Comparative assessment of three image reconstruction techniques for image quality and radiation dose in patients undergoing abdominopelvic multidetector CT examinations

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Objective: To compare image quality and radiation dose of abdominal CT examinations reconstructed with three image reconstruction techniques.

Methods: In this Institutional Review Board-approved study, contrast-enhanced (CE) abdominopelvic CT scans from 23 patients were reconstructed using filtered back projection (FBP), adaptive statistical iterative reconstruction (ASiR) and iterative reconstruction in image space (IRIS) and were reviewed by two blinded readers. Subjective (acceptability, sharpness, noise and artefacts) and objective (noise) measures of image quality were recorded for each image data set. Radiation doses in CT dose index (CTDI) dose-length product were also calculated for each examination type and compared. Imaging parameters were compared using the Wilcoxon signed rank test and a paired *t*-test.

Results: All 69 CECT examinations were of diagnostic quality and similar for overall acceptability (mean grade for ASiR, 3.9 ± 0.3 ; $p=0.2$ for Readers 1 and 2; IRIS, 3.9 ± 0.4 , $p=0.2$; FBP, 3.8 ± 0.9). Objective noise was considerably lower with both iterative techniques ($p<0.0001$ and 0.0016 for ASiR and IRIS). Recorded mean radiation dose, *i.e.* CTDI_{vol}, was 24% and 10% less with ASiR (11.4 ± 3.4 mGy; $p<0.001$) and IRIS (13.5 ± 3.7 mGy; $p=0.06$), respectively, than with FBP: 15.0 ± 3.5 mGy.

Conclusion: At the system parameters used in this study, abdominal CT scans reconstructed with ASiR and IRIS provide diagnostic images with reduced image noise and 10–24% lower radiation dose than FBP.

Advances in knowledge: CT images reconstructed with FBP are frequently noisy on lowering the radiation dose. Newer iterative reconstruction techniques have different approaches to produce images with less noise; ASiR and IRIS provide diagnostic abdominal CT images with reduced image noise and radiation dose compared with FBP. This has been documented in this study.

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CT continues to expand its role as an essential imaging modality [1]. However, with its increasing use, concerns of radiation overexposure have prompted efforts to reduce the cumulative dose to a patient [2]. Recent studies have highlighted increased utilisation of radiological examination and 10-fold increase in medical radiation exposure at the population level [3, 4]. Therefore, lowering the CT radiation dose without compromising the image quality is desirable. Several technical approaches have been proposed to accomplish these goals including commonly used tube current modulation and adopting lower peak kilovoltage [5–8]. However, excessive dose reduction has remained difficult in the abdomen and pelvis CT due to increased levels of image noise and artefacts that lower the quality of the CT examination. Moreover, abdominopelvic CT demands higher image quality for confident detection of low-contrast lesions in various viscera [9].

The conventional technique of image reconstruction, filtered back projection (FBP), is an efficient method for image production, but makes several assumptions and therefore requires higher dose for delivering diagnostic quality images [10, 11]. To overcome these limitations, iterative reconstruction (IR) techniques have been introduced, which have been shown to render optimal image quality at lower radiation dose [12–20]. Unlike advanced iterative techniques, partial IR approaches such as adaptive statistical iterative reconstruction (ASiR) and iterative reconstruction in image space (IRIS) are computationally less demanding and therefore faster to process images. In essence, both rely on mathematic modelling of the CT raw data to selectively identify image noise and reduce it. The ASiR technique models statistical variations in the distribution of noise from acquired image data and improves the signal-to-noise ratio while preserving image contrast [5, 8, 12]. Since its introduction, several investigators have confirmed its capabilities to deliver diagnostic quality images at 30–50% lower radiation dose. [8, 12]. IRIS, on the other hand, reduces image noise by forming multiple iterations within the image space itself [10–14].

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Phantom studies have demonstrated its ability in maintaining transverse and z-axis spatial resolution, as well as CT number accuracy and linearity while reducing image noise [18]. Its capability in preserving diagnostic accuracy and improving image quality at lower tube potential settings has been documented by Schindera et al [18] as has its ability to reduce noise and radiation dose in clinical studies by approximately 35–50% [11–16]. Owing to differences in image reconstruction approach by ASiR and IRIS, we investigated the performance of these two IR methods on image quality and radiation dose in patients undergoing contrast-enhanced (CE) abdominal CT examinations compared with the FBP technique.

Materials and methods

Study design

We conducted a retrospective study at a single academic medical centre. Our study was compliant with guidelines set by the Health Insurance Portability and Accountability Act (HIPAA) and was approved by the Human Research Committee of our Institutional Review Board (IRB). Requirement for written informed consent was waived by our IRB. The system (Siemens Definition, Siemens Healthcare, Erlangen, Germany) with IRIS technology was installed in our department in April 2010, and that with ASiR (Discovery750 HDCT, GE Healthcare, Milwaukee, WI) in December 2008.

Patient selection

Adults (>18 years of age) with multiple portal venous phase abdominopelvic contrast-enhanced CT (CECT) examinations were included, with at least one performed using each of the three image reconstruction techniques using an institutional defined protocol. Excluded were those with unenhanced examinations, studies performed at a tube potential other than 120 kVp (e.g. low peak kilovoltage studies), CT examinations performed with a protocol targeted at specific indications such as

haematuria and renal mass evaluation, studies with an arterial phase or in those wherein intravenous contrast was considered suboptimal due to poor venous access, and patients with contrast allergy or reduced kidney function (estimated glomerular filtration rate <30). Between April 2010 and March 2011, a total of 4064 CT studies were carried out using IRIS technology. Of the 1161 abdominopelvic examinations with IRIS, 857 CE abdominopelvic studies undertaken in the portal venous phase were included. We selected only CE examinations, as this is the commonly used examination to evaluate multiple organ types. Our final cohort comprised 23 patients who met all eligibility criteria of having CECT of the abdomen using all three reconstruction methods and following our defined protocol (Figure 1). The lateral width of the abdomen, *i.e.* the maximum skin-to-skin diameter of the abdomen, was measured at the level of the upper pole of the right kidney for each patient.

Multidetector CT technique

Our protocol includes the administration of both oral and intravenous contrast media.

Oral contrast media protocol

To opacify the gastrointestinal tract, patients received a total of 800–1200 ml of positive oral contrast media, either containing barium (2.1% w/v, 2.0% w/w barium sulphate suspension, Read-Cat, Bracco diagnostics, Princeton, NJ) or iodine (660 mg ml⁻¹ 37% diatrizoate meglumine and 100 mg ml⁻¹ diatrizoate sodium solution, Gastrografin, Tyco Healthcare, Mansfield, MA). Contrast was ingested over 30–60 min using an institutionally defined protocol.

Intravenous contrast media protocol

Intravenous iodinated contrast media (370 mg I ml⁻¹ 75.5% Iopamidol, Isovue 370, Bracco Diagnostics) was administered at the rate of 2.5–3 ml s⁻¹. The volume of contrast administered was calculated based on the patient body weight, with the total dose being 80–120 ml, *i.e.* in

Figure 1. Flowchart depicting the study design. ASiR, adaptive statistical iterative reconstruction; CE, contrast enhanced; FBP, filtered back projection; IRIS, iterative reconstruction in image space; NC, non-contrast enhanced.

patients less than 60 kg (134 lb), 80 ml; 60–90 kg (134–200 lb), 100 ml; over 90 kg (200 lb), 120 ml. CT acquisition was initiated in the portal venous phase, with a fixed delay of 65–70 s after initiation of contrast bolus injection.

CT system parameters

The scan parameters for the two different vendor systems were chosen after initial phantom and pilot studies, and protocols were then established after gaining consensus of the subspecialty radiologists from our department. IR rendered scans were performed using reduced tube current compared with the FBP scans, and the other parameters were kept similar. The ASiR-enabled scans were performed as follows: 120 kVp, tube current ranged from a minimum of 150 to a maximum of 450 mA, tube rotation time of 0.5 s, helical mode, 55 mm table speed and a beam pitch of 1.375:1. A noise index of 36–42 was applied based on patients body weight (Auto mA 3D, GE Healthcare) and images were generated using a 30% ASiR (blend of 30% ASiR and 70% FBP). The ASiR selection to maintain an optimal balance of image quality and noise was based on our experience, since this technique had been in use for over a year, and on the published literature [12, 13]. Studies using IRIS were performed using a quality reference of 160 mAs (200 mAs for FBP), 120 kVp, beam pitch of 1.2:1 and a 75 mm table speed (Table 1). All the FBP examinations were performed on scanners from one equipment manufacturer (Lightspeed/VCT, GE Healthcare), and the noise index selection was 20–28 based on the patient's body weight [<60 kg (134 lb), 60–90 kg (134–200 lb) and 90 kg (>200 lb)].

Reconstruction parameters

Axial images reconstructed using 5-mm slice thickness and 3-mm thickness coronal and sagittal reformations were generated on the CT system console for all three techniques. Image data sets were subsequently transmitted to a picture archiving and communication system (PACS) for diagnostic interpretation.

Analysis of image quality

Two board-certified abdominal radiologists (AT and AA-E) with 5 and 6 years' of experience independently evaluated examinations on a two-monitor PACS workstation (AGFA Healthcare Corporation, Greenville, SC).

Both were blinded to CT system parameters, including the identity of each technique (accomplished by anonymising all DICOM headers from the PACS user interface), the patient's body weight and clinical and laboratory data. Subjective assessment of image quality was performed by viewing one examination at a time on a standardised scale as described in the European Guidelines on Quality Criteria for Computerized Tomography [20]. Diagnostic acceptability was assessed on a four-point scale based on the ability or confidence of the radiologist in assessing overall image quality (1, unacceptable; 2, acceptable only under limited conditions for visualisation of abnormalities; 3, probably acceptable for interpretation; and 4, fully acceptable for diagnostic interpretation). Visual sharpness of the abdominal viscera liver, intrahepatic portal veins, the liver–gallbladder interface, splenic parenchyma and margins of the intra-abdominal vasculature like the aorta, inferior vena cava and visceral arteries was evaluated on a five-point scale (1, unacceptable; 2, poor; 3, equivocal; 4, good; 5, excellent). Readers also noted the presence of image artefacts and their impact on image quality. The following were assessed: helical or windmill artefacts, streak artefacts due to metals, beam-hardening artefacts due to arms by the body side, truncation due to large body size or off-centring, and a blotchy pixelated appearance. The impact of these on image quality was graded on a four-point scale (1, no artefact; 2, minor artefacts not affecting diagnostic interpretation; 3, major artefacts affecting diagnostic interpretation; 4, artefacts rendering the study diagnostically unacceptable). Image noise was evaluated on a subjective and objective basis. Subjective analysis was done on a three-point scale (1, too little or less than usual noise; 2, acceptable noise; 3, excessive noise). Objective noise, *i.e.* the mean standard deviation of Hounsfield units (HU) in circular regions of interest (ROI) of 25–75 mm² area within the subcutaneous fat, was measured at soft-tissue window settings (window width, 400 HU; window level, 40 HU). This was recorded at three anatomical locations and performed at the same body location in all examinations: at the level of liver, at the kidney and at the sacrum; the mean value was then used for further calculations. To evaluate radiation dosimetry, CT dose descriptors, *i.e.* volume CT dose index (CTDI_{vol}) and dose–length product (DLP) indicated on the dose sheet examinations were recorded for each examination performed by each reconstruction method. The effective dose in millisieverts was calculated from the DLP as follows: effective dose (ED)=DLP×conversion factor, which in

Table 1. Protocols for each scanning technique

Parameter	FBP	ASiR 30%	IRIS
Reference mAs			160 mAs
Min–max mA		150–450	
Noise index	20–28	36–42	
Tube potential (kVp)	120	120	120
Pitch	1.375	1.375	1.2
Rotation time (s)	0.5	0.5	0.75
Kernel	Soft/standard	Standard	B31F
Slice thickness (axial/coronal)	5 mm/3 mm	5 mm/3 mm	5 mm/3 mm

ASiR, adaptive statistical iterative reconstruction; FBP, filtered back projection; IRIS, iterative reconstruction in image space.

the case of abdominal CT examinations is 0.015 [21]. Mean radiation dose measurements of all three image reconstruction techniques were then compared.

Statistical analysis

Data are shown as mean $\pm$ standard deviation unless otherwise noted. Differences in imaging characteristics (noise, acceptability, sharpness and artefact) and radiation dose between the three techniques were compared using a Wilcoxon signed rank test and a paired *t*-test. The test for interaction by weight group for all parameters was done using a two-sample equal variance *t*-test. As we made two pairwise comparisons (ASiR *vs* FBP and IRIS *vs* FBP), using a Bonferroni correction, a *p*-value less than 0.025 was required for statistical significant difference. Interobserver agreement was done using Cohen's κ test (poor agreement for $\kappa \leq 0.19$; fair agreement for $\kappa = 0.2$ –0.39; moderate agreement for $\kappa = 0.4$ –0.59, substantial agreement for $\kappa = 0.6$ –0.79 and very good agreement for $\kappa = 0.8$ –1.00 [22]). All calculations were performed using Microsoft Excel 2003 (Microsoft Office Excel 2003, Richmond, VA) and SAS software (SAS 9.1, SAS Institute, Carey, NC).

Results

All 69 studies performed in 23 patients with the three reconstruction techniques were deemed suitable for rendering diagnostic interpretation. The average time interval between ASiR and FBP was 5.7 ± 5.3 months (range 1–21 months) and that between IRIS and FBP was

Table 2. Demographic data of the study cohort

No. of patients	
Total	23
<90 kg (200 lb)	14
>90 kg (200 lb)	9
Mean age (years)	55.3 ± 12.1
Age range (years)	23–76
Male:Female	10M:13F
Weight FBP: mean (range)	180.8 ± 40.2 (129.8–249.9) lb ^a
Weight ASiR: mean (range)	183.9 ± 52.8 (103.4–330) lb
Weight IRIS: mean (range)	184.8 ± 46.4 (119.9–266.2) lb

ASiR, adaptive statistical iterative reconstruction; FBP, filtered back projection; IRIS, iterative reconstruction in image space.

Values represent mean $\pm$ standard deviation.

^aWeight in kilograms are FBP, 82.0 ± 18.2 (58.9–113.9); ASiR, 83.4 ± 23.9 (46.9–150.0); IRIS 83.8 ± 21.0 (54.4–121.0).

10.3 ± 8.0 months (range 0–26 months). 14 patients weighed less than 90 kg (200 lb), and 9 weighed more than 90 kg (200 lb). The mean weight for the group was 180.8 ± 41.4 kg (129.6–249.5 kg), and males outweighed the females ($p < 0.001$, Table 2). There was minimal weight fluctuation between the three sets of examinations (FBP, 180.8 ± 41.4 kg; ASiR, 183.9 ± 52.8 kg; IRIS, 184.8 ± 46.4 kg). The lateral width of the abdomen was also similar in the three groups (FBP, 34.1 ± 5.6 mm; ASiR, 33.2 ± 4.1 mm; IRIS, 36.7 ± 8.1 mm). Representative images of the three techniques are shown (Figures 2 and 3), and details of their qualitative and quantitative imaging analysis are described below.

Figure 2. Coronal CT images reconstructed using filtered back projection (FBP), adaptive statistical iterative reconstruction (ASiR) and iterative reconstruction in image space (IRIS) in a 58-year-old female weighing 59.7 kg (131.8 lb) with liver metastases (arrow), pancreatic calcification (arrows) and splenomegaly (*) shown. The FBP (a) examination was performed with an effective radiation dose of 10 mSv [volume CT dose index (CTDI_{vol}), 15.7 mGy; dose–length product (DLP), 665 mGy cm] while the subsequent examinations reconstructed using ASiR (b) and IRIS (c) were performed at a reduced radiation dose of 36.9% [CTDI_{vol}, 9.9 mGy; DLP, 552.3 mGy cm; effective dose (ED), 8.3 mSv] and 14.1% (CTDI_{vol}, 13.5 mGy; DLP, 652 mGy cm; ED, 10.1 mSv), respectively. The image quality and objective image noise were comparable in the three examinations.

Figure 3. A 57-year-old female weighing 69.8 kg (153.8 lb) with a history of endometrial carcinoma underwent serial examinations as part of her disease workup. Axial filtered back projection (FBP) image (a) shows multiple haemangiomas in the liver. Axial images from the follow up restaging examinations reconstructed using adaptive statistical iterative reconstruction (ASiR) (b) and iterative reconstruction in image space (IRIS) (c) were of diagnostic quality despite using a 28–33% lower dose than FBP examinations (ASiR: 448.9 mGy.cm, IRIS: 483 mGy.cm vs FBP: 670.5 mGy.cm).

Diagnostic acceptability

Images produced using all three techniques were comparable for diagnostic acceptability: ASiR mean, 3.9 ± 0.3 ($p=0.2$ for Readers 1 and 2); IRIS, 3.9 ± 0.4 ($p=0.2$); and FBP examinations, 3.8 ± 0.4 . Mean values were also similar in individuals from both weight subcategories (Table 3). There was no statistical difference for diagnostic acceptability in patients from both weight groups ($\kappa=0.5$ – 0.7).

Visual sharpness

There was no statistical difference in the mean image sharpness grades in the three image groups [FBP (4.8 ± 0.5); ASiR, 4.7 ± 0.5 ($p=0.4$); IRIS, 4.5 ± 0.5 ($p=0.4$)]. In patients weighing less than 90 kg (200 lb), IRIS-rendered images were rated slightly inferior to ASiR and FBP but similar for those weighing above 90 kg (200 lb), ($\kappa=0.4$ – 0.6 , Table 3).

Artefacts

The image artefacts were minimal and not statistically different in the three image reconstruction groups ($\kappa=0.3$ – 0.5 , Table 3). Truncation artefacts due to a large abdominal girth were present in three patients (13%), with a similar image score (Grade 2). In nine patients (39%), slight beam hardening from metallic hip and spinal prostheses and/or from lines and tubes was present. Pixilation at tissue interfaces was not reported in any case.

Subjective image noise

Subjective noise scores were marginally inferior for IRIS (1.5 ± 0.6 , $p=0.4$) images compared with ASiR (1.4 ± 0.5 , $p=0.4$) and FBP (1.3 ± 0.5), especially in patients weighing less than 90 kg (200 lb). Moderate interobserver agreement was seen for this parameter ($\kappa=0.5$ – 0.6 , Table 3).

Objective image noise

The mean objective image noise for ASiR and IRIS cohort was 12.5 ± 2.9 ($p=0.0016$) and 10.9 ± 4.1

($p<0.0001$), which represented a 32.2% and 40.7% reduction, respectively, compared with FBP (mean= 18.4 ± 7.7). In patients weighing less than 90 kg (200 lb), reduction in noise was greater with ASiR than with IRIS (36.6% vs 19.4%, $p<0.002$ vs $p<0.02$), but the noise reduction was comparable for both the iterative methods in those weighing over 90 kg (200 lb) (Table 3).

Radiation dose

The recorded CTDI_{vol} using ASiR, IRIS and FBP was 11.4 ± 3.4 , 13.5 ± 3.7 and 15.0 ± 3.5 mGy, respectively, representative of an average reduction of 24.0% and 10.0% with ASiR and IRIS, as well as a 20.0% and 11.5% decrease in DLP compared with FBP. The percentage reduction showed a similar trend in patients from both weight categories (Table 4).

Discussion

CT images reconstructed with the conventional FBP method suffer from artefacts and excessive image noise when low-dose scan parameters are used [10]. Though fast and computationally effective, FBP makes several assumptions but requires a substantially higher dose to render images of a diagnostic quality [11]. These challenges are perceived as sufficiently manageable in certain high-contrast examinations such as CT angiography, nephroureterolithiasis and CT colonography. However, in routine CECT of the abdomen, where multiple viscera and body parts are being examined, image quality expectations are different. Recently introduced iterative reconstruction algorithms have shown promise in reducing image noise and maintaining image quality of low-dose CT examinations over FBP images in the abdomen [23–25]. Our study validates the ability of both iterative techniques in delivering image quality of lower dose abdominopelvic CT studies similar to standard dose FBP examinations. We adopted an ASiR value of 20–40% because of the subspecialty radiologist's preference, and this was also similar to what has been described in prior studies [12, 13]. Although there were slight differences in recorded image quality scores for the

Table 3. Image quality assessment with each scanning technique

Parameter			FBP	ASiR	IRIS
Diagnostic acceptability ^a	All weights (n=23)	Mean ± SD	3.8 ± 0.4	3.9 ± 0.3	3.9 ± 0.4
		Weighted κ	0.6–0.7	0.6–0.7	0.5–0.7
		^f p-value		0.3/0.1	0.3/0.2
	<90 kg (200 lb) (n=14)	Mean ± SD	3.9 ± 0.1	3.9 ± 0.1	3.8 ± 0.4
	>90 kg (200 lb) (n=9)	Mean ± SD	3.8 ± 0.5	3.9 ± 0.3	3.8 ± 0.5
Visual sharpness ^b	All weights (n=23)	^c p-value		0.3	0.2
		Mean ± SD	4.8 ± 0.5	4.7 ± 0.5	4.5 ± 0.5
		Weighted kappa (κ)	0.4–0.5	0.4–0.6	0.4–0.6
	<90 kg (200 lb) (n=14)	^f p-value		0.04/0.7	0.7/0.004
	>90 kg (200 lb) (n=9)	Mean ± SD	4.8 ± 0.5	4.7 ± 0.5	4.5 ± 0.5
Artefact ^c	All wt. (n=23)	Mean ± SD	4.7 ± 0.5	4.7 ± 0.4	4.6 ± 0.6
		^g p-value		0.4	0.3
		Weighted kappa (κ)	0.3–0.4	0.3	0.4–0.5
	<90 kg (200 lb) (n=14)	^f p-value		0.3/0.03	0.2/1.0
	>90 kg (200 lb) (n=9)	Mean ± SD	1.2 ± 0.4	1.1 ± 0.3	1.2 ± 0.4
Subjective image noise ^d	All wt. (n=23)	Mean ± SD	1.3 ± 0.5	1.1 ± 0.2	1.2 ± 0.3
		^g p-value		0.6	0.8
		Weighted kappa (κ)	0.5	0.6	0.6
	<90 kg (200 lb) (n=14)	^f p-value		0.5/0.4	0.6/0.1
	>90 kg (200 lb) (n=9)	Mean ± SD	1.1 ± 0.3	1.4 ± 0.5	1.4 ± 0.6
Objective image noise ^e	All wt. (n=23)	Mean ± SD	1.6 ± 0.6	1.4 ± 0.5	1.5 ± 0.6
		^g p-value		0.5	0.4
		Percentage reduction		19.4	36.6
	<90 kg (200 lb) (n=14)	Mean ± SD	18.4 ± 7.7	12.5 ± 2.9	10.9 ± 4.1
		^f p-value		0.0016	<0.0001
		Percentage reduction		19.4	36.6
	>90 kg (200 lb) (n=9)	Mean ± SD	14.9 ± 5.1	12.1 ± 2.4	9.5 ± 2.5
		^f p-value		0.02	<0.002
		Percentage reduction		19.4	36.6
	All wt. (n=23)	Mean ± SD	23.6 ± 8.3	12.5 ± 3.2	12.9 ± 5.1
		^f p-value		<0.006	<0.004
		Percentage reduction		47.1	45.4
	<90 kg (200 lb) (n=14)	^h p-value		0.0482ⁱ	0.0094^j
		^h p-value			

ASiR, adaptive statistical iterative reconstruction; FBP, filtered back projection; IRIS, iterative reconstruction in image space. Values represent mean ± SD. Bold values represent *p*-values for statistical significance. Italics are interobserver agreement with weighted kappa.

^aDiagnostic acceptability was graded on a four-point scale: 1, unacceptable; 2, acceptable only under limited conditions for visualisation of abnormalities; 3, probably acceptable for interpretation; and 4, fully acceptable for diagnostic interpretation.

^bVisual Sharpness was graded on a five-point scale: 1, unacceptable; 2, poor; 3, equivocal; 4, good; 5, excellent.

^cArtefacts were graded on a four-point scale: 1, no artefact; 2, minor artefacts not affecting diagnostic interpretation; 3, major artefacts affecting diagnostic interpretation; 4, artefacts rendering the study diagnostically unacceptable.

^dSubjective image noise was evaluated on a three-point scale: 1, minimal or no noise; 2, acceptable level of noise not interfering with diagnostic interpretation; and 3, excessive noise affecting diagnostic interpretation.

^eObjective image noise was estimated by region of interest analysis and measured by obtaining standard deviation of mean CT number (HU value) of subcutaneous fat.

^f*p*-value of the difference between imaging quality of the three techniques are given for both readers as R1/R2 where R1 = Reader 1, R2 = Reader 2.

^g*p*-value for interaction by weight subcategories.

^h*p*-value is the mean absolute reduction and was calculated using Student's *t*-test and Satterthwaite's *t*-test (see footnotes *i* and *j*).

ⁱStudent's *t*-test comparing absolute reduction <200 vs ≥200 lb.

^jSatterthwaite's *t*-test for unequal variances comparing the two reconstruction techniques in the two weight categories.

three reconstruction methods, they all provided diagnostic quality images. Even the objective assessment of noise was lower with both iterative methods for this across the body weight spectrum. Both readers reported slightly altered texture of iteratively reconstructed images with the two techniques compared with FBP, but this did not negatively affect diagnostic performance. Overall, ASiR-rendered images were rated slightly better for image noise and sharpness than IRIS images. This could potentially be attributed to a longer reader experience with ASiR, which had been installed over a year before IRIS, giving our radiologists sufficient time to

get accustomed to these images. Since the estimated effective dose levels of FBP examinations were well within the range of acceptable limits (CTDI_{vol} 15 ± 3.5 mGy) of abdomen CT doses, the dose reduction accomplished with the modified protocols using iterative methods was in fact a true reduction [26]. Moreover, there was an insignificant fluctuation in patient total body weight in the time frame when all the three examinations were performed, and therefore this could not have influenced the results. In a phantom study using IRIS, Schindera et al [18] reported a 39.8–70.3% reduction in the CTDI_{vol} at different peak kilovoltage

Table 4. Recorded weight-based radiation dose for each scanning technique

Dose	Weights (lb)	FBP	ASiR	IRIS	Average dose reduction (%)	
CTDI _{vol} (mGy) ^a	All weights (n=23)	15.0 ± 3.5	11.4 ± 3.4	13.5 ± 3.7	24	10
		^a p-value			<0.001	0.06
	<90 kg (200 lb) (n=14)	13.4 ± 3.0	9.7 ± 2.2	12.2 ± 2.6	27.3	27.3
	>90 kg (200 lb) (n=9)	17.2 ± 3.0	13.7 ± 3.7	15.2 ± 4.4	20.3	11.6
		^b p-value			0.9	0.7
DLP (mGy cm)	All weights (n=23)	759.6 ± 198.2	607.9 ± 213.2	672.3 ± 168.7	20.0	11.5
		^a p-value			0.002	0.009
	<90 kg (200 lb) (n=14)	667.4 ± 156.5	513.7 ± 133.6	575.8 ± 144.9	23.0	13.7
	>90 kg (200 lb) (n=9)	892.8 ± 180.5	743.9 ± 239.5	801.0 ± 98.1	16.7	10.3
		^b p-value			0.8	0.6
ED (mSv)	All wt. (n=23)	11.4 ± 3.0	9.1 ± 3.2	10.1 ± 2.5	20.2	11.4
		^a p-value			0.002	0.009
	<90 kg (200 lb) (n=14)	10.0 ± 2.4	7.7 ± 2.0	8.6 ± 2.2	23.0	14.0
	>90 kg (200 lb) (n=9)	13.4 ± 2.7	11.2 ± 3.6	12.0 ± 1.5	16.4	10.4
		^b p-value			0.8	1.0

ASiR, adaptive statistical iterative reconstruction; CTDI_{vol}, volume CT dose index; DLP, dose-length product; ED, effective dose; FBP, filtered back projection; IRIS, iterative reconstruction in image space; R1, Reader 1; R2, Reader 2.

Values represent mean and standard deviation (mean ± SD). Bold values represent *p*-values.

^a*p*-value of the difference between imaging quality of the three techniques are given for both.

^b*p*-value for interaction by weight subcategories.

settings while maintaining the image quality. However, in our clinical study with IRIS, we had applied a constant peak kilovoltage and were able to obtain about 10% reduction in the CTDI_{vol}. We used a modest dose reduction in the abdomen CT examinations to ensure that the radiologists with various levels of experience within our department were comfortable with the image quality for rendering interpretations. Much higher dose reduction was applied to high-contrast abdomen CT examinations (such as CT angiographies) or screening studies (kidney stone evaluation, CT colonography). There are several limitations to our study. The retrospective nature and small study cohort limit the scope of our study to evaluate performance of images from three reconstruction techniques in diagnosing pathologies in the abdomen and pelvis. With newer techniques, logistic challenge exists in having sufficient experience in patients of a specific disease with three different methods. However, we used image quality as a surrogate for radiologist acceptance of these images in rendering a diagnosis. Also, direct comparison of the performance of image reconstruction techniques from two different vendors is difficult because of varied scan parameters and image processing algorithms. Similarly, differences in radiation dose reduction achieved with ASiR and IRIS could be attributed to the protocol approach taken at our institution to obtain diagnostic quality images. It is difficult to obtain the same dose reduction as the two iterative techniques are manufactured by different vendors and take different approaches to obtain images with reduced image noise. Additionally, the study design did not include FBP images obtained at low dose (LD-FBP) due to our inability to record raw data to generate these examinations. There is increasing interest in technological approaches to facilitate image quality improvements from low-dose examinations, and almost all equipment manufacturers are introducing their own versions of iterative image reconstruction techniques [27]. Indeed, it will be desirable to see if the extent of dose reduction is feasible in CT while meeting image

quality expectations for rendering interpretations. Advanced IR techniques from two major CT manufacturers, such as model-based iterative reconstruction (MBIR), a method that incorporates a physical model of the CT system into the reconstruction process, and Sinogram Affirmed Iterative Reconstruction (SAFIRE), which utilizes sinograms or raw data for iterative image improvement, have recently received FDA approval for clinical use, and they are likely to improve the CT doses further [28–30]. Unfortunately, these novel iterative techniques are currently applicable to high-end CT equipment and entail higher costs, and therefore their widespread utilisation is limited.

Conclusions

In conclusion, our study demonstrates the application of two iterative techniques, ASiR and IRIS, in patients undergoing abdominal CT during the portal venous phase. The study validates the ability of these two methods in providing diagnostic quality images similar to standard dose FBP at a lower radiation dose in patients undergoing abdominal CT examinations, at the defined system parameters.

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