or appendicitis. Patients with suspected appendicitis or uncomplicated renal colic were not included since these conditions are routinely investigated in our institution by different imaging algorithms. Patients who were under 18 years old, pregnant, or unable to sign the informed consent were not included.

During the study period, 441 consecutive adult patients were admitted for acute abdominal pain in our institution. One hundred and fifty-five of them, with a mean age of 61 years (range 22-104), required CECT for acute abdominal pain not suspect of appendicitis or renal colic; four refused to sign the informed consent and were excluded. Therefore, our study group consisted in 151 patients (83 females, 68 males). Patients' heights and weights were recorded and BMI values calculated.

CECT was performed by means of 64-row GE 750 HD CT (General Electric Company, Milwaukee, WI, USA) from lung base to pelvis using a power-injected bolus of 120 mL of non-ionic intravenous contrast material (Iohexol, 300 mg I/mL, AccupaqueR 300, GE Healthcare AG, Opfikon, Switzerland), at a flow rate of 3.5 mL/s, with a delay of 60 s before initiating CT data acquisition, followed by a 30 mL saline flush at the same flow rate. The following parameters were used for CT acquisition: 64 × 1.25 mm collimation, 0.9 pitch, 0.7-s gantry rotation period, 120 kV tube potential, automated tube current modulation, 2-1 mm reconstruction slice thickness, noise index 31.

The abdominal LDCT series were programmed on the same scout used for CECT series, applying the same field of view and scan length. LDCT images were automatically obtained 5 s after completing CECT images, while the contrast medium was still in the venous compartment, without adding more contrast material.

LDCT protocol was set up to deliver a fixed volume CT dose index ($CTDI_{vol}$) of 2.5 mGy on a 32-cm body phantom [26] using the following parameters: 64 × 1.25 mm collimation, 1.375 pitch, 0.7-s gantry rotation period, 120 kV tube potential, 25.2 mAs tube charge per gantry rotation (45 mA × 0.7 s/1.25), 2.5 mm reconstruction slice thickness. A 40% iterative reconstruction algorithm blended with filtered back projection (LDCT-IR-FBP) was selected on a 10% to 100% strength scale because it has been reported to offer both optimal noise reduction and a diagnostically acceptable image quality [27]. A LDCT model-based iterative reconstruction algorithm series (LDCT-MBIR) was obtained in a delayed fashion using the LDCT acquisition data, reconstructed with the MBIR algorithm. The mean reconstruction time per patient for LDCT-MBIR images was 32 min (range: 28-42 min).

Effective CECT and LDCT doses

The radiation doses by CT were estimated using the mean normalized values of effective dose per dose-length product (DLP) for the abdomen [26]. The mean DLP value was inferred from the DLP values indicated on each examination. The mean DLP for CECT was 743 [mGy × cm] (range 291-1343); the mean DLP for LDCT was 126 [mGy × cm] (range 110-137). The corresponding effective doses were 10.1 and 2.0 mSv, respectively.

CT analysis

CECT images were immediately interpreted by the senior resident and on-call attending radiologists at the emergency unit and then transmitted by written report to the physician in charge of the patients. Attending radiologists involved in the reading (n = 10) had prior experience of 4 to 17 years after radiology board certification in emergency abdominal CTs. LDCT-IR-FBP and LDCT-MBIR images were not immediately interpreted, but stored in the picture archiving and communication system (PACS) until the end of the case collection, when they were anonymized and downloaded from PACS using a similar workstation and visualization software as those used by the emergency radiology team for CECT images. This process was performed by an independent research fellow with no other involvement in this study. The images were then interpreted independently by two board-certified senior radiologists of the emergency radiology unit: Rater 1 and Rater 2. Rater 1 had 11 years' experience in abdominal CT imaging, including over 1500 LDCT-IR-FBP series involving patients with suspected appendicitis or renal colic. Rater 2 had 17 years' experience in abdominal CT imaging, including 400-500 LDCT-IR-FBP images involving suspected appendicitis or renal colic cases.

Three months after inclusion of the last patient in the series, LDCT-IR-FBP and LDCT-MBIR images were analyzed randomly and independently by both raters in multiple reformatting plans. Raters were given the patients' demographics, but not their names, while having access to the CT prescription form. They were blinded to all medical reports and to the CECT interpretation. For each patient, only one category of LDCT-reconstruction (IR-FBP or MBIR) was randomly selected to be analyzed first by the radiologists, during a 3-month time span. Once all these LDCT series were analyzed, radiologists were entitled to interpret the remaining LDCT-reconstructions during a second period of 3 months. For each case, the raters were asked to write on a form the most probable diagnosis directly related to the patient's complaint (primary diagnosis), as well as a secondary diagnosis, if any. A secondary diagnosis was defined as an incidental finding not associated with the primary diagnosis, possibly requiring immediate or delayed medical/surgical treatment.

The raters also evaluated the quality of the LDCT-IR-FBP and LDCT-MBIR images on a 5-point Likert scale, which we dichotomized as good quality (ratings 4 or 5) versus poor quality (ratings 1 to 3).

Once LDCTs were interpreted, CECT were re-analyzed in consensus by the same readers, to establish for each patient a primary and a secondary diagnosis, which were considered reference standard. The LDCTs diagnoses (primary and secondary) were then compared to the reference standard and logged in an Excel spreadsheet. An LDCT diagnosis was considered correct when it matched with the CECT diagnosis. It was considered incorrect when it differed from the CECT diagnosis or overlooked a significant finding visible on CECT.

Statistical analysis

For primary diagnoses, both raters produced a rating of concordance between the LDCT (IR-FBP and MBIR) and CECT, evaluated on a two-level scale: correct and incorrect diagnosis. The proportion of observations judged "correct" corresponded to the accuracy of LDCT imaging. We reported the distributions of the accuracy of diagnosis for the two imaging methods for each rater, comparing the between-method difference separately for each rater using McNemar-Bowker's test for paired data [28]. We examined the between-rater agreement separately for each method using an intraclass correlation coefficient (ICC) for absolute agreement. We used a two-way mixed model for ICC, where the imaging method was a fixed factor and the patient a random factor, with 95% confidence intervals. This was performed for the primary diagnosis on the whole sample, then separately for non-obese (BMI < 30) and obese patients (BMI ≥ 30). The proportions of good quality images within a rater were compared by means of a McNemar test.

We analyzed the conditions missed by LDCT-IR-FBP and LDCT-MBIR for the primary diagnosis, reported by each rater, depending on BMI.

We applied a second two-level rating of concordance for secondary diagnoses with the CECT, this time classed as detected (true positive) or missed (false negative) to assess sensitivity.

Results

Of the 151 patients included, 109 (72%) had a BMI <30 and 42 (28%) ≥30; the mean BMI was 27 (median: 27). In 120 patients (79%), CECT revealed conditions that could have caused abdominal pain, thus the primary diagnosis, while in 31 (21%), CECT imaging was normal. Of the 120 patients with primary diagnosis, 91 (76%) had a BMI <30 and 29 (24%) ≥30.

Of the 120 primary conditions diagnosed by CECT, 41 (34%) involved the large bowel, 30 (25%) small bowel and/or mesentery, 14 (12%) biliary tracts, 10 (8%) pancreas, eight (7%) kidney or bladder, seven (6%) pelvic collections, four (3%) abdominal wall, three (3%) liver, and two (2%) chest. Further details are given in Table 1.

For the whole population (n = 151), Raters 1 and 2 achieved accuracies of 93.4% (141/151) and 88.7% (134/151), respectively, in terms of the primary LDCT-IR-FBP-based diagnosis being correct, with regard to CECT findings (Table 2). For analysis based on LDCT-MBIR imaging, these accuracies improved to 96.7% (146/151) and 98% (148/151), for Raters 1 and 2, respectively. The inter-rarer agreement was good (0.57) for LDCT-IR-FBP and excellent (0.80) for LDCT-MBIR. Similar results were obtained after stratification by BMI (Table 2).

Table 1 Primary diagnoses reported using CECT

Location	Primary Diagnoses (n = 120)
Large bowel (n = 41)	diverticulitis (n = 25)
	colitis (n = 5)
	tumour (n = 5)
	epiploic appendagitis (n = 3)
	appendicitis (n = 2)
	occlusion (n = 1)
Small bowel/mesentery (n = 30)	occlusion (n = 18)
	ileitis (n = 5)
	carcinomatosis (n = 3)
	enteritis (n = 2)
	panniculitis (n =1)
	bowel ischemia (n = 1)
Gallbladder/biliary ducts (n = 14)	cholecystitis (n = 8)
	biliary duct obstruction (n = 5)
	abscess after cholecystectomy (n = 1)
Pancreas (n = 10)	pancreatitis (n = 9)
	tumour (n = 1)
Kidney/ureter/bladder (n = 8)	pyelo-ureteral obstruction (n = 3)
	pyelonephritis (n = 2)
	bladder distension (n = 2)
	complicated polycystic kidney (cyst bleeding) (n = 1)
Pelvis (n = 7)	pelvic collections (n = 7)
Abdominal wall (n = 4)	hernia (n = 3)
	abscess (n = 1)
Liver (n =3)	decompensated cirrhosis (n = 2)
	hemorrhagic cyst (n = 1)
Chest (n = 2)	pneumonia (n = 2)

CECT contrast-enhanced abdominal CT

In patients with a BMI <30, the accuracies of Raters 1 and 2 in accurately establishing the primary diagnosis were, respectively, 95.4% (104/109) and 92.7% (101/109) using LDCT-IR-FBP and 99% (108/109) and 100% (109/109) using LDCT-MBIR. In patients with a BMI ≥30, Raters 1 and 2 accurately established the primary diagnosis in 88.1% (37/42) and 78.6% (33/42), respectively, when using LDCT-IR-FBP, and 90.5% (38/42) and 92.9% (39/42) with LDCT-MBIR.

Both raters considered the images constructed using MBIR to be superior to images constructed using IR-FBP. For Rater 1, the proportions of good quality images were 87.4% for MBIR and 73.5% for IR-FBP ($p < 0.001$); for Rater 2, the proportions were 92.1% versus 64.2% ($p < 0.001$) (Table 3).

Of the 91 patients with a BMI <30 and abnormal CECT (primary diagnosis), a condition was missed by at least one rater in eight (8.8%) patients using LDCT-IR-FBP, with four conditions being missed by both raters. These conditions were related to the large bowel (n = 1, Fig. 1), small bowel or mesentery (n = 3), kidney or bladder (n = 2), biliary tracts (n = 1), and pelvis (n = 1, Fig. 2). In the same group, using LDCT-MBIR, only one (1.1%) primary diagnosis, related to the biliary tract (an early cholecystitis), was missed by Rater 1, with no condition missed by Rater 2.

Of the 17 patients with a BMI <30 and normal CECT (primary diagnosis), pyelonephritis was incorrectly diagnosed by Rater 1 using LDCT-IR-FBP, while Rater 2 made no false positive diagnoses. No false positive diagnosis was made using LDCT-MBIR.

Of the 42 patients with a BMI ≥30 and abnormal CECT (primary diagnosis), a condition was missed by one of the raters in nine (21.4%) patients using LDCT-IR-FBP. Four of these nine conditions were missed by both raters, related to the biliary tracts (n = 3), large bowel (n = 2), small bowel or mesentery (n = 1), kidney or bladder (n = 1), pancreas (n = 1), and pelvis (n = 1, Fig. 3). In the same patient group, three (9.5%) primary diagnoses were missed by either Rater 1 or Rater 2 using LDCT-MBIR. Two conditions were missed by both raters, relating to the biliary tracts.

Of the 13 patients with a BMI ≥30 and normal CECT (primary diagnosis), a condition related to the large bowel was incorrectly diagnosed by Rater 1 using both LDCT-IR-FBP and LDCT-MBIR, while Rater 2 made no false positive diagnoses with either technique.

A secondary diagnosis was revealed by CECT in 38 patients (25%), 28 (73%) of whom had a BMI <30. The secondary diagnoses consisted of liver lesions (n = 7), gallstones (n = 4), abdominal wall hernias (n = 4), adrenal gland nodules (n = 4), aortic or iliac aneurysms (n = 3), bile duct dilatation (n = 2, Fig. 4), pleural effusion (n = 3), bowel-wall thickening (n = 3), adnexal mass (n = 2), pulmonary nodules (n = 1),

Table 2 Accuracy of diagnosis obtained by two LDCT scan techniques compared with CECT, evaluated by two raters, overall and stratified by BMI

	Rater 1 Accuracy %			Rater 2 Accuracy %			Inter-rater agreement: ICC (95% CI)	
	LDCT- IR-FBP	LDCT-MBIR	*p* value	LDCT- IR-FBP	LDCT-MBIR	*p* value	LDCT- IR-FBP	LDCT-MBIR
Primary diagnosis, overall (N = 151)	93.4 (141/151)	96.7 (146/151)	0.063	88.7 (134/151)	98.0 (148/151)	<0.001	0.57 (0.45 – 0.67)	0.80 (0.74 – 0.85)
Secondary diagnosis, overall (N = 151)	96.7 (146/151)	98.0 (148/151)	0.50	96.0 (145/151)	98.7 (149/151)	0.12		
Primary diagnosis, stratified by BMI								
BMI <30 (N = 109)	95.4 (104/109)	99.1 (108/109)	0.12	92.7 (101/109)	100 (109/109)	<0.001	0.57 (0.43 – 0.68)	0.80 (0.72 – 0.86)
BMI ≥30 (N = 42)	88.1 (37/42)	90.5 (38/42)	1.00	78.6 (33/42)	92.9 (39/42)	0.031	0.55 (0.31 – 0.73)	0.79 (0.64 – 0.88)
p value for obese versus non-obese patients	0.14	0.021		0.021	0.020			

LDCT low-dose CT, *IR* iterative reconstruction, *FBP* filtered-back projection, *MBIR* model-based iterative reconstruction, *CECT* contrast-enhanced abdominal CT, *ICC* intraclass correlation coefficient, *CI* confidence interval, *BMI* body mass index

pericardial effusion (n = 1), pulmonary infiltrate (n = 1), urinary bladder mass (n = 1), mesenteric lymph node enlargement (n = 1), splenic nodules (n = 1), and severe coprostasis (n = 1). The LDCT-IR-FBP and LDCT-MBIR sensitivities for secondary diagnoses are given in Table 4. Five secondary diagnoses were missed using LDCT-MBIR by either Rater 1 or 2: dilated Wirsung's duct, non-specific liver nodule (missed by both raters), liver hemangioma (missed by both), adrenal nodule, and colonic wall thickening (colitis). Three of these five patients had a BMI <30, two (both with liver lesions) a BMI ≥30.

Discussion

Our study demonstrated that in patients with a BMI <30, LDCT-MBIR with intravenous contrast medium achieved diagnostic performances equivalent to CECT in identifying the cause of acute abdominal pain, providing correct diagnoses. LDCT-MBIR achieved an accuracy >99% for both raters, with a fivefold reduction in radiation doses compared to CECT. In this patient group, LDCT-MBIR correctly detected secondary diagnoses not related to abdominal pain, with a sensitivity of 92.8% and 96.4%, respectively, for both raters.

Given that such low radiation doses can be provided with high accuracy for imaging-based detection of common causes for acute abdominal pain constitutes a significant breakthrough for patient safety when using diagnostic management modalities under emergency conditions.

Such results could not, however, be achieved with the LDCT-IR-FBP protocol. In patients with a BMI <30, this technique was limited by a relatively high percentage of incorrect diagnoses by both raters (4.6 and 7.3%, respectively), and limited sensitivity (82%) for detecting secondary diagnoses.

LDCT-MBIR cannot reasonably be recommended for investigating acute abdominal pain in patients with a BMI ≥30 as both raters achieved relatively limited accuracy for the principal diagnoses (90.5 and 92.9%, respectively) and limited sensitivity (80%) for secondary diagnoses. The limitation of low-dose CT for overweight/obese patients was previously reported [10, 29]. A recent study reported on series of 41

Table 3 Proportion of imaging procedures considered to be of good quality by the two raters, overall and in subgroups, with regard to the reconstruction algorithm

	Rater 1			Rater 2		
	LDCT-IR-FBP %	LDCT-MBIR %	*p* value	LDCT-IR-FBP %	LDCT-MBIR %	*p* value
Overall (N = 151)	73.5 (111/151)	87.4 (132/151)	<0.001	64.2 (97/151)	92.1 (139/151)	<0.001
BMI < 30 (N = 109)	78.0 (85/109)	90.8 (99/109)	0.001	68.8 (75/109)	94.5 (103/109)	<0.001
BMI ≥ 30 (N = 42)	61.9 (26/42)	78.6 (33/42)	0.016	52.4 (22/42)	85.7 (36/42)	<0.001

Numbers in brackets correspond to the ratio of good quality/total number of examinations

LDCT low-dose CT, *IR* iterative reconstruction, *FBP* filtered-back projection, *MBIR* model-based iterative reconstruction, *BMI* body mass index

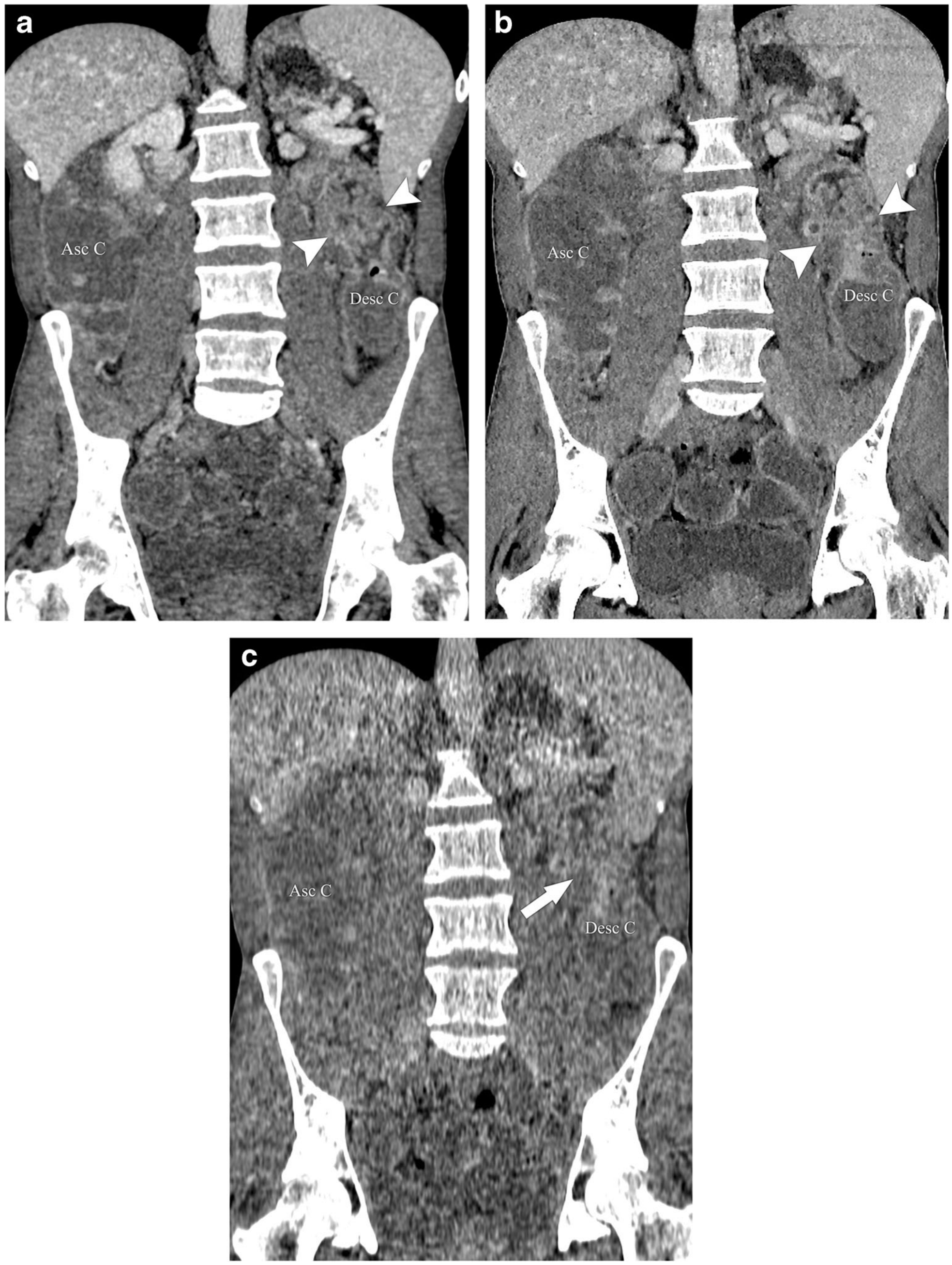

Fig. 1 Incorrect primary diagnosis on LDCT-IR-FBP images and correct diagnosis on LDCT-MBIR. 42-year-old man, BMI = 17, admitted for intense diffuse acute abdominal pain, disturbance of bowel mobility, and vomiting. **a** CECT (effective dose: 4.7 mSv), coronal reformation at the level of the ascending (*AscC*) and descending (*DescC*) colon. An occlusive tumoral mass within the descending colon (*arrowheads*) is well depicted, as is the consecutive distension of the ascending colon. **b** LDCT-MBIR (effective dose: 1.8 mSv), coronal reformation at the same level as A. The occlusive tumoral mass (*arrowheads*) was correctly reported by both raters. **c** LDCT-IR-FBP (effective dose: 1.8 mSv), coronal reformation at the same level as A. Both raters reported the distension of the ascending colon (AscC), but were unable to depict the tumoral mass (*arrow*) in the descending colon (DescC)

patients advocated using low-dose CT with hybrid iterative reconstruction (comparable to our LDCT-IR-FBP) for imaging miscellaneous abdominal conditions in patients with a BMI ≤25 [29]. In our study, we did not limit the evaluation of LDCT-IR-FBP and LDCT-MBIR to patients with a BMI ≤25, deemed too restrictive for real-life conditions.

One limitation of LDCT-MBIR for analyzing biliary tracts, using this type of low-dose radiation, was reported in a series of 28 patients by Padole *et al* [30]. In this study, the common bile duct could not be optimally visualized in 58% (15/26) of patients. Our series also confirmed a limitation of LDCT-IR-FBP and LDCT-MBIR for imaging the biliary tracts, primarily in obese patients. A limitation for imaging biliary tract-related conditions was already reported using CECT [31]. For this reason, sonography and magnetic resonance imaging (MRI) cholangiography are often advocated as a complement to CT in patients with right upper quadrant pain suspected to be of biliary origin [31, 32]. These recommendations likely compensate for the potential LDCT-MBIR limitation in imaging biliary tract-related conditions.

The interobserver agreement was higher for LDCT-MBIR (0.80) than LDCT-IR-FBP (0.57). The fact that LDCT-MBIR images look more similar to CECT images than LDCT-IR-FBP images do [33, 34] could account for this. Indeed, our

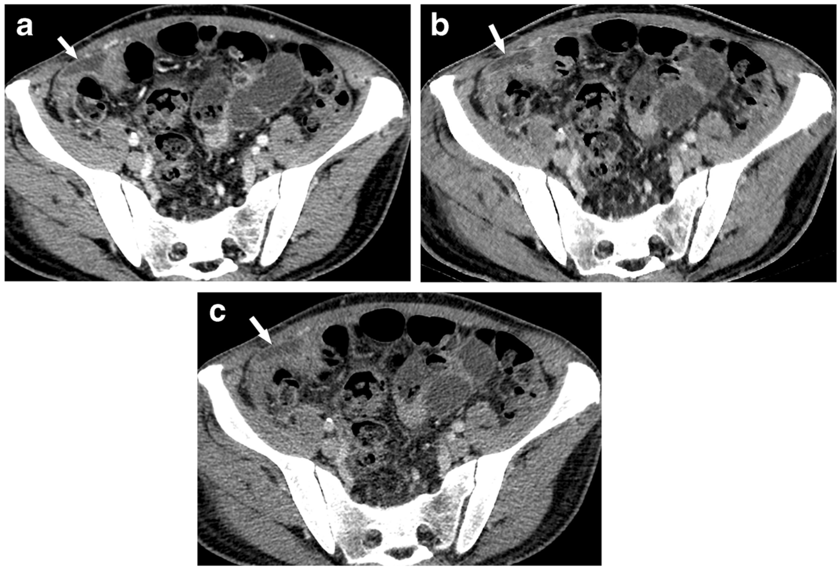

Fig. 2 Incorrect primary diagnosis on LDCT-IR-FBP images and correct diagnosis using LDCT-MBIR. 51-year-old man, BMI = 18, treated for pancreatic cancer, admitted with fever and sepsis. **a** Axial standard CECT (effective dose: 7.6 mSv) at the level of the pelvis. A well-delineated collection with peripheral enhancement, consistent with an abscess (*arrow*), is seen in the lower right quadrant. **b** Axial LDCT-MBIR (effective dose: 2.1 mSv) image at the same level as **A**. The collection (*arrow*) with the peripheral enhancement was reported by both raters. **c** Axial LDCT-IR-FBP (effective dose: 2.1 mSv) image at the same level as **A**. The peripheral enhancement of the collection was not conspicuous on this series, mimicking a normal bowel segment (*arrow*). The collection was thus overlooked by both raters, and the image was wrongly considered normal. Patient underwent broad spectrum antibiotic therapy, with improvement of the outcome.

data showed that the subjective quality of the examination was significantly higher for both raters when using LDCT-MBIR than LDCT-IR-FBP. Since Rater 2 was less familiar with LDCT-IR-FBP than Rater 1, proficiency in interpreting LDCT-MBIR images appears to be less dependent on the radiologist's prior experience with this iterative reconstruction method than it is the case regarding LDCT-IR-FBP proficiency.

One potential limitation is the choice of the CECT report as reference standard instead of the clinical follow-up. However, standard CT is currently considered the best diagnostic method in patients with acute abdominal pain and the clinical

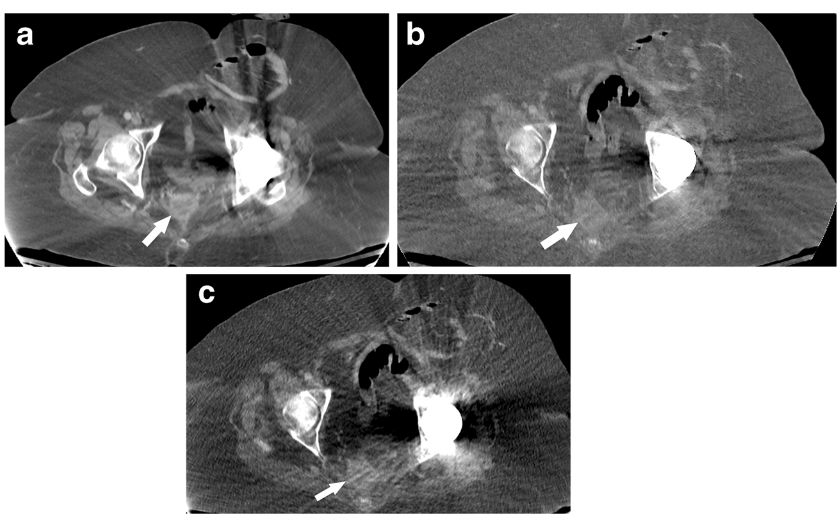

Fig. 3 Incorrect primary diagnosis using both LDCT-IR-FBP and LDCT-MBIR imaging for a pelvic abscess. 67-year-old woman, BMI = 45, admitted for fever and anal pain. **a** Axial CECT (effective dose: 20 mSv) at the level of the pelvis. A well-delineated collection with peripheral enhancement and hypodense centre, consistent with an abscess (*arrow*), is seen in the precoccygeal space. **b** Axial LDCT-MBIR and **c** Axial LDCT-IR-FBP (effective dose: 1.8 mSv) at the same level as **A**. The collection, which manifested as a homogenous structure (*arrow*), was not well-delineated on either modality and missed by both raters. Patient underwent surgery which confirmed the abscess; the bacteriological analysis showed enteric gram-negative rods

Fig. 4 False negative with LDCT-IR-FBP for secondary diagnosis. 51-year-old patient, BMI = 25, admitted for diffuse abdominal pain. LDCT-IR-FBP, LDCT-MBIR, and CECT imaging were all interpreted as negative for primary diagnosis. **a** CECT (effective dose: 10.7 mSv), coronal reformation at the level of the liver (*L*). An isolated linear hypodensity, extending from the periphery to the centre of the liver (*arrow*), was reported as a dilated biliary duct, requiring further investigation (secondary diagnosis). This structure was eventually diagnosed as the sequela of a prior cholangitis. **b** LDCT-MBIR (effective dose: 2.1 mSv), same level and reformation as **A**. This hypodensity (*arrow*) was interpreted as a dilated biliary duct and reported as secondary diagnosis by both Raters 1 and 2. **c** LDCT-IR-FBP (effective dose: 2.1 mSv), same level and reformation as **A**. The images were interpreted as normal for both primary and secondary diagnoses by both raters. The dilated biliary duct (*arrow*) was overlooked by both raters

follow-up cannot always be considered a perfect reference standard [35]. Furthermore, the potential bias of using CECT instead of clinical follow-up could have only reduced the LDCT-IR-FBP and LDCT-MBIR accuracy, rather than improving it, which would have been more concerning.

Our study did not evaluate the diagnostic performance of LDCT-IR-FBP and LDCT-MBIR with respect to lesion size, which could constitute a study limitation. Prior series reported a lower cumulative lesion detection capacity (169/213, 79%) using LDCT-MBIR compared to CECT, with a 74% dose reduction [33], suggesting that clinically significant lesions under 7 mm [34] or 8 mm [30] in diameter could be missed. Other studies reported a reduction in subjective image quality and conspicuity of liver lesions using LDCT-MBIR with a dose reduction of 50% [36] to 59% [37]. These reports may explain why our LDCT-IR-FBP and LDCT-MBIR protocols performed better in detecting acute abdominal conditions than incidental findings like small parenchymal nodules. Nonetheless, the actual LDCT-MBIR efficacy in detecting small lesions might have been slightly underestimated in prior reports. In these studies, including our own, contrast-enhanced LDCT protocols were performed after completing the CECT series in a more delayed portal phase, which could have impaired the lesions' contrast levels and thus their detectability. Further series are warranted to assess better the diagnostic value of LDCT-MBIR protocols in detecting small lesions.

The fact that patients admitted with a suspicion of appendicitis were not included in our series may also be considered as a limitation, since right lower quadrant pain is frequent and have multiple alternative diagnoses other than appendicitis, that were unrepresented in our study population.

Although the long processing time for LDCT-MBIR may currently constitute a limitation to its use, this problem is

Table 4 Sensitivity for the detection of secondary diagnosis on LDCT-IR-FBP and LDCT-MBIR imaging compared with CECT, reported by two raters

Secondary diagnosis (N = 38)	Rater 1 Sensitivity (%)		Rater 2 Sensitivity (%)	
	LDCT-IR-FBP	LDCT-MBIR	LDCT-IR-FBP	LDCT- MBIR
All patients (N = 38)	81.5 (31/38)	89.5 (34/38)	78.9 (30/38)	92.1 (35/38)
BMI <30 (N = 28)	82.1 (23/28)	92.8 (26/28)	82.1 (23/28)	96.4 (27/28)
BMI ≥30 (N = 10)	80 (8/10)	80 (8/10)	70 (7/10)	80 (8/10)

LDCT low-dose CT, *IR* iterative reconstruction, *FBP* filtered-back projection, *MBIR* model-based iterative reconstruction, *CECT* contrast-enhanced abdominal CT, *BMI* body mass index likely to be solved in the near future by the consistent improvements made to advanced high-performance computers and near real time graphics processing unit (GPU) and cloud-based computing capacities.

In conclusion, our study demonstrated that CT imaging of non-obese patients with acute abdominal pain in an emergency ward can be achieved with radiation doses close to those used for abdominal radiography when applying model based iterative reconstruction algorithm.

Acknowledgements The scientific guarantor of this publication is: Prof. Pierre-Alexandre Poletti, Department of Radiology, University Hospital of Geneva, Switzerland. The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article. The authors state that this work has not received any funding. One of the authors has significant statistical expertise: Prof. Thomas Perneger, from the Division of Clinical Epidemiology, University Hospital of Geneva, Switzerland. Institutional Review Board approval was obtained. Written informed consent was obtained from all subjects (patients) in this study. Methodology: prospective, diagnostic study, performed at one institution.

References

1. Rao VM, Levin DC, Parker L, Frangos AJ, Sunshine JH (2011) Trends in utilization rates of the various imaging modalities in emergency departments: nationwide Medicare data from 2000 to 2008. J Am Coll Radiol 8:706–709
2. Larson DB, Johnson LW, Schnell BM, Salisbury SR, Forman HP (2011) National trends in CT use in the emergency department: 1995-2007. Radiology 258:164–173
3. Brenner DJ, Hall EJ (2007) Computed tomography–an increasing source of radiation exposure. N Engl J Med 357:2277–2284
4. Shuryak I, Sachs RK, Brenner DJ (2010) Cancer risks after radiation exposure in middle age. J Natl Cancer Inst 102:1628–1636
5. Roch P, Aubert B (2013) French diagnostic reference levels in diagnostic radiology, computed tomography and nuclear medicine: 2004-2008 review. Radiat Prot Dosim 154:52–75
6. Wall B, Haylock R, Jansen J, Hillier M, Hart D, Shrimpton P (2011) Radiation risks from medical x-ray examinations as a function of the age and sex of the patient. HPA
7. Alshamari M, Norrman E, Geijer M, Jansson K, Geijer H (2016) Diagnostic accuracy of low-dose CT compared with abdominal radiography in non-traumatic acute abdominal pain: prospective study and systematic review. Eur Radiol 26:1766–1774
8. Tack D, Sourtzis S, Delpierre I, de Maertelaer V, Gevenois PA (2003) Low-dose unenhanced multidetector CT of patients with suspected renal colic. AJR Am J Roentgenol 180:305–311
9. Fontarensky M, Alfidja A, Perignon R et al (2015) Reduced radiation dose with model-based iterative reconstruction versus standard dose with adaptive statistical iterative reconstruction in abdominal CT for diagnosis of acute renal colic. Radiology 276:156–166
10. Poletti PA, Platon A, Rutschmann OT, Schmidlin FR, Iselin CE, Becker CD (2007) Low-dose versus standard-dose CT protocol in patients with clinically suspected renal colic. AJR Am J Roentgenol 188:927–933
11. Platon A, Jlassi H, Rutschmann OT et al (2009) Evaluation of a low-dose CT protocol with oral contrast for assessment of acute appendicitis. Eur Radiol 19:446–454
12. Kim K, Kim YH, Kim SY et al (2012) Low-dose abdominal CT for evaluating suspected appendicitis. N Engl J Med 366:1596–1605
13. Kim SH, Yoon JH, Lee JH et al (2015) Low-dose CT for patients with clinically suspected acute appendicitis: optimal strength of sinogram affirmed iterative reconstruction for image quality and diagnostic performance. Acta Radiol 56:899–907
14. Desai GS, Thabet A, Elias AY, Sahani DV (2013) Comparative assessment of three image reconstruction techniques for image quality and radiation dose in patients undergoing abdominopelvic multidetector CT examinations. Br J Radiol 86:20120161
15. McCollough CH, Bruesewitz MR, Kofler JM Jr (2006) CT dose reduction and dose management tools: overview of available options. Radiographics 26:503–512
16. Patino M, Fuentes JM, Hayano K, Kambadakone AR, Uyeda JW, Sahani DV (2015) A quantitative comparison of noise reduction across five commercial (hybrid and model-based) iterative reconstruction techniques: an anthropomorphic phantom study. AJR Am J Roentgenol 204:W176–183
17. Laqmani A, Veldhoen S, Dulz S et al (2016) Reduced-dose abdominopelvic CT using hybrid iterative reconstruction in suspected left-sided colonic diverticulitis. Eur Radiol 26:216–224
18. Schindera ST, Diedrichsen L, Muller HC et al (2011) Iterative reconstruction algorithm for abdominal multidetector CT at different tube voltages: assessment of diagnostic accuracy, image quality, and radiation dose in a phantom study. Radiology 260:454–462
19. Kaza RK, Platt JF, Goodsitt MM et al (2014) Emerging techniques for dose optimization in abdominal CT. Radiographics 34:4–17
20. Yu Z, Thibault JB, Bouman CA, Sauer KD, Hsieh J (2011) Fast model-based X-ray CT reconstruction using spatially nonhomogeneous ICD optimization. IEEE Trans Image Process 20:161–175
21. Millon D, Vlassenbroek A, Van Maanen AG, Cambier SE, Coche EE (2016) Low contrast detectability and spatial resolution with model-based Iterative reconstructions of MDCT images: a phantom and cadaveric study. Eur Radiol
22. Herin E, Gardavaud F, Chiaradia M et al (2015) Use of Model-Based Iterative Reconstruction (MBIR) in reduced-dose CT for routine follow-up of patients with malignant lymphoma: dose savings, image quality and phantom study. Eur Radiol 25:2362–2370
23. Buls N, Van Gompel G, Van Cauteren T et al (2015) Contrast agent and radiation dose reduction in abdominal CT by a combination of low tube voltage and advanced image reconstruction algorithms. Eur Radiol 25:1023–1031
24. Nelson RC, Feuerlein S, Boll DT (2011) New iterative reconstruction techniques for cardiovascular computed tomography: how do they work, and what are the advantages and disadvantages? J Cardiovasc Comput Tomogr 5:286–292
25. Geyer LL, Schoepf UJ, Meinel FG et al (2015) State of the art: iterative CT reconstruction techniques. Radiology 276:339–357
26. Huda W, Ogden KM, Khorasani MR (2008) Converting dose-length product to effective dose at CT. Radiology 248:995–1003
27. Hara AK, Paden RG, Silva AC, Kujak JL, Lawder HJ, Pavlicek W (2009) Iterative reconstruction technique for reducing body radiation dose at CT: feasibility study. AJR Am J Roentgenol 193:764–771
28. Agresti A (1990) Categorical data analysis. John Wiley & sons, pp 35–361
29. Khawaja RD, Singh S, Blake M et al (2015) Ultralow-dose abdominal computed tomography: comparison of 2 iterative reconstruction techniques in a prospective clinical study. J Comput Assist Tomogr 39:489–498
30. Padole A, Singh S, Lira D et al (2015) Assessment of filtered back projection, adaptive statistical, and model-based iterative reconstruction for reduced dose abdominal computed tomography. J Comput Assist Tomogr 39:462–467

31. Nino-Murcia M, Jeffrey RB Jr (2001) Imaging the patient with right upper quadrant pain. Semin Roentgenol 36:81–91
32. Watanabe Y, Nagayama M, Okumura A et al (2007) MR imaging of acute biliary disorders. Radiographics 27:477–495
33. Pickhardt PJ, Lubner MG, Kim DH et al (2012) Abdominal CT with model-based iterative reconstruction (MBIR): initial results of a prospective trial comparing ultralow-dose with standard-dose imaging. AJR Am J Roentgenol 199:1266–1274
34. Deak Z, Grimm JM, Treitl M et al (2013) Filtered back projection, adaptive statistical iterative reconstruction, and a model-based iterative reconstruction in abdominal CT: an experimental clinical study. Radiology 266:197–206
35. Rosen MP, Siewert B, Sands DZ, Bromberg R, Edlow J, Raptopoulos V (2003) Value of abdominal CT in the emergency department for patients with abdominal pain. Eur Radiol 13:418–424
36. Nakamoto A, Kim T, Hori M et al (2015) Clinical evaluation of image quality and radiation dose reduction in upper abdominal computed tomography using model-based iterative reconstruction; comparison with filtered back projection and adaptive statistical iterative reconstruction. Eur J Radiol
37. Shuman WP, Chan KT, Busey JM et al (2014) Standard and reduced radiation dose liver CT images: adaptive statistical iterative reconstruction versus model-based iterative reconstruction-comparison of findings and image quality. Radiology 273:793–800