Original Article / Gastrointestinal Imaging

Standard dose versus low-dose abdominal and pelvic CT: Comparison between filtered back projection versus adaptive iterative dose reduction 3D

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Keywords
Multidetector CT; Dose reduction; Image quality; Iterative reconstruction; Abdominal and pelvic CT

Abstract
Purpose: To compare the dose and image quality of a standard dose abdominal and pelvic CT with Filtered Back Projection (FBP) to low-dose CT with Adaptive Iterative Dose Reduction 3D (AIDR 3D).

Materials and methods: We retrospectively examined the images of 21 patients in the portal phase of an abdominal and pelvic CT scan before and after implementation of AIDR 3D iterative reconstruction. The acquisition length, dose and evaluations of the image quality were compared between standard dose FBP images and low-dose images reconstructed with AIDR 3D and FBP using the Wilcoxon test.

Results: The mean acquisition length was similar for both CT scans. There was a significant dose reduction of 49.5% with low-dose CT compared to standard dose CT (mean DLP of 451 mGy.cm versus 892 mGy.cm, P < 0.001). There were no differences in image quality scores between standard dose FBP and low-dose AIDR 3D images (4.6 ± 0.6 versus 4.4 ± 0.6 respectively, P = 0.147).

Conclusion: AIDR 3D iterative reconstruction enables a significant reduction in dose of 49.5% to be achieved with abdominal CT scan compared to FBP, whilst maintaining equivalent image quality.

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http://dx.doi.org/10.1016/j.diii.2013.05.005
The number of CT scans performed has increased relentlessly over the last decade, to more than 68.7 million investigations in the United States in 2007 [1]. Although this increase is associated with a large improvement in diagnostic performance, it is also a source of increased personal and population exposure to radiation [2,3] as well as being the source of a potential risk of radiation-induced cancer from low doses of X-rays [4,5]. Reducing the radiation dose delivered by CT scans has therefore become a major concern, particularly in abdominal imaging where the acquisition protocol may include three or four acquisition phases [6].

The widespread use of several new technologies such as automatic milliamperage modulation [7–9] and active collimation [10] has already reduced doses delivered in abdominal and pelvic CT scans. This reduction, however, is limited by the use of standard Filtered Back Projections (FBP) as these cause a significant increase in image noise if the dose is reduced too much [11]. The recent emergence of iterative reconstructions solves this problem by greatly reducing image noise and therefore allowing the dose to be significantly reduced in comparison with standard FBP reconstructions [12,13].

A first version of the iterative reconstructions was marketed on the 320-detector CT scanner (Aquilion ONE, Toshiba, Japan) in 2010 (Adaptive Iterative Dose Reduction, Toshiba, Japan). This model showed considerable potential to improve image quality of the scanners and reduce their dose, although it had the disadvantage of only being available retrospectively and only for volume and not helicoidal-mode acquisitions [14,15]. A new, more sophisticated version of these iterative reconstructions has now been marketed (Adaptive Iterative Dose Reduction 3D [AIDR 3D], Toshiba, Japan) and is available in our institution. This can be used prospectively and for helicoidal acquisitions. It has a more complicated algorithm than the first version of the AIDR iterative reconstructions and contains iteration loops in the image and raw data fields. To create the AIDR 3D image, the final iterative image and the original image are combined and weighted in order to ensure a reduction in noise, at the same time preserving normal textures and anatomical outlines. Initial tests on model systems on our scanner showed that AIDR 3D iterative reconstructions could potentially reduce the radiation dose by nearly 50%. AIDR 3D is now, therefore, the reconstruction mode used in routine clinical practice. We are not aware, however, of any patient studies which have assessed the utility of this new reconstruction algorithm in order to reduce the radiation dose for abdominal and pelvic CT scans in clinical practice.

The aim of our study was to compare the dose and image quality of an abdominal and pelvic CT scan using standard dose FBP compared to an abdominal and pelvic CT scan with low-dose and AIDR 3D iterative reconstructions and standard FBP reconstructions in the same patient.

**Study population**

This was a single-centre retrospective study which included 21 patients who had had contrast-enhanced abdominal and pelvic CT in the portal phase within our institution. Both investigations were performed on the same machine (Aquilion ONE), the first using standard dose with standard FBP reconstructions (FBP standard dose group) and the second using low-dose with AIDR 3D iterative reconstructions (AIDR 3D low-dose group). The images obtained with low-dose were also reconstructed by FBP (FBP low-dose group). Patients were identified and selected from our institution’s PACS system (Picture Archiving and Communication System) (Impax V5, ES; AGFA Technical Imaging Systems, Ridgefield, NJ, USA) by searching, during the 3 months after the introduction of AIDR 3D iterative reconstructions (from September to November 2011), for all patients who had a portal phase abdominal and pelvic CT scan and who had already had the same scan before the iterative reconstructions were introduced. The exclusion criteria were patients who were minors, pregnant women and those who had an interval of more than 18 months between the two scans. Patients’ weights were recorded at the time of the low-dose scan.

**Acquisition protocol**

All of the abdominal and pelvic scans were obtained using a 320-detector CT scan instrument (Aquilion ONE, Toshiba, Japan) with acquisition covering the abdomen and pelvis from the bases of the lungs to the pubic symphysis. All of the patients had at least one portal phase acquisition after intravenous administration of 150 mL of contrast medium (OMNIPAQUE 350, GE Healthcare, Chalfont St. Giles, UK) via peripheral infusion over a period of 70 seconds with flow rate of 4 mL/s. The acquisition parameters were identical (Table 1) except for the automatic milliamperage modulation noise index in the three planes (SURE Exposure 3D, Toshiba) which were set at 9 for a 5 mm section of the “soft tissues” window for the standard dose scan and 10 for the low-dose scan. With the introduction of the AIDR 3D, the automatic milliamperage modulation automatically and prospectively reduces the exposure parameters.

**Image reconstruction**

For the standard dose scans, the images were reconstructed with FBP reconstructions (standard dose FBP group). Images for the low-dose scans were reconstructed using AIDR 3D iterative reconstructions in “standard” mode (AIDR 3D low-dose group) and using FBP reconstructions (FBP low-dose group). The three series of images were reconstructed in 2 mm transverse sections every 1.6 mm with an FC 07 reconstruction filter. All of the images were sent to and archived in our PACS system.

**Assessment of image quality**

Image noise was assessed quantitatively by measuring the standard deviation of the regions of interest (ROI) located in the liver and aorta (Fig. 1). These regions were positioned in a standardised manner by the same radiologist.
(A.G.) on a 2 mm thick transverse section of the abdomen at the level of the portal vein bifurcation, from an Aquilion ONE post-treatment console (Display console, version 4.74, Toshiba, Japan). For the aorta, noise was defined as having a standard deviation of a $100 \pm 20 \text{ mm}^2$ region of interest placed in the centre of the vessel in a homogenous region distant to the walls. For the liver, three circular $200 \pm 50 \text{ mm}^2$ regions of interest were positioned in

**Figure 1.** Abdominal CT images in a 26-year-old female patient being followed up for post-traumatic liver fracture. Two-millimetre transverse CT sections of the abdomen at standard dose with FBP reconstructions (a) and low-dose CT with AIDR 3D iterative reconstructions (b) and with FBP reconstructions (c). The position and size of the ROIs in the aorta (ROI #1) and in the liver (ROI #2–4) were maintained between the three image series. Note the large reduction in image noise between the AIDR 3D low-dose (b) and FBP low-dose (c) groups. Also note the similar image noise between the FBP standard dose (a) and AIDR 3D low-dose (b) groups, despite the large reduction in dose with the second scan (529 mGy.cm vs. 267 mGy.cm respectively, i.e. a dose reduction of 50.5%).

<table>
<thead>
<tr>
<th>Scan acquisition and reconstruction settings.</th>
<th>Standard dose scan</th>
<th>Low-dose scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition mode</td>
<td>FBP</td>
<td>AIDR 3D</td>
</tr>
<tr>
<td>Helicoidal</td>
<td>Helicoidal</td>
<td>Helicoidal</td>
</tr>
<tr>
<td>Detector collimation</td>
<td>$64 \times 0.5 \text{ mm}$</td>
<td>$64 \times 0.5 \text{ mm}$</td>
</tr>
<tr>
<td>Kilovoltage</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Noise index</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>mA minimum/maximum</td>
<td>50/500</td>
<td>50/500</td>
</tr>
<tr>
<td>Section thickness/interval</td>
<td>2/1.6 mm</td>
<td>2/1.6 mm</td>
</tr>
<tr>
<td>Reconstruction algorithm</td>
<td>FBP</td>
<td>AIDR 3D</td>
</tr>
</tbody>
</table>

FBP: Filtered Back Projection; AIDR 3D: Adaptive Iterative Dose Reduction 3D; SureExposure3D: three dimensional automatic milliamperage (mA) modulation (Toshiba, Japan).
the left and right lobes of the liver, carefully avoiding the intra-hepatic vessels, focal lesions and artefacts, as described by Marin et al. [16]. Liver noise was defined as the mean of the standard deviations of the three liver ROIs.

In order to establish the independent relationship between image noise and dose for each of the three series of images, a figure of merit (FOM) was calculated for the aorta and for the liver using the equation described by Marin et al. [16] where $B^2$ is the square of the noise and ED is the effective dose: $\text{FOM} = 1/(B^2 \cdot \text{ED})$.

Three senior radiologists (B.O., M.L. and A.B.) then performed a qualitative assessment of image quality. These radiologists have 6, 9 and 25 years of experience respectively in interpreting abdominal CT scans. They were not involved in patient selection or in positioning the ROIs for the quantitative image analysis. The images were read independently by the three radiologists on randomised, anonymised investigations which did not show the dates that the scans were performed. The assessment was scored on a visual scale from 1 to 5 (1 = unacceptable image quality, unable to interpret; 2 = poor image quality, interfering with interpretation; 3 = average image quality, interpretation possible; 4 = good image quality; 5 = excellent image quality) on PACS consoles after a joint reading session. Image quality scores 1 and 2 were deemed to be unacceptable for interpretation in clinical practice.

### Measurement of doses delivered

The doses delivered were provided directly from the investigation report which could be accessed in the PACS system. They correspond to the CTDIvol (volume CT dose index) expressed in mGy and the Product Dose and Length expressed in mGy.cm. The effective dose (ED) expressed in milliSievert (mSv) was calculated using the tissue conversion coefficient (k) for the abdomen of 0.015 [17] by the equation $\text{ED} = k \times \text{PDL}$ [18].

### Evaluation of acquisition lengths

Acquisition length was expressed in centimetres and was measured as the difference in position between the first and last acquisition sections.

### Evaluation of transverse and anteroposterior abdominal diameters

Transverse and anteroposterior abdominal diameters (in cm) were measured for each patient on the standard dose and low-dose scans in order to ensure that there had been no significant change in patient body morphology between the two investigations. These measurements were performed by the same radiologist (A.G.), on a PACS console, on the same transverse sections passing through the portal vein bifurcation used to position the ROIs for the quantitative measurement of image noise.

### Statistical analyses

Findings were analysed on R for Windows software (R Foundation for Statistical Computing, Vienna, Austria). Mean values were calculated for the image quality from the quantitative analysis by each radiologist to produce an overall image quality score for each group. The Wilcoxon signed rank test was used to compare acquisition lengths, doses delivered and abdominal diameters between the two types of scan. The same test was used to compare the qualitative and quantitative assessments of image quality between the AIDR 3D low-dose, FBP low-dose and FBP standard dose groups. A P value of less than 0.05 was deemed to be a statistically significant difference.

### Results

Twenty-one patients were included in the study (10 men and 11 women). The average age of the patients at the time of the low-dose scan was 43 ± 18 years (range: 21 to 86 years) and mean weight was 71 ± 8 kg (range: 45 to 88 kg). The average interval between the two scans was 177 days (range: 92 to 380 days). There were no significant differences in acquisition lengths or abdominal diameters between the low-dose and standard dose scans (Table 2).

Mean CTDIvol, DLP and effective doses of the low-dose scans were significantly lower than with the standard dose scans (effective doses of 6.8 ± 2.5 mSv compared to 13.4 ± 4.3 mSv respectively, $P < 0.001$). The average reduction in dose was 49.5% (Table 2).

For the quantitative assessment of image quality, we found that mean image noise in the liver and aorta was...
Table 3 Quantitative and qualitative image quality assessment.

<table>
<thead>
<tr>
<th></th>
<th>Standard dose scan</th>
<th>Low-dose scan</th>
<th>P value</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>FBP</td>
<td>AIDR 3D</td>
<td>FBP</td>
</tr>
<tr>
<td>Noise (UH)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liver</td>
<td>15.86 ± 2.7</td>
<td>16.47 ± 1.4</td>
<td>27.21 ± 4.2</td>
</tr>
<tr>
<td>Aorta</td>
<td>17.62 ± 3.3</td>
<td>17.70 ± 2.5</td>
<td>31.84 ± 6.8</td>
</tr>
<tr>
<td>FOM (× 10⁻⁴)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liver</td>
<td>3.47 ± 1.0</td>
<td>6.27 ± 2.0</td>
<td>2.19 ± 1.0</td>
</tr>
<tr>
<td>Aorta</td>
<td>2.89 ± 1.0</td>
<td>5.71 ± 2.4</td>
<td>2.0 ± 1.0</td>
</tr>
<tr>
<td>Image quality score</td>
<td>4.6 ± 0.6</td>
<td>4.4 ± 0.6</td>
<td>3.3 ± 0.6</td>
</tr>
</tbody>
</table>

FBP: Filtered Back Projection; AIDR 3D: Adaptive Iterative Dose Reduction 3D. Apart from the P values, the results are expressed as mean ± standard deviation.

significantly lower in the AIDR 3D low-dose group than in the FBP low-dose group with noise reductions of 39 and 44% respectively. However, there was no significant difference between mean liver or aortic image noise between the FBP standard dose and AIDR 3D low-dose groups (Table 3). The mean of the FOMs in the liver and aorta were significantly higher for the AIDR 3D low-dose images compared to the FBP standard dose images (6.27 ± 2.0 compared to 3.47 ± 1.0, P < 0.001 for the liver and 5.71 ± 2.4 compared to 2.89 ± 1.0, P < 0.001 for the aorta, respectively) and FBP low-dose (Table 3).

The qualitative assessment of the image quality showed this to be significantly higher in the FBP low-dose and AIDR 3D low-dose groups (3.3 ± 0.6 compared to 4.4 ± 0.6 respectively, P < 0.001). There was no statistically significant difference in mean image quality score between the FBP standard dose and AIDR 3D low-dose groups (4.6 ± 0.6 compared to 4.4 ± 0.6 respectively, P = 0.147) (Table 3).

Discussion

Our study confirms that the use of AIDR 3D iterative reconstructions greatly reduces image noise as compared to standard FBP reconstructions. Our comparison between the FBP low-dose and AIDR 3D low-dose series images shows a significant improvement in subjective image quality and in the quantitative assessment of image noise. Two of the patients in the FBP low-dose group scored 2 out of 5 for quality, thus the quality of the image interfered with interpretation, no patients in the AIDR 3D low-dose group scored 2 and only one of the 21 patients scored 3 in this group.

As a result of this reduction in image noise, it has become possible to reduce acquisition parameters and therefore the dose. Our comparison between the AIDR 3D low-dose and FBP standard dose groups confirms that it is possible to halve the radiation dose delivered in abdominal CT scans by using AIDR 3D iterative reconstructions. This reduction in dose has enabled us to reduce the average PDL in our abdominal scans from 892 mGy.cm to 451 mGy.cm, or a mean dose beneath the diagnostic reference level defined in the 2012 legislation (800 mGy.cm) [19].

The results of our study are similar to those of an initial study on the effectiveness of AIDR iterative reconstructions (Toshiba’s first version of iterative reconstructions) on lumbar spine CT scans which showed the potential to reduce the dose by 52% [14]. This dose reduction, however, was only based on indirect calculation by extrapolating the reduction in noise from FBP to AIDR images on the same acquisition.

Our results are also similar to other types of iterative reconstructions which have already been marketed and which are currently available in clinical practice [20–23]. Sagara et al. [20] and Prakash et al. [21] showed that it was possible to reduce abdominal CT scan doses by 33% and 25% respectively, using ASIR, whilst improving image quality in comparison with FBP reconstructed scans in patient studies using Adaptive Statistical Iterative Reconstruction (ASIR). Mitsumori et al. [22] showed that the abdominal scan dose could be reduced by 41% with ASIR in comparison with FBP reconstructions. In addition, as in our own study, May et al. [23] demonstrated a 50% reduction in abdominal scan dose using Iterative Reconstruction in Image Space (IRIS) iterative reconstructions compared to standard FBP reconstructions, with equivalent image quality.

It is difficult, however, to compare our results with other types of iterative reconstructions as their implantation is different for each manufacturer. The ASIR and IRIS iterative reconstructions, for example, respectively require a percentage mixing of FBP and ASIR images and a number of iterations to be selected during the IRIS reconstruction process. The dose reduction and quality of the final image both depend on these parameters [20–24]. If an ASIR percentage that is too high is chosen, or if too many iterations are used for IRIS, changes may occur in the usual appearance of the images with an “over-smoothing” effect due to a change in the image noise spectra [11,12].

AIDR 3D also allows us to choose from four predetermined modes: “weak”, “mild”, “standard” and “strong”. These different modes allow a greater or lesser number of iterations to be performed and the mixing percentage of AIDR
3D and FBP to be changed in the iterative reconstruction process. The “standard” setting is the one recommended by the manufacturer for abdominal imaging and is a compromise between dose reduction and maintaining usual image quality. In practice, we have not noticed any difference in image texture on the AIDR 3D images and it was difficult for the readers to distinguish the FBP standard dose and AIRD 3D low-dose images (Fig. 1). The “strong” setting may cause a slight change in usual image texture, although this setting can further reduce the radiation dose delivered. Yamada et al. showed that by using the “strong” setting with AIRD 3D iterative reconstructions, the dose could be reduced by 64% whilst maintaining equivalent image quality compared to standard FBP reconstructions in a study on chest CT scans [25]. Further studies are therefore needed to establish whether it is possible to use the “strong” setting in abdominal imaging in order to further decrease the dose without reducing the diagnostic performance of the investigations.

Another advantage of some types of iterative reconstruction algorithms is that they reduce beam intensification artefacts and metallic artefacts. AIDR 3D iterative reconstructions can partially correct these artefacts by using a reconstruction algorithm with a double loop in the raw data fields and in the image field. This partly explains the improvement in subjective image quality between FBP low-dose and AIDR low-dose images (Fig. 2).

There are several limitations to our study. Firstly, it is a retrospective study which included a small number of patients. A larger-scale prospective study is needed in order to confirm these results. Secondly, we only assessed image quality and not the diagnostic performance of the scans in our study. This would have been a more appropriate style of assessment but it is difficult to implement. Thirdly, we did not study the effect of patient body morphology on the effectiveness of iterative reconstructions because of the small numbers of patients included and as body mass index was not available for all patients. It would, however, be useful to carry out such a study with AIDR 3D as several publications have shown that iterative reconstructions produce variable and contradictory results depending on patient morphology [20,22]. Similarly, as this was a retrospective study, we did not have a record of the patient’s weight at their first scan and so we were not able to compare their weights between the two investigations to ensure that this had not changed significantly. Menke [26], however, has shown that measurements of anteroposterior and transverse abdominal diameters correlate with patient body morphology and particularly with body mass index.

The fact that these abdominal diameters did not change between the two scans in our study argues against a change in body morphology in our patients. Finally, the dose reduction found in our study only applies to abdominal CT scans performed on our scanner and using our protocol. Other studies are needed to assess the dose reduction for other reconstruction parameters, particularly with the “strong” setting, and also for other types of CT scan investigations, particularly chest and brain.

Conclusion

AIDR 3D iterative reconstructions can halve the radiation dose from an abdominal CT scan compared to standard FBP reconstructions whilst maintaining equivalent image quality. Further studies are needed to confirm the utility of iterative reconstructions in other types of CT scan investigations, particularly chest and brain.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References


