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FULL PAPER

Diagnostic efficacy of single-pass abdominal multidetector-row CT: prospective evaluation of a low dose protocol

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Objective: To evaluate the diagnostic efficacy of single-pass contrast-enhanced multidetector CT (CE-MDCT) performed with a low-radiation high-contrast (LR-HC) dose protocol in selected patients with non-traumatic acute bowel disease.

Methods: 65 (32 males, 33 females; aged 20–67 years) consecutive patients with non-traumatic acute bowel disease underwent single-pass CE-MDCT performed 70–100 s after i.v. bolus injection of a non-ionic iodinated contrast medium (CM) (370 mgI ml^{-1}). In 46 (70%) patients with a clinical and/or ultrasonographic suspicion of inflammatory bowel disease, up to 1.2–1.4 l of a 7% polyethylene-glycol solution was orally administered 45–60 mins prior to the CT examination. Patients were then divided into two groups according to age: Group A (20–44 years; $n = 34$) and Group B (45–70 years; $n = 31$). Noise index (NI) and CM dose were selected as follows: Group A ($\text{NI} = 15$; 2.5 ml kg^{-1}) and Group B ($\text{NI} = 12.5$; 2 ml kg^{-1}). All patients of Group A underwent thyroid functional tests at 4–6 weeks. Final diagnoses were obtained by open ($n = 12$) or laparoscopic surgery ($n = 4$), endoscopy w/without biopsy ($n = 24$) and clinical ($n = 19$) and/or instrumental (ultrasonography) ($n = 6$) follow-up at 11 ± 4 months (range 6–18 mo.). Statistical analysis was performed by χ^2 and Student's t -test for categorical and continuous variables, respectively.

Results: Sensitivity and specificity were 91.3 vs 95.4% ($p = 0.905$) and 90.9 vs 88.8% ($p = 0.998$) with an overall diagnostic accuracy of 91.1 vs 93.5% ($p = 0.756$), whereas

the radiation (in millisievert) and CM dose (in millilitre) were $7.5 \pm 2.8 \text{ mSv}$ and $155 \pm 30 \text{ ml}$ for Group A and $14.1 \pm 5.3 \text{ mSv}$ and $130 \pm 24 \text{ ml}$ for Group B ($p < 0.001$), respectively. No patients of Group A showed laboratory signs of thyrotoxicosis at follow-up.

Conclusion: The LR-HC has proved to be a safe and a dose-effective protocol in the evaluation of selected young patients with non-traumatic acute bowel disease.

Advances in knowledge: (1) As reaching the highest diagnostic benefit to risk ratio (AHARA) appears to be the current principle of MDCT imaging, an increased amount of iodinated CM ($0.7\text{--}0.9 \text{ gI ml}^{-1}$) can be safely administered to young patients (< 40 years) with normal thyroid and renal function to compensate for the lower image quality resulting from low-dose CT protocols performed with the standard filter back-projection algorithm. Such an approach will result in a significant reduction of the radiation dose, which could be otherwise achieved only using iterative reconstruction algorithms combined with either low tube voltage and/or low tube current protocols. (2) An optimal scan delay (T_{delay}) for a venous phase caudocranial acquisition can be calculated by the following formula: $T_{\text{delay}} = \text{CI} + 25 - T_{\text{SD}}$, where CI is the duration of the contrast injection, 25 is the average of the sum of abdominal aortic and peak hepatic arrival times and T_{SD} is the scan duration. With such an approach, the radiation exposure resulting from bolus tracking, albeit performed with low-dose scans, can be spared in patients with normal transit times.

INTRODUCTION

Minimizing the radiation dose delivered to patients while preserving the diagnostic accuracy of the CT examination should be a radiologist duty in the current era of multidetector CT (MDCT) technology.¹ Indeed, radiologists

should always attempt to obtain a diagnostic benefit to risk ratio as high as reasonably achievable (AHARA)¹ and such a radiation consciousness should primarily involve patients under 30 years, as the lifetime risk of radiation-induced cancer is greater the younger the patient.²

While several dose reduction strategies can be successfully applied in contrast-enhanced abdominal MDCT, such as the use of iterative reconstruction algorithms combined with either low tube voltage^{3,4} and/or low tube current protocols,⁵ these technologies are still not widely available in clinical practice. Moreover, dose reduction in MDCT should primarily result from the optimization of acquisition protocols, as unindicated phases in contrast-enhanced MDCT (CE-MDCT) are a major source of unjustified radiation exposure.⁶

Radiologists should therefore become familiar with single-pass acquisitions, as they can effectively address the vast majority of clinical questions in contrast-enhanced abdominal CT⁷ and even in the clinical context of a non-traumatic acute abdomen, there seems to be no diagnostic gain of multiphasic acquisitions compared with venous phase alone.⁸

However, as improvement in the quality of CT images obtained using low-dose protocols can also be achieved by increasing the amount of iodinated contrast media (CM) administered,⁹ the possibility of balancing the effects of radiation dose and CM dose on the image quality of contrast-enhanced abdominal CT has been investigated in both an experimental¹⁰ as well as a clinical setting.¹¹ In this latter study, we have recently shown that a constant image quality, as assessed by both qualitative and quantitative analysis, could be maintained in contrast-enhanced single-pass multidetector abdominal CT, balancing the amount of radiation and CM dose according to the age of the patients.¹¹

In the present study, we prospectively investigated in the same patient population the diagnostic efficacy of CE-MDCT performed with a low-radiation high-contrast (LR-HC) dose protocol comparing its accuracy with that of a standard dose (SD) protocol in the evaluation of selected patients with non-traumatic acute bowel disease, a clinical condition including several acute gastrointestinal disorders such as inflammatory bowel disease (IBD), acute diverticulitis, small bowel obstruction (SBO) or large bowel obstruction (LBO), infective or autoimmune enteritis, ischaemic or infective colitis etc.¹²

METHODS AND MATERIALS

This prospective study was approved by the local ethical committee board on 26 February 2014, and written informed consent was obtained from all patients.

Population

From 4 April to 31 October 2014, 80 (41 males, 39 females; aged 20–67 years) consecutive patients referred from the Department of Gastroenterology of our institution to undergo CE-MDCT for non-traumatic acute bowel disease were enrolled in this prospective study. Eligibility criteria included the absence of cardiovascular, renal or thyroid comorbidities.

As 12 (15%) patients underwent additional delayed acquisitions for diagnostic needs such as the characterization of incidentally found focal hepatic lesions ($n = 4$), the evaluation of penetrating Crohn's disease ($n = 3$), the presence of pelvic abscesses ($n = 4$)

or abdominal wall endometriosis ($n = 1$) and 3 more patients were lost to follow-up, the final population included 65 patients who were divided into 2 groups according to age: Group A (20–44 years; $n = 34$, 34 ± 8 years) and Group B (45–70 years; $n = 31$, 56 ± 7 years).

CT technique

All patients underwent single-pass CE-MDCT (Aquilion 64TM; Toshiba, Tokyo, Japan) with a caudocranial acquisition performed with the following scanning parameters: detector configuration = 1×32 mm; table feed 36 mm s^{-1} ; rotation time 0.75 s; helical pitch = 27; section thickness = 5 mm; 120 kVp; automated tube current modulation (ATCM). All images were reconstructed with a standard (kernel = 3) filter back-projection algorithm. 46 patients (24 males, 22 females) with a clinical and/or ultrasonographic suspicion of IBD were given 1200–1400 ml of a 7% polyethylene-glycol solution administered orally 45–60' prior to the CT examination, followed by ingestion of 500 ml of tap water 10–15 mins prior to the CT acquisition.¹³

For each group, a different noise index (NI) (NI = 12.5 vs 15) was selected in the ATCM system and a different amount (2.0 vs 2.5 ml kg^{-1}) of non-ionic iodinated CM (Iopamiro 370 mgI ml^{-1} ; Bracco Imaging, Milan, Italy) was administered as follows: Group A (NI = 15; 2.5 ml kg^{-1}) and Group B (NI = 12.5; 2 ml kg^{-1}).

Single-pass contrast-enhanced abdominal CT was then performed according to a LR-HC (NI = 15) (2.5 ml kg^{-1}) dose protocol in Group A and a SD protocol (NI = 12.5; 2 ml kg^{-1}) in Group B. In all patients, the i.v. contrast injection was followed by 100 ml of saline solution administered at the same rate with an automated dual-head injector (Stellant Medrad Inc., Indianola, IA).

In each patient, the scan delay was calculated according to the following formula:¹¹

$$T_{\text{delay}} = \text{CI} + 25 - T_{\text{SD}},$$

where CI is the duration of contrast injection, T_{SD} is the scan duration and 25 is the average of the sum of the abdominal aortic (15–18 s) and the hepatic arrival times (30–40 s).¹⁴

All patients of Group A underwent evaluation of thyroid function (Thyroid Stimulating Hormone or Thyrotropin (TSH), Free triiodothyronine (FT3), Free thyroxine (FT4)) tests at 4–6 weeks to exclude an iodine-induced thyrotoxicosis.¹⁵ In all patients, the radiation dose delivered was reported as a dose-length product (in milligray centimetre) and the effective dose (ED) (in millisievert) was calculated by applying a conversion factor of 0.015.¹⁶

Reference standard

All CT scans were interpreted by two experienced abdominal radiologists and prospective CT reports were compared with final diagnoses based on open ($n = 12$) or laparoscopic surgery ($n = 4$), colonoscopy with ($n = 7$) or without biopsy ($n = 15$), gastroscopy ($n = 1$), ultrasonography-guided biopsy ($n = 1$) and

clinical ($n = 19$) or instrumental (ultrasonography) follow-up ($n = 6$) performed at 11 ± 4 months (range 6–18 mo.).

Statistical analysis

Statistical analysis was performed by using SPSS® v. 20.0 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL).

Differences in continuous variables were analyzed by the unpaired Student's *t*-test, whereas χ^2 test was used for categorical variables, both with a level of significance of 0.05.

RESULTS

Patient characteristics

Patient features [age, gender, body weight, height and body mass index (BMI)] are summarized in Table 1 along with the serum creatinine (in milligram per millilitre) and Glomerular Filtration Rate (GFR) (millilitre per minute) levels. Gender distribution was similar between Groups A and B, whereas non-significant differences were observed between patient weight, height and BMI of Groups A and B (Table 1). Serum creatinine levels and GFRs of patients of Groups A and B were also not significantly different (Table 1).

Non-ionic iodinated contrast media

No adverse reaction to the non-ionic iodinated CM used was observed in both groups. The amounts of CM injected (in millilitre) were significantly different between the two groups with 155 ± 30 and 128 ± 24 ml for Groups A and B ($p < 0.001$) corresponding to an iodine dose of 56 ± 11 and 47 ± 8 g, respectively (Table 2). None of the patients of Group A developed signs of thyroid dysfunction at follow-up.

Effective absorbed dose

Dose-length products (in milligray centimetre) and effective absorbed doses (in millisievert) were significantly different between the two groups with respective values of 500 ± 192 mGy cm and 7.5 ± 2.8 mSv for Group A and 940 ± 353 mGy cm and 14.1 ± 5.3 mSv for Group B ($p < 0.001$) (Table 2).

Scan delays

Scan delays ranged between 70 and 100 s depending on the duration of contrast injection (CI), which was equal to the body weight as the rate of the injection was kept identical to the

amount of iodinated CM administered per kilogram of body weight, and the scan duration which ranged between 12 and 15 s.

In detail, scan delays ranged between 70 and 90 s in Group A and between 70 and 100 s in Group B with mean values of 76 ± 7 vs 78 ± 8 s ($p = 0.457$) for Groups A and B, respectively (Table 2).

Diagnostic accuracy

Diagnostic accuracies were similar for the LR-HC and the SD protocol with respective values of 91.1% (95% confidence interval = 78.3–98.7) in Group A and 93.5% (95% confidence interval = 81.4–99.2) in Group B ($p = 0.756$) (Table 3). Sensitivity was higher but not significantly different in Group B (95.4 vs 91.3%; $p = 0.905$), whereas specificity was higher but not significantly different in Group A (90.9 vs 88.8% $p = 0.998$) (Table 3). Overall, single-pass CE-MDCT findings were true positive in 42 patients (21 patients in Group A; 21 patients in Group B) and true negative in 18 patients (10 patients in Group A; 8 patients in Group B) with 2 false-negative and 1 false-positive findings in Group A (Table 4) and 1 false-positive and 1 false-negative finding in Group B (Table 5).

In detail, peroral CT enterography performed with an LR-HC protocol (Group A) correctly identified the site, extension and pattern (stricturing or penetrating) of disease in 13 patients with Crohn's disease as assessed by surgery ($n = 8$) (Figure 1a), colonoscopy with ($n = 2$) or without ($n = 1$) biopsy and instrumental (ultrasonography) follow-up ($n = 2$). True-positive findings were also observed in three patients with ulcerative colitis, as confirmed by colonoscopy with biopsy, whereas true-negative findings were obtained in seven patients, as assessed by endoscopy ($n = 3$), clinical ($n = 2$) or instrumental follow-up ($n = 2$). There were also two false-negative and one false-positive findings (Table 4). In the remaining eight patients of Group A, single-pass CE-MDCT performed with an LR-HC protocol showed true-positive findings in three patients with a perforated acute diverticulitis—two patients operated on and one patient treated conservatively (Figure 2a)—in one patient with Budd-Chiari syndrome and in two patients with adhesive SBO who were both treated conservatively with a nasogastric intubation (Figure 3a), whereas true-negative findings were observed in two patients referred for acute sigmoid diverticulitis, as both confirmed by colonoscopy (Table 4).

Table 1. Patient anagraphic and physical characteristics, creatinine levels and GFRs in both groups

Patients characteristics	Group A ($n = 34$)	Group B ($n = 31$)	<i>p</i> -value
Age (years)	20–44 (34 ± 8)	45–70 (56 ± 7)	–
Gender	M ($n = 17$) F ($n = 17$)	M ($n = 15$) F ($n = 16$)	–
Weight (kg)	62 ± 12	64 ± 13	0.428
Height (cm)	167 ± 8	165 ± 7	0.259
BMI (kg m^{-2})	21 ± 3	23 ± 4	0.155
GFR (ml min^{-1})	106 ± 22	97 ± 33	0.259
Creatinine (mg ml^{-1})	0.81 ± 0.17	0.75 ± 0.18	0.246

BMI, body mass index.

Table 2. Dose-length products (DLPs), effective doses (EDs), volumes of contrast media (CM) injected, iodine loads and scan delays of the CT acquisition performed in each group

Parameter	Group A	Group B	<i>p</i> -value
DLP (mGy cm)	500 ± 192	940 ± 353	<0.001
ED (mSv)	7.5 ± 2.8	14.1 ± 5.3	<0.001
CM (ml)	155 ± 30	128 ± 24	<0.001
Iodine load (g)	56 ± 11	47 ± 8	<0.001
Scan delay (s)	76 ± 7	78 ± 8	0.457

In Group B, peroral CT enterography ($n = 20$) correctly identified the site, extension and pattern (stricturing or penetrating) of disease in nine patients with Crohn's disease, as assessed by surgery ($n = 3$), colonoscopy with ($n = 1$) or without ($n = 2$) biopsy (Figure 1b) and clinical and instrumental follow-up ($n = 3$). True-positive findings were also obtained in four patients with ulcerative colitis, as confirmed by colonoscopy with biopsy, whereas true-negative findings were observed in five patients, as assessed by colonoscopy ($n = 1$) or clinical and instrumental (ultrasonography) follow-up ($n = 4$). One false-positive and one false-negative finding was also observed (Table 5). In the remaining 11 patients, true-negative findings were observed in 3 patients referred for acute sigmoid diverticulitis, as confirmed by clinical follow-up, whereas true-positive findings were obtained in 2 patients with non-occlusive ischaemic colitis (Figure 2b), as assessed by colonoscopy in both, in 2 patients with LBO—1 due to a sigmoid cancer and 1 due to a sigmoid inflammatory stenosis (Figure 3b)—who both underwent surgery, and in other 5 patients with miscellaneous disorders such as sclerosing mesenteritis, gastric outlet syndrome and celiac disease (Table 5).

DISCUSSION

As the radiation exposure resulting from unindicated phases in MDCT has become a major issue in the radiological community,⁶ single-pass protocols have been recommended to address the vast majority of clinical questions in contrast-enhanced abdominal CT.⁷ Indeed, even in the clinical context of a non-traumatic acute abdomen, there seems to be no diagnostic gain of multiphasic acquisition compared with venous phase alone.⁸

In the present study, we prospectively investigated the diagnostic efficacy of single-pass CE-MDCT performed according to an LR-

HC dose protocol in the evaluation of selected patients with non-traumatic acute bowel disease comparing its accuracy with that of a standard protocol. In the same patient population, we have recently shown that a constant image quality could be maintained balancing the amount of radiation and CM dose according to the age of the patients.¹¹ Indeed, where peak hepatic enhancement was concerned, the LR-HC dose protocol proved to be most dose effective, as the relative figure of merit was significantly higher, despite surprisingly similar signal-to-noise ratios.¹¹ As figure of merit represents the ratio of contrast-to-noise ratio² to the ED, it is considered a useful mean to compare the effect on image quality of different CT acquisition protocols and to evaluate their dose efficacy.³ In accordance with our previous findings, the present study underscores that the LR-HC is also a dose-effective protocol in the evaluation of selected young patients with non-traumatic acute bowel disease showing a similar diagnostic accuracy as the standard protocol (Table 3) but with a significantly lower ED (Table 2).

While several other dose reduction strategies can be successfully applied in CE-MDCT such as the use of iterative reconstruction algorithms to reduce the image noise associated with either low tube voltage or low tube current protocols,^{3–5} these technologies are still not widely available in clinical practice, whereas our LR-HC protocol simply relies on commercially available ATCM systems to select a higher NI value to reduce the radiation dose,¹⁷ compensating the resulting increase in image noise with a larger amount of non-ionic iodinated CM, as first suggested by Watanabe et al.⁹ To the best of our knowledge, there has been no other study prospectively addressing this issue in clinical practice aside from our previous investigation performed in the same patient population.¹¹ While the possibility of balancing the effect of radiation and CM on image quality was also investigated by Falt et al.,¹⁰ this was performed retrospectively and the ideal combination of tube load and iodinated contrast to obtain a constant image quality was only extrapolated.

While the amounts of non-ionic iodinated CM administered to patients of Group A (0.92 gI kg^{-1}) were largely above the recommended values¹⁸ with a mean value of $58 \pm 11 \text{ g}$ (Table 2), the total iodine load should not be an issue in patients with a normal thyroid¹⁵ or renal function.¹⁹ Indeed, none of these patients showed signs of a contrast-induced thyrotoxicosis at follow-up. However, recent data seem to indicate that the absorbed dose in contrast-enhanced CT is indeed higher than that in unenhanced acquisition with an average dose increment

Table 3. Sensitivity, specificity, accuracy, positive-predictive value (PPV) and negative-predictive value (NPV) for both protocols are reported along with 95% confidence interval (CI₉₅) and the *p*-value according to the χ^2 test

Diagnostic performance	Group A (CI ₉₅)	Group B (CI ₉₅)	<i>p</i> -value
Sensitivity	91.3% (73–98.9)	95.4% (76.1–99.8)	0.905
Specificity	90.9% (55.5–99.7)	88.8% (51.4–98.5)	0.998
Accuracy	91.1% (78.3–98.7)	93.5% (81.4–99.2)	0.756
PPV	95.4% (78–99.8)	95.4% (78–98.8)	1
NPV	83.3% (48.2–97.7)	88.8% (51.7–99.7)	0.850

Table 4. Patients of Group A (20–44 years): anagraphic details are shown along with the CT diagnoses and the results of the test according to the reference standard

Patient	Age (years)	Sex	CT diagnosis	Reference standard	Test
1	31	F	No evidence of bowel pathology	Clinical follow-up	TN
2	35	M	Perforated diverticulitis	Clinical and CT follow-up	TP
3	31	F	Budd–Chiari syndrome	Clinical and ultrasonographic follow-up	TP
4	37	M	Perforated diverticulitis	Surgery	TP
5	20	M	Stricture Crohn's disease	Retrograde ileoscopy	TP
6	26	M	Perforated diverticulitis	Surgery	TP
7	20	F	Adhesive SBO	Clinical follow-up	TP
8	39	M	Anastomotic fibrotic stricture	Colonoscopy and biopsy (Crohn's recurrence)	FN
9	44	F	No evidence of bowel pathology	Clinical follow-up	TN
10	41	M	Diverticulosis	Colonoscopy	TN
11	32	F	No evidence of bowel pathology	Clinical follow-up	TN
12	43	F	Stricture Crohn's disease	Clinical and ultrasonographic follow-up	TP
13	29	M	Penetrating Crohn's disease	Surgery	TP
14	41	F	Diverticulosis	Colonoscopy	TN
15	42	M	Left ulcerative colitis	Colonoscopy and biopsy	TP
16	42	M	Penetrating Crohn's disease	Surgery	TP
17	44	F	Adhesive SBO	Clinical follow-up	TP
18	37	F	SBO	Clinical and ultrasonographic follow-up (functional disorder)	FP
19	21	F	No evidence of bowel pathology	Colonoscopy	TN
20	39	M	Stricture Crohn's disease	Retrograde ileoscopy	TP
21	44	M	Penetrating Crohn's disease	Surgery	TP
22	43	M	Penetrating Crohn's disease	Surgery	TP
23	44	F	Adynamic ileus	Clinical follow-up	TN
24	44	F	No evidence of bowel pathology	Retrograde ileoscopy (terminal ileitis)	FN
25	28	F	No evidence of bowel pathology	Clinical follow-up	TN
26	32	M	Crohn's anastomotic recurrence	Surgery	TP
27	27	F	Left ulcerative colitis	Colonoscopy and biopsy	TP
28	25	F	No evidence of bowel pathology	Clinical follow-up	TN
29	34	M	Stricture Crohn's disease	Retrograde ileoscopy	TP
30	25	M	Left ulcerative colitis	Colonoscopy and biopsy	TP
31	24	M	No evidence of bowel pathology	Clinical Follow-up	TN
32	26	M	Penetrating Crohn's disease	Surgery	TP
33	20	F	Crohn's colitis	Surgery	TP
34	40	F	Penetrating Crohn's disease	Surgery	TP

F, female; M, male; SBO, small bowel obstruction.

FN, false negative; FP, false positive; TN, True negative; TP, True positive.

of 19% for the liver.²⁰ As this is likely the result of the major contribution of photoelectric effect in the attenuation of the X-ray beam by iodine (k -edge = 33.2 keV),²¹ further studies are needed to assess the benefit to risk ratio of contrast-enhanced

examinations in different clinical contexts. In the present one, the LR-HC has resulted in halving of the ED administered to patients of Group A (7.5 ± 2.5 mSv) compared with that delivered to patients of Group B (14.1 ± 5.3 mSv) (Table 2). As

Table 5. Patients of Group B (45–70 years): anagraphic details are shown along with the CT diagnoses and the results of the test according to the reference standard

Patientt	Age (years)	Sex	CT diagnosis	Reference standard	Test
1	58	M	Ulcerative colitis	Colonoscopy and biopsy	TP
2	49	M	Small bowel Crohn's recurrence	Retrograde ileoscopy	TP
3	59	M	Sclerosing mesenteritis	Ultrasonography-guided biopsy	TP
4	60	M	LBO (sigmoid cancer)	Surgery	TP
5	57	M	Diverticulosis	Clinical follow-up	TN
6	48	M	No evidence of bowel pathology	Clinical follow-up	TN
7	55	F	No evidence of bowel pathology	Colonoscopy	TN
8	65	F	No evidence of bowel pathology	Clinical follow-up	TN
9	60	F	Strictureing Crohn's disease	Colonoscopy	TP
10	66	M	No evidence of bowel pathology	Retrograde ileoscopy (terminal ileitis)	FN
11	56	F	LBO (inflammatory stenosis)	Surgery	TP
12	66	F	Ischaemic colitis	Colonoscopy	TP
13	46	F	Strictureing Crohn's disease	Clinical and ultrasonographic follow-up	TP
14	52	M	Diverticulosis	Clinical follow-up	TN
15	67	F	Diverticulosis	Clinical follow-up	TN
16	60	M	Sclerosing mesenteritis	Surgery	TP
17	54	F	Left ulcerative colitis	Colonoscopy and biopsy	TP
18	67	M	Ulcerative pancolitis	Colonoscopy and biopsy	TP
19	45	M	No evidence of bowel pathology	Clinical follow-up	TN
20	64	F	Ulcerative colitis	Colonoscopy and biopsy	TP
21	50	M	Penetrating Crohn's disease	Surgery	TP
22	68	F	No evidence of bowel pathology	Clinical follow-up	TN
23	46	F	Strictureing Crohn's disease	Surgery	TP
24	57	F	Crohn's colitis	Colonoscopy (functional disorder)	FP
25	54	F	Strictureing Crohn's disease	Clinical and ultrasonographic follow-up	TP
26	60	F	Penetrating Crohn's disease	Surgery	TP
27	49	F	Peptic stenosis	Gastroscopy	TP
28	60	M	Ischaemic colitis	Colonoscopy	TP
29	46	M	Strictureing Crohn's disease	Retrograde ileoscopy	TP
30	53	M	Strictureing Crohn's disease	Clinical and ultrasonographic follow-up	TP
31	54	F	Celiac disease	Clinical follow-up	TP

F, female; LBO, large bowel obstruction; M, male.

FN, false negative; FP, false positive; TN, True negative; TP, True positive.

there were no significant differences in patient weights, heights and BMI between Groups A and B (Table 1), such a significant dose reduction can be solely attributed to the higher NI value (15 vs 12.5) selected in our ATCM system (Sure Exposure 3D Toshiba, Japan), which was effectively compensated by a significantly higher amount of non-ionic iodinated CM injected (155 ± 30 vs 128 ± 24 cc) (Table 2).

As far as the formula we used to calculate the optimal scan delay in each patient is concerned, it was largely derived from the data of

Bae,¹⁴ with the only difference that the total scan duration was subtracted by the sum of the CI time and the averaged sum of the aortic and peak hepatic transit times. This adjustment was made because in our protocol, hepatic parenchyma was scanned at the end of the caudocranial acquisition.¹¹

As far as the diagnostic performance of our single-pass protocol is concerned, it compares favourably with the most recent literature,^{8,22,23} with an overall diagnostic accuracy of 91.2% for Group A and 90.3% for Group B (Table 3). There are indeed

Figure 1. Single-pass peroral CT enterography in a 32-year-old male [Group A; 69 kg, body mass index (BMI) 23.6] and in a 49-year-old male (Group B, 71 kg, BMI 24): 5 mm thick coronal reformatted images are shown. In both patients, recurrent Crohn's disease can be appreciated at the level of the ileocolic anastomosis (arrowheads) with stratified thickening of the bowel wall, stiffening of the vasa recta and narrowing of the bowel lumen. In (b), proliferation of the mesenteric fat is also depicted in the pelvis (asterisk) along with mesenteric lymphadenomegalies. Peroral CT enterography findings were both true positive as assessed by surgery (a) and retrograde ileoscopy (b) with effective doses of 7.48 and 15 mSv, respectively.

major discrepancies in the prevalence of different aetiologies of non-traumatic acute bowel disease in our population compared with that of the literature.^{8,22,23} Several acute gastrointestinal disorders which are fairly common in clinical practice such as appendicitis are not even represented in our population, and the exclusion of patients with cardiac comorbidities may also have underestimated the prevalence of ischaemic bowel disease in Group B. Therefore, further studies are warranted to validate our LR-HC protocol in a larger and unselected series of patients

with non-traumatic acute bowel disease. Such discrepancies, however, can be largely accounted for by our institution being a tertiary-care centre without an emergency department but a referral centre for IBD.²⁴ Indeed, up to 70% of the patients (46 out of 65 patients) underwent CE-MDCT performed according to a peroral CT enterography protocol, which is always indicated whenever there is a clinical and/or ultrasonographic suspicion of IBD in the acute setting.²⁵ In particular, peroral CT enterography showed a diagnostic accuracy of 88.4% in Group A

Figure 2. Single-pass contrast-enhanced multidetector CT (CE-MDCT) in a 35-year-old male [Group A; 70 kg, body mass index (BMI) 24.2] and in a 60-year-old male (Group B; 87 kg, BMI 28.4) with acute abdominal pain associated with fever (a) and bloody diarrhoea (b): 5-mm-thick coronal reformatted images are shown. In (a), a large intramural fluid collection is depicted in the pelvis (asterisk) with displacement of the sigmoid colon (arrowhead). In (b), extensive thickening of the bowel wall with submucosal oedema and a collapsed lumen is depicted at the level of descending colon (arrowheads) along with haziness of the adjacent mesenteric fat (asterisk) and fluid in the left parietocolic gutter (arrow). Both CE-MDCT findings were true positive for a perforated acute sigmoid diverticulitis (a) and ischaemic colitis (b) as confirmed by clinical and instrumental follow-up (a) and colonoscopy (b), with effective doses of 8.5 and 22 mSv, respectively.

Figure 3. Single-pass contrast-enhanced multidetector CT (CE-MDCT) in a 44-year-old female [Group A; 62 kg, body mass index (BMI) 22.4] and in a 56-year-old female (Group B; 67 kg, BMI 23.8) with acute abdominal pain: 5-mm-thick coronal reformatted images are shown. In (a), dilated, fluid-filled small bowel loops can be appreciated in the left flank and in the pelvis with evidence of the “beak sign” (arrowhead) at the transition zone. In (b), abnormal dilation and faecal impaction can be appreciated at the level of the descending colon with inhomogeneous thickening of the intestinal wall at the transition zone (arrowhead) and an associated hyperplastic mesenteric lymph node (arrow). CE-MDCT findings were considered consistent for an adhesive low-grade small bowel obstruction (a) and for a long-standing large bowel obstruction owing to an inflammatory sigmoid stenosis (b) and were both true positive as assessed by clinical follow-up (a) and surgery (b) with effective doses of 7.2 and 15.8 mSv, respectively.

and 90% in Group B, both of which are in complete accordance with the literature,^{26–28} indicating the reliability and reproducibility of CT enterography findings of IBD (Figure 1).

As far as the overall radiation dose delivered to patients of Group A is concerned (7.5 ± 2.5 mSv), it also compares favourably with the data reported by both Kambadakone *et al*²⁶ and Ippolito *et al*²⁸ using low-dose CT enterography protocols, which resulted in EDs of 8.6 ± 2.5 and 9.07 ± 2.71 mSv, respectively, whereas they were higher than the values reported by Kaza *et al*²⁷ using low-kilovoltage CT enterography protocols which delivered EDs as low as 4.6 ± 1.05 mSv. However, all these studies used iterative methods such as reconstruction algorithms and compared them with either filter back-projection^{26,27} or the use of standard kilovoltage settings,²⁸ which respectively resulted in EDs of 14 ± 6 , 14.6 ± 6.6 and 15.8 ± 3.7 mSv, all comparable with the figures observed in the present study in Group B (Table 2). While the radiation exposure would not be a concern using MR enterography, which has indeed shown a similar diagnostic accuracy as CT enterography in evaluating Crohn's disease similar to CT enterography,²⁹ MR is less suited for the acute setting.²⁵ This is mainly due to the complexity and overall duration of the MR examination, which may also result in a suboptimal image quality compared with CT enterography.²⁹

In the eight patients referred for acute diverticulitis, single-pass CE-MDCT performed with either an LR-HC ($n = 5$) (Figure 2a) or a standard protocol ($n = 3$) did not show false-negative or false-positive findings with an overall diagnostic accuracy of 100%. While this figure is likely the result of the small sample size, a diagnostic accuracy as high as 98% has been reported in a much larger series by Werner *et al*.³⁰ Similarly, no false-negative or false-positive results were observed in the four

patients referred for either SBO or LBO, who underwent single-pass CE-MDCT according to either the LR-HC protocol ($n = 2$) (Figure 3a) or the standard protocol ($n = 2$) (Figure 3b). However, the diagnostic role of CE-MDCT in the clinical setting of either SBO or LBO is well acknowledged and undisputed.³¹ True-positive findings were finally observed in two patients with non-occlusive ischaemic colitis (Figure 2b), whose CT findings are often pathognomonic,³² and in other miscellaneous disorders such as acute Budd–Chiari syndrome, which usually manifests with hepatic vein thrombosis,³³ gastric outlet syndrome and sclerosing mesenteritis. This latter patient has been described in detail elsewhere.³⁴

Our study has several limitations. First, there was a selection bias in patient enrolment, as patients with thyroid, cardiovascular or renal comorbidities were excluded. However, as we did not use a bolus tracking technique, patients with cardiac diseases had to be excluded because of unpredictable transit times,¹⁴ whereas the presence of either thyroid or renal comorbidities represented a contraindication for being included in the LR-HC protocol, considering that the amount of iodine administered to this group was above the recommended values.¹⁸ Second, the prevalence of different aetiologies in the present series is quite different from that reported in the literature.^{8,22,23} However, we wanted to test our protocol in the evaluation of non-traumatic acute bowel disease, a clinical context we are commonly faced with at our institution, which is a tertiary-care centre without an emergency department but a referral centre for IBD.²⁴ Third, as the patients were grouped according to age, the spectrum of pathologies encountered was different in the two groups and direct comparison of the diagnostic performance of CE-MDCT was not always possible (Figures 1–3). As far as the age threshold chosen is concerned, although arbitrary, it was based on epidemiological data.² Finally, we are aware that the amount of

iodinated CM injected according to the standard protocol (Group B) is indeed higher (0.74 gI kg^{-1}) than the recommended dose of $0.5\text{--}0.6 \text{ gI kg}^{-1}$ of total body weight.¹⁸ However, it is close to the maximum dose of 0.75 gI kg^{-1} of lean body weight.

CONCLUSION

The results of the present study indicate that single-pass CE-MDCT can be safely and effectively performed in selected patients with non-traumatic acute bowel disease according to an

LR-HC dose protocol, which showed the highest benefit to risk ratio according to the AHARA principle of CT imaging,¹ with a similar diagnostic accuracy as a standard protocol but a significantly lower ED comparing favourably with the values delivered using iterative methods such as reconstruction algorithms.

Further studies are needed to validate such an approach in a much larger and unselected series of patients and possibly expand it to other clinical contexts.

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