Adaptive iterative dose reduction (AIDR) 3D in low dose CT abdomen-pelvis: Effects on image quality and radiation exposure

W C Ang[1], S Hashim[1,2], M K A Karim[1, 3], N A Bahruddin[1], N Salehhon[1] and Y Musa[1]

[1] Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[2]Centre for Sustainable Nanomaterials (CSNano), Ibnu Sina Institute for Scientific and Industrial Research (ISI-SIR), Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
[3]Department of Diagnostic Imaging, National Cancer Institute, Precint 7, 62250 Putrajaya, Malaysia

E-mail: angelangweechin@yahoo.com

Abstract. The widespread use of computed tomography (CT) has increased the medical radiation exposure and cancer risk. We aimed to evaluate the impact of AIDR 3D in CT abdomen-pelvic examinations based on image quality and radiation dose in low dose (LD) setting compared to standard dose (STD) with filtered back projection (FBP) reconstruction. We retrospectively reviewed the images of 40 patients who underwent CT abdomen-pelvic using a 80 slice CT scanner. Group 1 patients (n=20, mean age 41 ± 17 years) were performed at LD with AIDR 3D reconstruction and Group 2 patients (n=20, mean age 52 ± 21 years) were scanned with STD using FBP reconstruction. Objective image noise was assessed by region of interest (ROI) measurements in the liver and aorta as standard deviation (SD) of the attenuation value (Hounsfield Unit, HU) while subjective image quality was evaluated by two radiologists. Statistical analysis was used to compare the scan length, CT dose index volume ($CTDI_{vol}$) and image quality of both patient groups. Although both groups have similar mean scan length, the $CTDI_{vol}$ significantly decreased by 38% in LD CT compared to STD CT (p<0.05). Objective and subjective image quality were statistically improved with AIDR 3D (p<0.05). In conclusion, AIDR 3D enables significant dose reduction of 38% with superior image quality in LD CT abdomen-pelvis.

1. Introduction

Radiation protection has been a prime concern due to globally increase use of computed tomography (CT) examinations in radio-diagnostic imaging. Although CT has the capability to provide more details for early detection of diseases, it has been considered as a major radiation source that contribute to cancer risk [1]. To overcome these cancer risks, improved version of hardware and software products have been developed by multiple CT manufacturers for dose reduction while maintaining optimal diagnostic image quality.

Moreover, implementation of iterative reconstruction (IR) with newly evolved algorithms was reintroduced in clinical CT imaging further facilitate better quality image with reduced radiation exposure to the patients. Several studies were performed using hybrid or full IR algorithms with iDose and iterative model reconstruction (IMR) from Philips Healthcare [2], iterative reconstruction in image space (IRIS) [3], sinogram affirmed iterative reconstruction (SAFIRE) [2], and advanced modeled iterative reconstruction (ADMIRE) [4] offered by Siemens Healthcare, adaptive statistical iterative reconstruction (ASIR) [2] and model-based iterative reconstruction (MBIR) [5] from GE Healthcare. The recent iterative reconstruction technology, adaptive iterative dose reduction three dimensional (AIDR 3D) unveiled by Toshiba Medical Systems was introduced for clinical use [6]. This advanced IR adopted a statistical noise model and a scanner model in its operation process, followed by image noise elimination which happened in the projection data in considering of photon starvation [6].

AIDR 3D is the successor to AIDR and it considerably reduced radiation dose, lowered image noise and increased signal to noise ratio (SNR) while having same diagnostic acceptability in CT chest as reported in previous literature [6]. However, potential of AIDR 3D in clinical abdominal-pelvic CT has not been addressed formally. According to our knowledge, AIDR 3D reconstruction would obtain good diagnostic image quality while low dose setting was used. Hence, the aim of our study was to compare the image quality and radiation dose between low dose (LD) scan with AIDR 3D reconstruction and standard dose (STD) with traditional filtered back projection (FBP) reconstruction in CT abdomen-pelvic examinations with the use of 80 multi-detector CT system.

2. Methodology

This study was carried out in a hospital located in Johor Bahru that equipped with a clinical grade CT scanner (Acquilion PRIME 80, Toshiba Medical Systems) for radiological diagnostic purpose. CT abdomen-pelvis examinations completed without contrast administration were retrieved from hospital PACS (Picture Archiving and Communication System) and anonymised prior to analysis for this study.

We retrospectively reviewed CT images performed in patients with a protocol using same tube potential of 120 kVp and different automatic tube current modulation (SURE Exposure 3D) noise index selection. According to the CT abdomen-pelvis protocol setting in the hospital, the noise index of 12.5 is applied for all 5 mm slice thickness of the soft tissue window (window width, 400 HU; window level, 40 HU) in LD scan and noise index of 10 is used in the STD scan. Other acquisition parameters are fixed: detector collimation = 100 × 0.5 mm, slice interval = 5 mm, rotation time = 0.5 s, beam pitch = 0.81 and reconstruction kernel FC18 at matrix size of 512 × 512. The CT images acquired in LD scan and reconstructed with AIDR 3D was categorized as group 1, while STD scan reconstructed using FBP was categorized as group 2.

All CT images were analysed on a dedicated medical image post-processing workstation (Myrian® 641.14.3, Intrasense). Measurement of image quality involved both objective and subjective criteria. Objective image quality was assessed by measuring the standard deviation (SD) of the attenuation value (HU) at the predefined ROIs in abdominal region as the image noise. In this study, circular 5 mm^2 ROIs were drawn in homogenous area at right lobe of liver and aorta in axial image located at the level of main portal vein [7]. Each ROI measurement was repeated three times and the mean value was taken. Subjective image quality evaluation involved two experienced radiologists in reading clinical CT abdomen-pelvis examinations. Image assessment criteria comprised of subjective image noise, image artifacts and overall diagnostic acceptability. Each image data set from group LD AIDR and group STD FBP was randomly displayed and reviewed directly without technical parameter, reconstruction technique and patient's information. The image quality rating is based on a qualitative five point likert scales (1=unacceptable; 2=suboptimal; 3=average; 4=good; 5=excellent) with no time restriction on viewing duration.

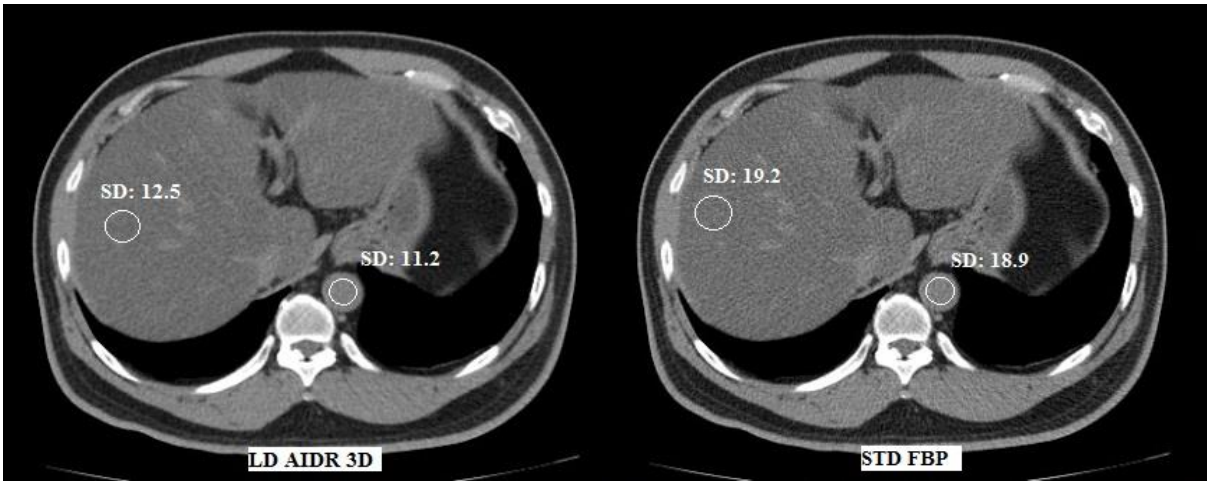
The radiation dose was evaluated by CT dose index volume ($CTDI_{vol}$), expressed in mGy which displayed on the CT console upon completion of the scan. The total scan length of each scan was recorded. Patient's demographic data including age, weight and height was also documented. The body mass index (BMI) of each patient was calculated as weight in kilograms (kg) divided by height in meter squared (m^2). Radiation dose, scan length and objective image noise, and scores for subjective image criteria obtained from LD AIDR 3D reconstruction were compared with STD FBP reconstruction. Statistical analysis was performed with commercially available statistical package SPSS version 23.0.

3. Results

In this study, the number of patients in LD AIDR (group 1) and STD FBP (group 2) were equal (20 patients in each group). The mean age, weight and height (± standard deviation) for group 1 patients was 41 ± 17 years, 59.03 ± 12.75 kg and 1.67 ± 0.03 m; 52 ± 21 years, 61.83 ± 13.53 kg and 1.68 ± 0.04 m for group 2 patients. Group 1 and group 2 patients had mean BMI (± standard deviation) of 20.99 ± 4.0 and 22.17 ± 4.61 respectively, ranging from minimum of 16.63 to the maximum 30.29.

3.1. Objective and subjective image quality

All CT abdomen-pelvis examinations included in the present study obtained diagnostic quality images. The objective image quality in mean SD of HU measured at liver and aorta were 12.95 ± 2.03 versus 18.61 ± 2.74 and 13.65 ± 1.99 versus 18.96 ± 3.58 respectively for LD AIDR 3D versus STD FBP. Significant lower objective image noise was achieved by AIDR 3D reconstruction as compared to FBP images (all, $p<0.05$) in spite of LD scan was performed (figure 1).



(a) (b)

Figure 1. Comparison of objective image quality reconstructed with (a) LD AIDR 3D and (b) STD FBP. The measured objective image noise at liver and aorta were lower in (a) with SD of 12.5 and 11.2, as compared to (b) with SD of 19.2 and 18.9, respectively. The image quality is markedly better in the LD AIDR 3D reconstruction than in the STD FBP reconstruction.

The rating results of subjective image quality by radiologists are shown in table 1. The lowest mean score ± standard deviation of 2.80 ± 0.38 was found in group 2 for subjective image noise criteria while the highest mean score ± standard deviation of 3.93 ± 0.29 was recorded in group 1 for image artifacts parameter. When compared to group 2, group 1 images scores showed significant reduced subjective image noise and artifacts by 32% and 28 % respectively. Overall diagnostic acceptability was considered good in both LD scan and STD scan with mean scores statistically higher in AIDR 3D images ($p<0.05$). The LD AIDR 3D images were superior to the STD FBP images in terms of all subjective criteria of image quality.

Table 1. Subjective image scores analysis.

Subjective criteria	Group 1 LD AIDR 3D	Group 2 STD FBP	p
Subjective image noise	3.70 ± 0.29	2.80 ± 0.38	
Image artifacts	3.93 ± 0.29	3.08 ± 0.44	<0.05
Overall diagnostic acceptability	3.78 ± 0.26	3.03 ± 0.26	

3.2. Scan length and radiation dose

The mean scan length ± standard deviation in group 1 patients was 47.3 ± 3.44 cm (range, 40-55 cm) and 46.83 ± 4.22 cm (range, 40.5-55 cm) in group 2 patients. No significant difference in mean scan length was found between the assessed patients in LD AIDR 3D and STD FBP protocols (p>0.05).

The mean $CTDI_{vol}$ ± standard deviation for LD CT and STD CT were 4.03 ± 0.95 mGy (range, 3.2-7.0 mGy) and 6.45 ± 1.49 mGy (range, 5.3-11.9 mGy), respectively. There was a significant dose reduction of 38% in group 1 when compared to group 2 (p<0.05). Figure 2 shows the distribution of scan length and $CTDI_{vol}$ in our study with horizontal lines indicate median, whiskers minimum and maximum values.

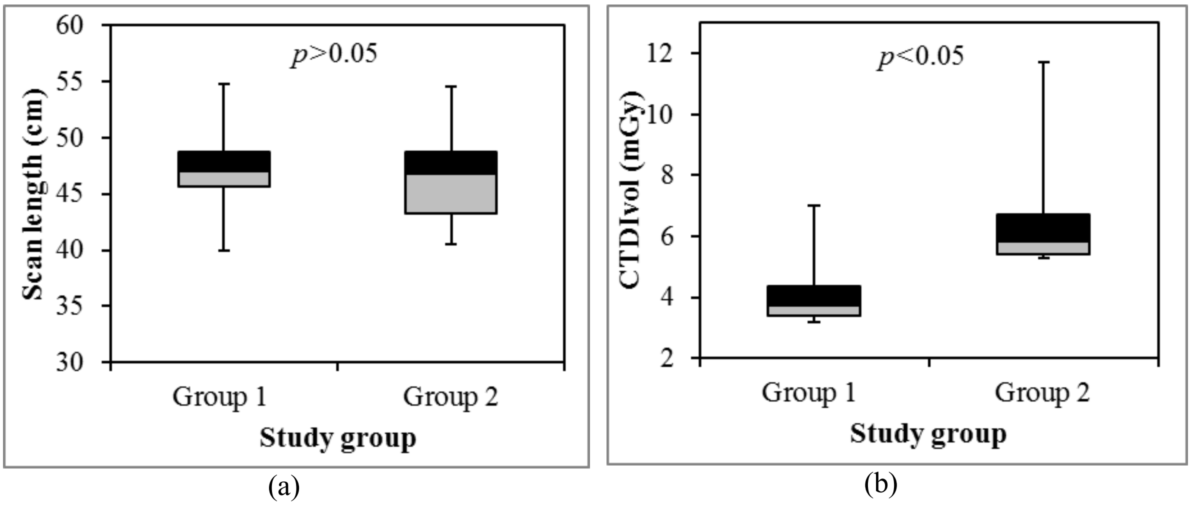


Figure 2. (a) Scan length of CT abdomen-pelvis in group 1-LD AIDR 3D and group 2-STD FBP were almost identical with p>0.05. (b) $CTDI_{vol}$ was significantly higher in group 2 as compared to group 1, p<0.05.

4. Discussion

Among all iterative reconstruction technologies in the CT market, AIDR 3D is a relatively new iterative reconstruction technique introduced by Toshiba Medical Systems. Although iterative reconstruction is considered as a new development in image processing, it has been long occurred and installed in the very first CT scanners [8]. Prior major limitation of iterative reconstruction on the reconstruction time had overcome by recent expedited computer technologies. Thus, the ultimate advantage of iterative reconstruction was known to process images with less noise than the FBP. Subsequently, reduced radiation dose could also be achieved without compromising image quality as demonstrated in previous phantom and patients studies [9-12].

In this study we analysed the effects of AIDR 3D in clinical low dose abdominal-pelvic CT image quality improvement and radiation dose reduction. Our results in the present study showed that application of AIDR 3D is useful in low dose CT abdomen-pelvis with consistently superior objective and subjective image quality as compared with FBP in STD scan. In addition, ROIs measurements of objective image noise in the two regions (liver and aorta) found an average 30% reduction of image noise using AIDR 3D reconstruction compared with images reconstructed with FBP specifically. These results are in line with prior researchers' finding where AIDR 3D greatly reduces image noise in LD CT protocol [6, 13, 14]. Since AIDR 3D is available in 3 settings (mild, standard and strong), it is expected that stronger AIDR 3D setting would provide more distinct image denoising effects than the AIDR 3D standard setting used in the current study. Therefore, further study should be involve different strength of AIDR 3D setting in various CT examinations.

Apart from objective image quality improvement with AIDR 3D, group 1 (LD AIDR 3D) image quality evaluation by radiologists demonstrated excellent subjective scores throughout the image noise, image artifacts and diagnostic acceptability criteria in the present study. It is worth to mention that none of the image is graded score value of 2 or less out of 5 in AIDR 3D images regardless the subjective parameters being assessed. In contrast, five cases out of 20 patients in group 2 (STD FBP) were rated as suboptimal image when considering the image noise and image artifacts subjectively. Accordingly, the diagnostic acceptability also quarterly decreased in group 2 images with FBP reconstruction. The results of our investigation extend the feasibility of AIDR 3D in obtaining remarkable better quantitative and qualitative image quality than Juri *et al.* and Gervaise *et al.* initial experiences on LD CT compared to routine dose CT [13, 15]. The benefits of AIDR 3D reconstruction not only removing unnecessary image noise and artifacts, it also indirectly eased the radiologists in making diagnosis without superimposition of noise on the anatomy of interests. However, diagnostic acceptability in this study does not represent diagnostic accuracy in detection of diseases and anatomical details. Hence, further study on the effects of AIDR 3D on diagnostic accuracy is required.

As above-mentioned, AIDR 3D attributed image noise and artifacts reduction. Thus, it is possible to use lower level acquisition parameters and therefore reduce the dose to the patients. In view of comparison analysis between LD AIDR 3D group and STD FBP group in the current study, it confirmed that significant less radiation dose as low as 3.2 mGy could have delivered in CT abdomen-pelvis by using AIDR 3D reconstruction. This positive finding is consistent with ALARA principle where radiation exposure as low as reasonably achievable should be applied in all ionizing radiation examinations without degrading image quality.

The average $CTDI_{vol}$ in the present study reduced from 6.45 ± 1.49 mGy to 4.03 ± 0.95 mGy, reaching 38% dose saving. Our results are in good agreement with William *et al.* study where 39% dose reduction was achieved by AIDR 3D in CT coronary angiography [16]. Similarly, a phantom study carried out by Joemai *et al.* established a calculated average dose reduction of 36% in order to maintain the low contrast detectability [17]. Although some study showed half dose delivered in CT abdomen-pelvis when low-dose AIDR 3D was used, CTDIvol obtained in this study was far less than 10.3 ± 3.6 mGy as stated in Gervaise et al. study [15]. Therefore, AIDR 3D can be a great tool in optimizing radiation exposure while increasing the image quality as image quality and diagnostic accuracy is often interrelated [18].

There were few limitations in our study reported here. First, this was a single centre study and had a relatively small sample size in each group. We included these patients retrospectively in order to avoid additional irradiation to the patients that would have resulted from performing a prospective study. Accordingly, the number of patients was limited for this preliminary results. However, future studies of a larger sample size must be conducted to confirm our results. Second, we only evaluated CT abdomen-pelvis on the CT unit used for our study with specific low dose and standard dose settings at different reconstructions. This study concept could also be adopted and extended to other imaging protocols and CT units made by other manufacturers in future research.

5. Conclusion

Our study demonstrated that there was 38% dose reduction in LD CT protocols compared to STD CT. Moreover, by using AIDR 3D reconstruction in LD CT, considerable improvement in objective and subjective image quality which was superior to STD FBP reconstruction in spite of lower radiation dose. AIDR 3D reconstruction is a promising CT dose optimization tool that benefit clinical CT imaging by producing excellent image quality at low dose exposure to the patients.

6. References

[1] De Gonzalez A B, Mahesh M, Kim K P, Bhargavan M, Lewis R, Mettler F and Land C 2009 *Arch. Intern. Med.* **169** 2071-77
[2] Love A, Olsson M L, Siemund R, Stalhammar F, Bjorkman-Burtscher I M and Soderberg M 2013 *Br. J. Radiol.* **86** 20130388
[3] Bittencourt M S, Schmidt B, Seltmann M, Muschiol G, Ropers D, Daniel W G and Achenbach S 2011 *Int. J. Cardiovasc. Imaging* **27** 1081-87
[4] Gordic S, Desbiolles L, Stolzmann P, Gantner L, Leschka S, Husarik D B and Alkadhi H 2014 *Clin. Radiol.* **69** 497-504
[5] Pickhardt P J, Lubner M G, Kim D H, Tang J, Ruma J A, Del Rio A M and Chen G H 2012 *AJR. Am. J. Roentgenol.* **199** 1266
[6] Yamada Y, Jinzaki M, Hosokawa T, Tanami Y, Sugiura H, Abe T and Kuribayashi S 2012 *Eur. J. Radiol.* **81** 4185-95
[7] Kim J H, Kim M J, Kim H Y and Lee M J 2014 *Clin. Imaging* **38** 710-4
[8] Fleischmann D and Boas FE 2011 *Eur. Radiol.* **21** 510-7
[9] Hara A K, Paden R G, Silva A C, Kujak J L, Lawder H J and Pavlicek W 2009 *AJR. Am. J. Roentgenol.* **193** 764-71
[10] Sagara Y, Hara A K, Pavlicek W, Silva A C, Paden R G and Wu Q 2010 *AJR. Am. J. Roentgenol.* **195** 713-9
[11] May M S, Wüst W, Brand M, Stahl C, Allmendinger T, Schmidt B, Uder M and Lell MM 2011 *Invest. Radiol.* **46** 465-70
[12] Pontana F, Pagniez J, Flohr T, Faivre J B, Duhamel A, Remy J and Remy-Jardin M 2011 *Eur. Radiol.* **21** 627-35
[13] Juri H, Matsuki M, Itou Y, Inada Y, Nakai G, Azuma H and Narumi Y 2013 *J. Comput. Asist. Tomogr.* **37** 52-7
[14] Matsuki M, Murakami T, Juri H, Yoshikawa S and Narumi Y 2013 *Acta Radiol.* **54** 869-75
[15] Gervaise A, Osemont B, Louis M, Lecocq S, Teixeira P and Blum A 2014 *Diagn. Interv. Radiol.* **95** 47-53
[16] Williams M C, Weir N W, Mirsadraee S, Millar F, Baird A, Minns F, Uren N G, McKillop G, Bull R K, Van Beek E J and Reid J H 2013 *Clin. Radiol.* **68** 570-7
[17] Joemai R M, Veldkamp W J, Kroft L J, Hernandez-Giron I and Geleijns J 2013 *AJR. Am. J. Roentgenol.* **201** 1291-7
[18] Dewey M *et al.* 2010 *AJR. Am. J. Roentgenol.* **194** 93

Acknowledgements

The authors would like to express their appreciation for the support of the Research University Grant Scheme with Project No Q.J130000.2517.13H39 and MyMaster MyBrain15 Scholarship.