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Diagnostic performance of ultra-low dose *versus* standard dose CT for non-traumatic abdominal emergencies

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Abstract

Purpose. The purpose of this study was to compare the diagnostic performance of ultra-low dose (ULD) to that of standard (STD) computed tomography (CT) for the diagnosis of non-traumatic abdominal emergencies using clinical follow-up as reference standard.

Materials and Methods. All consecutive patients requiring an emergency abdomen-pelvic CT from March to September 2017 were prospectively included. ULD and STD CTs were acquired after injecting iodinated contrast medium (portal phase). CT acquisitions were performed at 125 mAs for STD and 55 mAs for ULD. Diagnostic performance was retrospectively evaluated on ULD and STD CTs using clinical follow-up as a reference diagnosis.

Results. A total of 308 CT examinations from 308 patients (145 men; mean age 59.1±20.7 (SD) years; age range: 18–96 years) were included; among which 241/308 (78.2%) showed abnormal findings. The effective dose was significantly lower with the ULD protocol (1.55 ± 1.03 [SD] mSv) than with the STD (3.67 ± 2.56 [SD] mSv, $P < 0.001$). Sensitivity was significantly lower for the ULD protocol (85.5% [95%CI: 80.4–89.4]) than for the STD (93.4% [95%CI: 89.4–95.9], ***P < 0.001***) whereas specificities were similar (94.0% [95%CI: 85.1–98.0] *vs.* 95.5% [95%CI: 87.0–98.9], respectively). ULD sensitivity was equivalent to STD for bowel obstructions and colitis/diverticulitis (96.4% [95%CI: 87.0–99.6] and 86.5 % [95%CI: 74.3–93.5] for ULD *vs.* 96.4% [95%CI: 87.0–99.6] and 88.5% [95%CI: 76.5–94.9] for STD, respectively) but lower for appendicitis, pyelonephritis, abscesses and renal colic (75.0% [95%CI: 57.6–86.9], 77.3% [95%CI: 56.0–90.1], 90.5% [95%CI: 69.6–98.4] and 85% [95%CI: 62.9–95.4] for ULD *vs.* 93.8% [95%CI: 78.6–99.2], 95.5% [95%CI: 76.2–100.0] 100.0% [95%CI: 81.4–100.0] and 100.0% [95%CI: 80.6–100.0] for STD, respectively). Sensitivities were significantly different between the two protocols only for appendicitis ($P = 0.041$).

Conclusion. In an emergency context, for patients with non-traumatic abdominal emergencies, ULD-CT showed inferior diagnostic performance compared to STD-CT for most abdominal conditions except for bowel obstruction and colitis/diverticulitis detection.

Keywords: Abdomen; Emergencies; Pelvis; Tomography, X-ray computed; Ultra-low dose CT.

Abbreviations

AAPM: American Association of Physicists in Medicine; **Am**: Ante meridiem; **AP**: Antero-posterior; **BMI**: body mass index;**CT**: Computed tomography;**CTDI**: CT dose index; **DLP**: Dose length product;**ED**: Effective diameter;**HU**: Hounsfield unit;**IR**: Iterative reconstruction; **kVp**: KiloVoltage peak; **LAT**: Lateral; **NPV**: Negative predictive value; **Pm**: Post meridiem; **PPV**: Positive predictive value; **ROI**: Region of interest; **SD**: Standard deviation; **SSDE**: Size-specific dose estimate; **STD**: Standard dose; **ULD**: Ultra low dose

1. Introduction

Considering the high, constantly increasing number of computed tomography (CT) examinations performed and the associated risks, particularly radiation-induced cancer, reducing the dose delivered to the patient is an important issue [1; 2]. Many tools have been developed such as tube current modulation or iterative reconstruction (IR) algorithms. Tube current modulation consists in adapting the tube current as a function of the patient's attenuation to provide a more uniform dose distribution which was shown to improve image quality and reduces artifacts [3]. IR algorithms decrease the image noise for a given dose level, and therefore allow dose reduction while maintaining image quality indexes [4]. They led to substantial dose reductions without compromising the diagnostic performances compared to the standard (STD) protocols [5-7]. In several centers, ultra-low-dose (ULD) CT protocols are now often used in clinical practice as they have shown good diagnostic performance results, although with lower image quality, for various pathologies including pulmonary nodules [8], synovitis [9], or exploration of low back pain [10]. The goal is to achieve effective doses close to those of standard X-ray examination.

About one third of all CT examinations performed are abdominopelvic examinations [11]. Abdominopelvic CTs are easy to access and fast to perform and remain an essential examination for disease diagnosis, especially in abdominal emergencies [12]. Only a few studies have compared the performance of ULD CT to those of STD CT in abdominal emergencies [13-16]. Studies on specific patients have been published, among them appendicitis in young adults [13] and pregnant women [14]. Our team, among others, has conducted and published a study on urolithiasis [17; 18]. Recently, two studies have taken a more global approach to dose reduction in abdominal emergencies [15; 16]. In 57 patients presenting with acute abdominal symptoms, Moloney et al. showed that the dose delivered during abdominopelvic CT could be reduced while maintaining excellent diagnostic

performance [16]. Similarly, Poletti et al. reported excellent results in 151 patients but these researchers excluded certain pathologic conditions and used the results of conventional CT as the reference standard, and not clinical follow-up [14].

The purpose of this study was to compare the diagnostic performance of ULD CT to that of STD CT for the diagnosis of non-traumatic abdominal emergencies using clinical follow-up as a reference standard.

2. Materials and Methods

2.1 Patients

From March to September 2017, all eligible consecutive patients with an indication for non-traumatic emergency abdominopelvic CT were prospectively enrolled from Monday to Friday and from 8AM to 6PM. The study was approved by the local institutional review board (*N°1886328 v 0*) and an informed consent was waived. Only patients for whom a single portal phase acquisition was requested by the radiologist were included in the study. All patients in whom the suspected diagnosis did not require intravenous administration of contrast material contrast or needed multiphasic injection were excluded. No enteric contrast was used. The protocol was left at the discretion of the radiologist. Patients were also not included in the study if they were under 18 years old, had a contraindication for intravenous administration of iodinated contrast medium or if the suspected diagnosis did not require an injection of contrast medium, or if they were pregnant women. A total of 308 patients were included in the study, and 49 patients were excluded. **Figure 1** shows study flow chart.

2.2 CT protocols

Images were acquired on a Somatom® Definition AS+ CT-scan (Siemens Healthineers). CT acquisitions were performed with the following parameters: physical beam collimation, 64 × 0.6mm; data collection diameter, 500mm; pitch factor, 0.8; and rotation time, 0.5s. The tube potential was set at 100 kVp and the automatic tube voltage selection (Care kV®) was activated on the "parenchyma injected" cursor. The automatic tube current modulation system (CareDose 4D®, using both longitudinal and angular modulations) was used with a reference tube current of 125 mAs for the STD protocol and 55 mAs for the ULD protocol [19].

Reference kVp and reference mAs used for both protocols were defined after optimization process on phantoms [5] and usually used on our institution for abdominopelvic examination [18-20].

For both protocols, raw data were reconstructed using Level 3 of SAFIRE® and the "moderately smooth" (I30f) reconstruction kernel. Images were reconstructed with a 500 mm field of view and a 1mm slice thickness (0.7mm increment).

All 308 patients underwent two abdomen-pelvic helical acquisitions: one with the STD protocol and one with the ULD protocol. For 154 patients, the STD helical acquisition was performed before the ULD acquisition, and vice versa for the other 154 patients. The order of the series had been randomly predefined. Scanning for each pass was performed during relaxed inspiration, in a cranial to caudal direction, starting just above the diaphragm and moving down to the symphysis pubis.

Portal phase images were obtained 65 s (first acquisition, STD or ULD) and 75 s (second acquisition, STD or ULD) after the start of intravenous administration of iohexol (Omnipaque 350®, GE Healthcare; 350 mg of iodine per mL). Injection was performed at an injection rate of 3 to 5 mL/s (as function of venous access) using a standard power injector. The total volume of iodinated contrast medium injected was adapted to the patient's body weight (2 mL/kg).

2.3 Dosimetry evaluation

At the end of the acquisitions, the CT dose index volume ($CTDI_{vol}$) and the Dose length product (DLP) were retrieved from the report in the CT workstation. The effective dose was calculated for each CT examination by multiplying the DLP by the specific abdomen-pelvic conversion coefficient (0.015 $mSv.mGy^{-1}.cm^{-1}$) [21].

To account for patient abdominal morphology, the maximum anteroposterior (AP) and lateral (LAT) diameters were measured on a single axial slice centered on the z-position of the third lumbar vertebral. The effective diameter (ED) was computed for each patient using the methodology defined by the Task report 204 of the American Association of Physicists in Medicine (AAPM) [22], as follows:

$$ED = \sqrt{AP \times LAT}$$ (Formula 1)

The size-specific dose estimate (SSDE) was calculated [AAPM Task 204] as follows:

$SSDE = f_{size}^{32D} \times CTDI_{vol}$ (Formula 2)

where f is the conversion factor as a function of the patient's effective diameter.

2.4 Diagnosis of emergency abdominal pathologies

2.4.1 CT analysis

Interpretation was retrospectively performed distant from patient care and management in the emergency unit. It was done on the manufacturer's workstations (Syngovia®, Siemens Healthineers) by one senior (E.A) and one junior (N.A.Z) radiologists. The senior radiologist (10-year experience) routinely used ULD protocols, but the junior radiologist (4-year experience) had never interpreted on ULD CT examinations before the study. Readers were informed of the abdominal emergency context and they were blinded to the dose level, clinical and biological examinations, and the other radiologist's interpretation. Diagnosis was performed according to the national radiological guidelines, among a 10-item data collection list (bowel obstruction, appendicitis, colitis and diverticulitis, cholecystitis, pyelonephritis, postoperative abscess, renal colic, acute colitis, pancreatitis, no acute condition, and others) [23]. In case of discordance between the two readers, a consensus was found between them. For patients with more than one abnormality, the most severe diagnosis (*i.e.,* the one that required an emergency treatment such as surgery or specific medication) was selected and recorded.

2.4.2 Standard reference diagnosis

The standard of reference for diagnosis was the most consequent diagnosis retained by clinicians at the end of clinical follow-up. The surgical report, hospitalization report or emergency department visit were reviewed. Follow-up was performed by the junior radiologist, using the patients' medical files, until the patient' discharge. To avoid delayed diagnosis not considered, data were collected at least 6 months after patient examination at the emergency department. When patients did not return, the initial diagnosis was considered and recorded.

2.5 Image quality assessment

2.5.1 Quantitative analysis

The objective image-quality analysis was performed by a medical physicist (J.G.) on the manufacturer's workstation (SyngoVia®, Siemens Healthineers), independently of the image review results. All images were displayed with a soft tissue window (window width, 370 Hounsfield units [HU]; window level, 60 HU). Circular regions of interest (ROI) were placed on the liver (left and right liver), portal vein, hepatic vein, spleen, kidney, gallbladder, para spinal muscle, bladder and subcutaneous or intra-abdominal fat. Mean attenuation (average of pixels) and image noise (standard deviation of pixels) were computed on each ROI. For all measurements, the size, shape and location of the ROIs were kept constant between the two protocols for each patient by applying the Syngo®.via workstation's copy-and-paste function.

2.5.2 Qualitative analysis

For each CT image, both readers also assessed the subjective overall image quality (1=not evaluable; 2 = interpretable in spite of moderate artefact or noise; 3 = fully interpretable with mild noise or artefacts; 4 = no artefacts or noise), diagnostic quality (1 = unacceptable; 2 = suboptimal; 3 = acceptable; 4 = above average; 5 = excellent), and confidence level (1 = very poor; 2 = poor; 3 = average; 4 = high; 5 = excellent) [24; 25].

2.6 Statistical analysis

Statistical analysis was performed using 'Biostatgv' (http://marne.u707.jussieu.fr/biostatgv). The reference diagnosis was used to test the specificity and the sensitivity of both the ULD and STD protocols for all patients, or for the most frequent lesions (over 20 patients). The McNemar test was used to compare the sensitivities and the specificities between STD and ULD protocols. $CTDI_{vol}$, DLP, effective dose, mean attenuation and image noise values were compared between both protocols using the paired Mann-Whitney-Wilcoxon test. A *P*-value lower than 0.05 was considered significant. For a given CT protocol, the agreement between radiologists for qualitative analysis was computed with the Cohen's kappa test and classified as poor (κ = 0.00–0.20), fair (κ = 0.21–0.40), moderate (κ = 0.41–0.60), good (κ = 0.61–0.80), or excellent (κ = 0.81–1.00) [24,25]. To examine the relationship between the patient morphology and the outcomes of image quality, dose levels, sensibility and specificity, the study population was split into three groups according to the quartile of the ED distribution: group 1 $\leq$ Q1; Q1 < group 2 < Q3; Q3 $\leq$ group 3. The Kruskal-Wallis test was used to

compare the distribution of dosimetric values, objective and subjective values between each group.

3. Results

3.1 Study patients

During the study period, 308 patients, mean age 59.1 ± 20.7 (SD) years (range: 18-96 years) were included. Of the 308 patients, 241 (241/308; 78.2%) had an CT examination with abnormal findings (**Table 1**).

Pathologies were predominantly bowel obstructions (n = 56/241, 23.2%), colitis and diverticulitis (n = 52/241, 21.6%), appendicitis (n = 32/241, 13.3%), pyelonephritis (n = 22, 9.1%), abscesses (n = 21/241, 8.7%), renal colic (n = 20/241, 8.3%) and cholecystitis (n = 11/241, 4.6%), angiocholitis (n = 4/241, 1.7%), pancreatitis (n = 4/241, 1.7%) and others (n = 19/241, 7.9%).

The mean ED for all patients and for each group is presented in **Table 2**. Overall, the mean ED was 28.2 ± 4.4 (SD) cm [range:18.2–42.8 cm] with a mean AP diameter of 24.2 ± 4.5 (SD) cm [range:14.0–39.9 cm] and a mean LAT diameter of 33.0 ± 4.8 (SD) cm [range: 21.5–48.7 cm].

3.2 Sensitivity and specificity

Table 1 presents the overall results of sensitivities and specificities and for the most frequent pathologies (number of patients per pathologic condition >20). For all patients, sensitivity was significantly greater ($P < 0.001$) for STD (sensitivity: 93.4% [95%CI: 89.4–95.9] and NPV: 79.7% [95%CI: 70.9–88.6]) than for ULD (sensitivity: 85.5% [95%CI: 80.4–89.4] and NPV: 64.6% [95%CI: 55.2–74.1]) whereas specificities were similar (specificity: 94.0% [95%CI: 85.1–98] and PPV: 98.3% [95%CI: 96.6–100] *vs.* specificity: 95.5% [95%CI: 87–98.9] and PPV: 98.6% [95%CI: 97–100], respectively).

The sensitivities were in the same range for all patients and for each patient group for the STD protocol. For ULD protocol, sensitivity was higher for the ED group 2 than for group 3 then group 1. For each ED group, sensitivities were significantly higher with STD than with ULD ($P < 0.05$).

For the main pathologies assessed, no false positives were found with either of the two CT protocols. 11/241 CTs (4.6%) did not show any abnormalities but the disease was diagnosed during follow-up, including 1 proctitis, 5 colitis, 1 acute pyelonephritis diagnosed clinically; 1 appendicitis found during surgery; 1 cholecystitis, 1 hemorrhagic ovarian cyst and 1 aseptic necrobiosis of a myoma diagnosed by ultrasound.

The sensitivity was equivalent with the STD and ULD protocols for bowel obstructions and colitis/diverticulitis (96.4% [87.0–99.6] and 86.5 % [74.3–93.5], respectively) without significant impact of ED (**Figure 2**). However, sensitivity of ULD protocols was poorer for other abdominal pathologies such as appendicitis, pyelonephritis, postoperative abscesses, and renal colic. A higher number of false-negative results was reported with ULD protocol (n = 35/241, 14.5%) than with STD protocol (n = 16/241, 6.6%). Sensitivity was significantly higher with STD than ULD only for appendicitis (*P = 0.041*).

3.4 Dosimetry

The dose was significantly lower with the ULD protocol than with STD protocol ($P < 0.001$). Mean $CTDI_{vol}$ was 5.1 ± 3.3 (SD) mGy [range: 1.8–23.7 mGy] for the STD protocol and 2.2 ± 1.3 (SD) mGy [range: 0.8–8.9 mGy] for the ULD protocol (mean -56.9%). DLP for STD and ULD was 244.5 ± 170.8 (SD) mGy.cm [range: 76–1177 mGy.cm] and 103.6 ± 68.9 (SD) mGy.cm [range: 32–442 mGy.cm], respectively. The mean SSDE was 6.4 ± 3.1 (SD) mGy (range: 2.7–22.8 mGy) for the STD protocol and 2.2 ± 1.3 (SD) mGy (range: 1.2–8.5 mGy) for the ULD protocol (mean, -57.1%).

Effective doses for STD and ULD were 3.67 ± 2.56 (SD) mSv and 1.55 ± 1.03 (SD) mSv, respectively. Cumulative DLP was above the national diagnostic reference level (625 mGy.cm) for 16 patients (5.2%); 2 for the group 2 and 14 for the group 3.

All dosimetric indicators increased as the ED increased and the differences between the groups were significant ($P < 0.0001$).

3.5 Quantitative analysis

The mean attenuation values were significantly different between ULD and STD (**Table 2**) for the left liver ($P < 0.001$), right liver ($P = 0.01$), spleen ($P < 0.001$), kidney ($P = 0.02$) and main portal vein ($P < 0.001$). It decreased as the ED increased and the differences between

groups were significant ($P < 0.05$) for all structures and CT protocols, except for the bladder ($P = 0.293$ for ULD and $P = 0.336$ for STD).

Image noise was significantly higher with the ULD protocol than with the STD dose for all tissues assessed ($P < 0.001$). The image noise increase varied from 43.9 ± 34.7% (SD) (range: -32–182%) for the hepatic vein to 56.0 ± 23.9% (SD) (range: -6–150%) for the gallbladder. It increased as the effective diameter increased and the differences between the groups were significant ($P < 0.05$) for all structures and CT protocols, except for the fat with the ULD protocol ($P = 0.240$) and for the kidney ($P = 0.126$) and gall bladder ($P = 0.138$) with the STD protocol.

3.6 Qualitative analysis

Figure 3 depicts the visual image quality obtained using both ULD and STD CT protocols for the diagnosis of simple acute appendicitis, ileitis, acute pyelonephritis and acute cholecystitis.

For the ULD protocol, the overall image quality was considered as “without artefacts or noise” or “fully interpretable” in 59.1% (182/308) for Radiologist 1 but in 0.7% (2/308) of patients for Radiologist 2 (**Table 3**). The majority (98.5 %; 303/308) of ULD images were considered as “interpretable in spite of moderate artefacts or noise” by Radiologist 2. The inter-observer agreements were fair for the STD dose (k = 0.327) and poor for the ULD protocol (k = 0.031).

Likewise, the ULD diagnostic image quality was rated “above average” in 42.5% (131/308) and “acceptable” in 44.5% (137/308) by Radiologist 1 whereas the majority of ULD images (90.9%; 280/308) were only "acceptable" for Radiologist 2. Inter-observer agreements were fair for the STD (k = 0.345) and poor for the ULD (k = 0.191) protocols.

For ULD images, the diagnostic confidence level was considered “high” or “excellent” for 57.5% (177/308) by Radiologist 1 and 44.5% (137/308) by Radiologist 2 and ranked “average” for 38.3% (118/308) by Radiologist 1 and 46.1% (142/308) by Radiologist 2. The inter-observer agreements were moderate for STD (κ = 0.533) and good for ULD (κ = 0.737).

For each subjective image quality criterion, the differences between the mean score for all groups were not significant ($P = NS$). Mean score values were in the same range for all patients and for each group.

4. Discussion

In the present study, STD showed a significant better global sensitivity than ULD for the diagnosis of abdominal emergencies, especially for appendicitis with a significant statistical difference between the two protocols. For other specific pathologies, sensitivities did not show significant differences. With more than 50% of effective dose reduction, ULD had an equivalent diagnostic performance to STD for diagnosis of bowel obstructions and colitis/diverticulitis but it was insufficient to make a decision-management, restricting its use in clinical practice.

To our knowledge, this study reports on the largest number of patients presenting with non-traumatic abdominal emergencies. We decided to include all patients with a unique portal phase regardless of their BMI or specific pathologies, to be more representative of everyday clinical life. Thus, the quantity and variety of pathologies encountered were equivalent to other studies carried out on the same subject [15; 16].

The detection of lesions was suboptimal with the ULD protocol, except in the case of bowel obstructions for which the sensitivity of detection was excellent and reached 96.4% with ULD (against 75.0% to 90.5% for the other main pathologies) and STD protocols. Our sensitivity and specificity results are slightly lower than those previously published by Poletti *et al.* and others [15; 28]. For their entire population (with no BMI subdivision), their diagnostic accuracy was 96.7% and 98.0 % (raters 1 and 2) with the model-based iterative reconstruction algorithm. The difference may be due to the use of a different gold standard in the two studies. Indeed, one of the strengths of our study is to have used anatomopathological results or clinical follow-up as a reference rather than standard dose CT that does not take into account all clinical and biological data. Some false negatives may be related to the absence of clinical information to help the radiologist's interpretation. In addition, some pathologies such as colitis, may be diagnosed by the emergency physician although not detectable on CT examination even using the STD protocol.

Compared to the literature, the effective dose for STD and ULD (respectively 3.67 ± 2.56 (SD) mSv and 1.55 ± 1.03 (SD) mSv) were the lowest [15; 16]. Applying ALARA principles and taking in account the radiation induced cancer risk, dose reduction remains an important issue [1; 2]. A major reduction in DLP was achieved using the ULD protocol, -83% compared to the national Diagnostic Reference Level for abdominopelvic CT examinations (DLP: 625 mGy.cm), with an effective dose close to the abdominal X-ray reference (0.884 mSv). Only

5.2 % of patients had a higher dose with the sum of the 2 CT acquisitions than our national Diagnostic Reference Level. This might be due to the use of the tube current modulation system, which automatically increases the dose if a patient has a high BMI (CareDose 4D) for all patients.

Regarding the quantitative analysis of image quality, the anatomical structures for which a significant difference in mean attenuation was found were those that took on contrast in the portal phase. This is probably due to the time lapse between two acquisitions, STD and ULD. The higher image noise with the ULD protocol for all assessed tissues may be explained by the dose reduction while keeping the same reconstruction parameters for both CT protocols. Indeed, we had chosen not to increase the image thickness or the SAFIRE level as this might have resulted in an over-smooth appearance for abdominal interpretation. However, increasing the SAFIRE level and image thickness have shown to provide better image quality for thoracic and bone ULD CT protocols [29; 30].

Inter-observer agreement for the overall image quality and diagnostic image quality was fair for the STD protocol and poor for the ULD CT. The junior radiologist (R2), who had no experience of ULD images, was more critical of the image quality. Similar results were also found in a previous study on ULD chest CT acquisition [29] and this confirms that a learning period for interpreting ULD-CT images for various pathologies is recommended.

Although, ULD-CT showed inferior diagnostic performance compared to STD-CT for the majority of abdominal pathologies, its diagnostic performance was equivalent for the detection of bowel obstruction and colitis/diverticulitis with a dose close to that of an abdominal X-ray. Our results of subgroups according to the mean effective diameter suggest that weight does not seem an issue for the use of STD or ULD CT-scan protocols in the emergency unit. Although the noise increased with the effective diameter, a better contrast was reported, which may be due to the larger amount of abdominal fat, which may improve diagnostic performance.

This study has some limitations. Pathologic conditions explored with another protocol were excluded, especially suspicion of renal colic, which was under-represented in our sample but ULD protocol for ULD CT has already been validated [18]. Also, the portal phase remains the most important phase used to investigate non-traumatic abdominal emergencies in our clinical practice. Our study thus did not include patients who underwent other imaging phases (arterial or late series). This may explain the lack of power of the subgroup analyses. Also, BMI

should have warranted further invistigations, but as it was not available for all patients in the emergency context, we have used the mean effective diameter instead. Also, specifically detailed complications were not analyzed and only the principal diagnosis was retained. For example, although it may be easy to radiologically diagnose an bowel obstruction, the real challenge for the radiologist remains the mechanism and related complications. Moreover, inclusions were performed only during usual working hours; it would be interesting to study the performance diagnosis of ULD during night shifts. Last, all CT acquisitions were made on a single CT system with only one iterative reconstruction algorithm (SAFIRE) and the same iterative level was used [31]. These results would need to be confirmed on other CT systems and iterative reconstruction algorithms.

In conclusion, for patients needing an emergency abdomen-pelvic CT, the ultra-low dose protocol significantly reduced doses but had a poorer diagnostic performance than the standard protocol. The ULD protocol seemed to be insufficient to make a decision-management thus restricting its use in clinical practice.

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Human rights

The authors declare that the work described has been carried out in accordance with the Declaration of Helsinki of the World Medical Association revised in 2013 for experiments involving humans.

Informed consent and patient details

Institutional ethic committee approval was obtained. Written informed consent from the patients was waived. The authors declare that this report does not contain any personal information that could lead to the identification of the patients. The authors also confirm that the personal details of the patients have been removed.

Disclosure of interest

The authors declare that they have no competing interest.

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Author contributions

All authors attest that they meet the current International Committee of Medical Journal Editors (ICMJE) criteria for Authorship.

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Figure legends

Figure 1: Flowchart of the study. STD = standard; ULD = ultra-low dose.

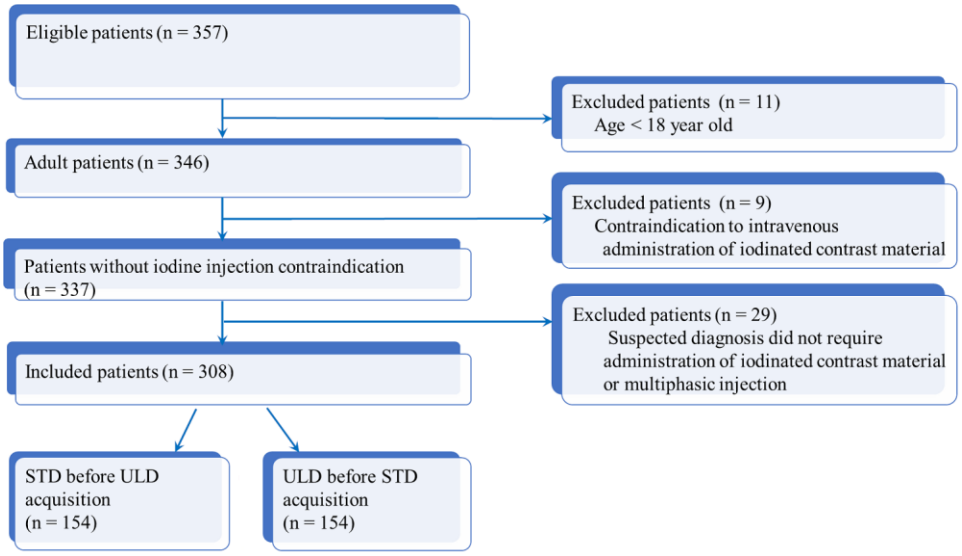
Figure 2: Ileal bowel obstructions in 3 patients of the 3 different groups based on the effective diameter (ED), with the standard (STD) (left) and ultra-low dose (ULD) (right) protocols. Top (a and b): 45-year-old man, ED 21.7 cm; a: STD, SSDE 4.64 mGy, b: ULD, SSDE 2.00 mGy. Middle (c and d): 83-year-old man, ED 28.5 cm; c: STD, SSDE 6.31 mGy, d: ULD, SSDE 2.80 mGy. Bottom (e and f): 80-year-old man, ED 35.6 cm; e: STD, SSDE 8.99 mGy, f: ULD, SSDE 3.10 mGy.

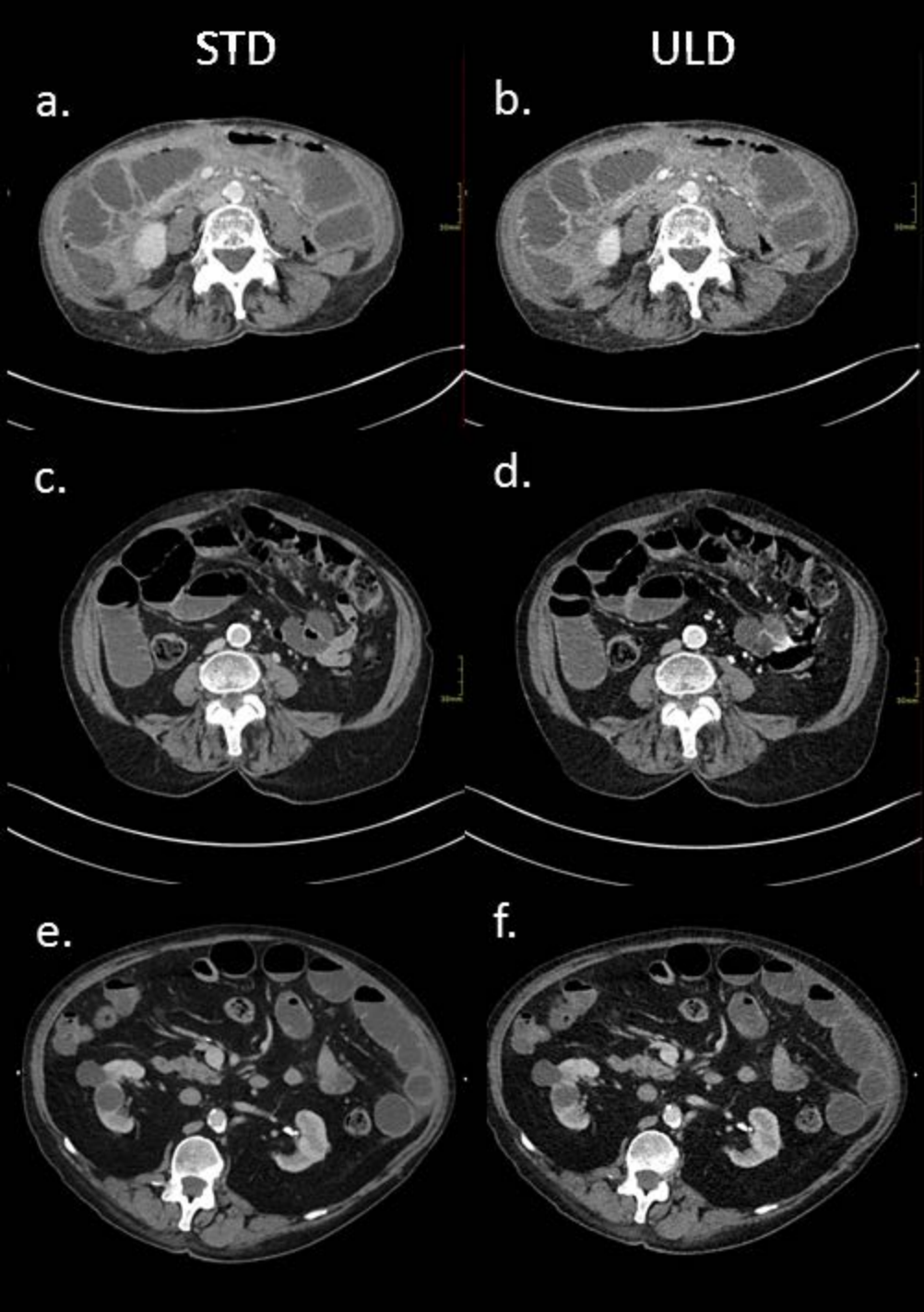
Figure 3: Comparison between STD (left) and ULD (right) protocols for acute pathologic conditions: 4 examples. a) and b) CT of an 80-year-old woman (ED 36.1 cm) with an acute cholecystitis: gallbladder wall defect associated with fat infiltration; a) STD, SSDE 9.99 mGy; b) ULD, SSDE 3,90 mGy. c) and d) 24-year-old woman (ED 20.6 cm) with acute pyelonephritis and diffuse right mediorenal hypoattenuation; c) STD, SSDE 4.75mGy; d) ULD, SSDE 2.07 mGy. e) and f) 21-year-old man (ED 22.1 cm) with thickened ileum walls and infiltration of adjacent fat suggesting an acute ileitis; e) STD, SSDE 4.75 mGy; f) ULD, SSDE 2.03 mGy. g) and h) 25-year-old man (ED 28.5 cm) with acute appendicitis and thickening of the appendicular walls, infiltration of the peri-appendicular fat and a stercolith at the base of the appendix; g) STD, SSDE 4.19 mGy; h) ULD, SSDE 1.86 mGy.

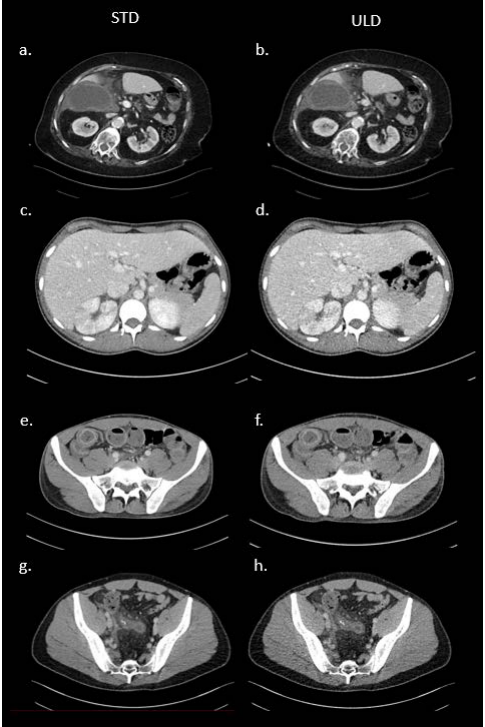
Table 1. Sensitivity and specificity of STD and ULD CT compared with the diagnostic reference for all patients with CT revealing abnormal findings.

Table 2. Dosimetric indicators and outcomes of image quality assessment for the three groups of patients defined according to the quartile of the effective diameter distribution.

Table 3. Subjective image quality with ultra-low dose CT and standard CT.


Eligible patients (n = 357)
Excluded patients (n = 11)
Age < 18 year old
Adult patients (n = 346)
Excluded patients (n = 9)
Contraindication to intravenous
administration of iodinated contrast material
Patients without iodine injection contraindication
(n = 337)
Excluded patients (n = 29)
Suspected diagnosis did not require
administration of iodinated contrast material
or multiphasic injection
Included patients (n = 308)
STD before ULD
acquisition
(n = 154)
ULD before STD
acquisition
(n = 154)


STD
ULD
a.
b.
c.
d.
e.
f.


STD
ULD
a.
b.
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d.
e.
f.
g.
h.

Table 1. Sensitivity and specificity of STD and ULD CT compared with the diagnostic reference for all patients with CT revealing abnormal findings

		STD CT			ULD CT			*P-value STD CT vs ULD CT*	
		TP/FP/FN/TN	Sensitivity	Specificity	TP/FP/FN/TN	Sensitivity	Specificity	Sensitivity	Specificity
For all patients with abnormal CT findings	*All (n = 241)*	225/4/16/63	93.4 [89.4; 95.9]	94.0 [85.1; 98.0]	206/3/35/64	85.5 [80.4; 89.4]	95.5 [87; 98.9]	***P* < 0.001**	*P* > 0.999
	Group 1 (n= 67)	59/0/4/17	93.7 [84.2; 97.9]	100.0 [77.9; 100.0]	52/0/11/17	82.5 [71.1; 90.1]	100.0 [77.9; 100.0]	***P* = 0.023**	*P* > 0.999
	Group 2 (n= 115)	111/2/28/29	93.3 [87.0; 96.7]	93.5 [78.0; 99.1]	104/2/15/29	87.4 [80.1; 92.3]	93.5 [78.0; 99.1]	***P* =0.023**	*P* > 0.999
	Group 3 (n= 59)	55/2/4/17	93.2 [83.2; 97.7]	89.5 [67.1; 98.1]	50/1/9/18	84.7 [73.2; 91.9]	94.7 [73.2; 100.0]	***P* =0.008**	*P* > 0.999
For patientq with the most frequent pathologic condition (n = 203)	Obstructive syndrome (n = 56)	54/0/2/0	96.4 [87.0; 99.6]	-	54/0/2/0	96.4 [87.0; 99.6]	-	*P* > 0.999	-
	Colitis and diverticulitis (n = 52)	46/0/6/0	88.5 [76.5; 94.9]	-	45/0/7/0	86.5 [74.3; 93.5]	-	*P* > 0.999	-
	Appendicitis (n = 32)	30/0/2/0	93.8 [78.6; 99.2]	-	24/0/8/0	75.0 [57.6; 86.9]	-	***P* = 0.041**	-
	Pyelonephritis (n = 22)	21/0/1/0	95.5 [76.2; 100.0]	-	17/0/5/0	77.3 [56.0; 90.1]	-	*P* = 0.134	-
	Postoperative abscess(n = 21)	21/0/0/0	100.0 [81.4; 100.0]	-	19/0/2/0	90.5 [69.6; 98.4]	-	*P* = 0.480	-
	Renal colic (n = 20)	20/0/0/0	100.0 [80.6; 100.0]	-	17/0/3/0	85.0 [62.9; 95.4]	-	*P* > 0.999	-

FN: False negative; FP: False positive; STD: Standard protocol; TN: True negative; TP: True positive; ULD: Ultra low dose protocol. Bold indicates significant *P* values.

Sensitivity (and their respective 95% confidence intervals) for STD and ULD CT were reported for the main pathologic conditions (*i.e.*, with more than 20 patients).

Results obtained in consensus between both radiologists were compared with the diagnostic reference results for the sensitivity and specificity analyses.

	Group 1 (ED ≤ 25.6 cm)		Group 2 (25.7 < ED < 3		Group 3 (ED ≥ 30.8 cm)	
	ULD CT	STD CT	ULD CT	STD CT	ULD CT	STD CT
Number of patients	80		150		78	
Effective diameter (cm)	22.9 ± 2 [18.2; 25.6]		28 ± 1.3 [25.6; 30.6]		33.9 ± 2.6 [30.8; 42.7]	
CTDIvol (mGy)	1.3 ± 0.3 [0.8; 2.1]	3.0 ± 0.8 [1.8; 5.2]	1.9 ± 0.7 [0.9; 6.5]	4.6 ± 2.0 [2	3.5 ± 1.9 [1.4; 8.9]	8.3 ± 4.6 [3.1; 23.7]
SSDE (mGy)	2.1 ± 0.5 [1.4; 3.3]	4.8 ± 1.2 [3.2; 8.1]	2.6 ± 0.9 [1	6.1 ± 2.6 [2	3.6 ± 1.6 [1.6; 8.2]	8.6 ± 4.0 [3.6; 19.5]
DLP (mGy.cm)	59 ± 16 [32; 103]	136 ± 40 [76; 252]	91 ± 35 [36	217 ± 99 [8	174 ± 95 [68; 442]	409 ± 233 [157; 1177]
E (mSv)	0.9 ± 0.2 [0.5; 1.5]	2.0 ± 0.6 [1.1; 3.8]	1.4 ± 0.5 [0	3.3 ± 1.5 [1	2.6 ± 1.4 [1.0; 6.6]	6.1 ± 3.5 [2.4; 17.7]
Mean attenuation (HU)						
Left liver	126.4 ± 21 [40; 190]	123.8 ± 19.4 [41; 168]	112.7 ± 17.	110.9 ± 17.	95 ± 22.8 [24; 151	91.4 ± 22.2 [24; 140]
Right Liver	117.6 ± 21.2 [28; 191]	116.2 ± 19.8 [29; 161]	102.1 ± 18.	101.1 ± 16.	84.2 ± 20.6 [21; 13	80.9 ± 20.9 [13; 125]
Spleen	124.7 ± 22.8 [79; 205]	121.9 ± 22.6 [86; 218]	111.3 ± 21.	107.2 ± 18.	103.5 ± 19.5 [65; 1	98.3 ± 19.5 [58; 137]
Kidney	188.1 ± 32.6 [99; 286]	186.2 ± 34.5 [95; 332]	166.8 ± 31.	165.2 ± 32	153.5 ± 36.8 [95; 3	146.2 ± 38.2 [70; 324]
Portal trunk	185.3 ± 35.6 [122; 281]	179 ± 39.2 [121; 360]	167.6 ± 39	161.7 ± 29.	158.4 ± 34.5 [101;	152.2 ± 33.1 [95; 229]
Gallbladder	16.4 ± 8.4 [-1; 39]	16.4 ± 7.2 [4; 37]	15.1 ± 8.5 [	14.8 ± 8.1 [	9 ± 9.7 [-10; 41]	8.1 ± 10.1 [-19; 39]
Hepatic vein	181.8 ± 34.9 [101; 266]	181.7 ± 34.7 [109; 271]	165.1 ± 33.	168.9 ± 28.	150.3 ± 32.1 [71; 2	141.9 ± 30.2 [67; 224]
Muscle	60.5 ± 11.5 [36; 81]	61 ± 11.1 [32; 79]	52.9 ± 11.2	53.7 ± 10.6	44.1 ± 11.5 [22; 68	44 ± 10.2 [20; 64]
Fat	-82.4 ± 12.9 [-109; -54]	-83 ± 13.5 [-111; -60]	-97.3 ± 13.	-96.7 ± 14.	-103.9 ± 12.7 [-126	-104.1 ± 11.7 [-126; -64]
Bladder	20.3 ± 12.3 [-5; 54]	20.4 ± 11.2 [-1; 45]	18.5 ± 14.2	18.9 ± 14.5	18.4 ± 12.7 [-5; 47	17.4 ± 13.6 [-8; 49]
Image noise (HU)						
Left liver	20.9 ± 2.9 [15; 29]	13.9 ± 2 [10; 19]	23.5 ± 3.1 [	15.6 ± 2.5 [	24.8 ± 3.5 [16; 33]	16.5 ± 3.1 [9; 26]
Right Liver	22.7 ± 4.2 [14; 36]	14.7 ± 2.3 [10; 21]	24.2 ± 4.1 [	16.3 ± 3.2 [	26.2 ± 4.7 [16; 38]	16.8 ± 3.9 [8; 26]
Spleen	21.7 ± 3.3 [15; 29]	14.6 ± 2.6 [9; 24]	24 ± 4.3 [1	16.2 ± 3.3 [	25.6 ± 4.7 [16; 36]	16.9 ± 3.7 [10; 34]
Kidney	26 ± 4.1 [16; 36]	**18.2 ± 3.6 [11; 29]**	27.2 ± 4.6 [	**19.1 ± 4.1 [**	27.2 ± 4.9 [18; 41]	**18.7 ± 3.7 [10; 26]**
Portal trunk	24.9 ± 4.7 [17; 39]	16.8 ± 3.1 [11; 24]	26.9 ± 5.2 [	18.8 ± 9.8 [	26.4 ± 4.5 [17; 39]	17.7 ± 3.5 [10; 28]
Gallbladder	19.4 ± 3.3 [10; 29]	12.9 ± 2.1 [8; 18]	22 ± 3.7 [1	14.4 ± 2.5 [	22.4 ± 3.9 [16; 32]	14.2 ± 3.4 [8; 26]
Hepatic vein	23.3 ± 5.2 [12; 39]	16.1 ± 4 [9; 27]	24.1 ± 4.8 [	17.7 ± 3.8 [	25.9 ± 4.9 [16; 38]	18 ± 3.9 [10; 28]
Muscle	21 ± 3.5 [13; 31]	14.2 ± 2.5 [9; 21]	23.3 ± 4.1 [	16.1 ± 3.1 [	25.4 ± 4.6 [16; 38]	17.1 ± 3.9 [10; 24]
Fat	22.4 ± 4.9 [13; 37]	15.6 ± 2.9 [9; 25]	23.7 ± 4.4 [	16.4 ± 3.4 [	25.7 ± 4.9 [15; 37]	16.9 ± 3.9 [10; 29]

Bladder	18.2 ± 2.9 [12; 24]	12.2 ± 2.2 [8; 18]	19.9 ± 4 [1:	12.9 ± 2.8 [	22 ± 5.2 [9; 33]	14.7 ± 3.7 [6; 25]

ED = effective diameter; CTDI: CT dose index; DLP = dose length product; HU: Hounsfield unit; ULD = ultra-low dose; SSDE: Size-specific dose estimate; STD = standard dose.
Variables are expressed as means standard deviations; numbers in brackets are ranges

			ULD (n = 308)			STD (n = 308)		
			R1	R2	Kappa [95% CI]	R1	R2	Kappa [95% CI]
Overall image quality	Not evaluable		3	3	0.031 [0.014-0.048]	0	1	0.327 [0.274-0.381]
	Interpretable in spite of moderate artifact or noise		123	303		30	81	
	Fully interpretable with mild noise or artifact		177	2		133	217	
	No artifact or noise		5	0		145	9	
	Average score	*All*	2.6 ± 0.5 [1-4]	2.0 ± 0.1 [1-3]		3.4 ± 0.7 [2-4]	2.8 ± 0.5 [1-4]	
		Group 1	2.4 ± 0.5 [2-4]	2.0 ± 0.2 [1-2]		3.4 ± 0.6 [2-4]	2.8 ± 0.5 [2-4]	
		Group 2	2.7 ± 0.5 [1-4]	2.0 ± 0.1 [1-3]		3.4 ± 0.7 [2-4]	2.7 ± 0.5 [1-4]	
		Group 3	2.7 ± 0.5 [1-3]	2.0 ± 0.1 [2-3]		3.4 ± 0.7 [2-4]	2.8 ± 0.5 [2-4]	
Diagnostic quality	Unacceptable		1	1	0.191 [0.146-0.235]	0	0	0.345 [0.284-0.406]
	Suboptimal		36	14		0	3	
	Acceptable		137	280		22	69	
	Above average		131	12		89	180	
	Excellent		3	1		197	56	
	Average score	*All*	3.3 ± 0.7 [1-5]	3.0 ± 0.3 [1-5]		4.6 ± 0.6 [3-5]	3.9 ± 0.7 [2-5]	
		Group 1	3.1 ± 0.7 [2-5]	3.0 ± 0.3 [2-4]		4.6 ± 0.6 [3-5]	3.9 ± 0.6 [3-5]	
		Group 2	3.3 ± 0.7 [2-5]	3.0 ± 0.3 [1-4]		4.5 ± 0.7 [3-5]	4.0 ± 0.7 [2-5]	
		Group 3	3.5 ± 0.7 [1-4]	3.0 ± 0.3 [2-5]		4.6 ± 0.6 [3-5]	4.0 ± 0.6 [2-5]	
Confidence level	Very poor		1	3	0.737 [0.668-0.806]	0	0	0.533 [0.461-0.604]
	Poor		12	26		3	1	
	Average		118	142		67	35	
	High		127	71		157	95	
	Excellent		50	66		81	177	
	Average score	*All*	3.7 ± 0.8 [1-5]	3.6 ± 1.0 [1-5]		4.0 ± 0.7 [2-5]	4.5 ± 0.7 [2-5]	
		Group 1	3.6 ± 0.8 [2-5]	3.4 ± 1.1 [1-5]		3.9 ± 0.7 [2-5]	4.5 ± 0.7 [3-5]	
		Group 2	3.7 ± 0.8 [2-5]	3.6 ± 0.9 [2-5]		4.1 ± 0.7 [2-5]	4.4 ± 0.7 [2-5]	

Group 3	3.8 ± 0.8 [1-5]	3.6 ± 1.0 [2-5]	4.1 ± 0.7 [3-5]	4.5 ± 0.7 [3-5]

R1: reader 1 (senior radiologist); R2: reader 2 (junior radiologist); STD: Standard protocol; ULD: Ultra low dose protocol. Values of mean score are expressed as mean ± standard deviations; numbers in brackets are ranges.