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Determination of a suitable low dose abdominopelvic CT protocol using model based iterative reconstruction through cadaveric study

Abstract

Objective

Cadaveric studies provide a means of safely assessing new technologies and optimising scanning prior to clinical validation~~use~~. Reducing radiation exposure in a clinical setting ~~usually requires~~can entail ~~small~~ incremental dose reductions to avoid missing important clinical findings. The use of cadavers allows assessment of the impact of more substantial dose reductions on image quality. Our aim was to identify a suitable low dose abdominopelvic CT protocol for subsequent clinical ~~use~~validation.

Methods

Five human cadavers were scanned at one conventional dose and three low dose settings. All scans were reconstructed using three different reconstruction algorithms: filtered back projection (FBP), hybrid iterative reconstruction (60% FBP and 40% adaptive statistical iterative reconstruction (ASIR40)), and model-based iterative reconstruction (MBIR). Two readers rated the image quality both quantitatively and qualitatively.

Results

MBIR reconstructions had significantly better objective image noise and higher qualitative scores compared with both FBP and ASIR40 reconstructions at all dose levels. The greatest absolute noise reduction, between MBIR and FBP, of 34.3 HU (equating to a 68.1% reduction) was at the lowest dose level. MBIR reduced image noise and improved image quality even in CT images acquired with a mean radiation dose reduction of 62.2% compared with conventional dose studies reconstructed with

ASIR40, with lower levels of objective image noise, superior diagnostic acceptability and contrast resolution, and comparable subjective image noise and streak artifact scores.

Conclusion

This cadaveric study demonstrates that MBIR reduces image noise and improves image quality in abdominopelvic CT images acquired with dose reductions of up to 62%.

Keywords

Abdominopelvic; Tomography, X-ray Computed; Cadaver; Iterative reconstruction; Radiation exposure

Introduction

There has been an exponential increase in the use of computed tomography (CT) in recent years with CT currently imparting more than 50% of all radiation exposure from diagnostic imaging[1]. The relationship of radiation exposure from diagnostic imaging to a quantifiable risk of cancer induction remains a controversial topic. However, protracted exposure to low-level ionising radiation is widely believed to be associated with an increased risk of malignancy[2-4] and dose optimisation without loss of diagnostic performance is essential to good practice when performing CT. Abdominopelvic CT accounts for 50% of total CT collective dose[5] in many patient cohorts, and dose reduction strategies in this area will therefore have a significant impact on the overall population dose from diagnostic imaging.

Potential dose reduction techniques that may be employed when performing abdominopelvic CT include automatic exposure control[6], low tube voltage techniques[7], scan range control[8], and adaptive collimation[9]. Some of ~~T~~these strategies are limited by a resultant increases in image noise and ~~resulting~~ reduced image quality especially with traditional analytical reconstruction algorithms such as filtered back projection (FBP). Advanced iterative reconstruction (IR) algorithms that reduce image noise facilitating the generation of diagnostic quality images at reduced radiation doses have received much attention in the literature recently[10-12]. IR techniques create a set of synthesized projections by accurately modelling the data collection process in CT. The model incorporates statistical information of the CT system including photon statistics and electronic acquisition noise to reduce image noise[13].

Hybrid iterative reconstruction techniques such as adaptive statistical iterative reconstruction (ASIR) (GE Healthcare, GE Medical Systems, Milwaukee, USA) is one such method that may be blended with FBP to reduce noise while preserving image quality and the familiar appearance of traditional FBP-reconstructed images. ASIR is ~~the most ~~a commonly studied iterative algorithm in abdominopelvic CT ~~to date ~~with studies reporting dose reductions ~~in the order of~~from 2~~5~~4% to 74% with preserved image quality and diagnostic value[14-17].

~~More r~~Recently, more computationally intense pure IR algorithms such as model-based iterative reconstruction (MBIR) (Veo) (GE Healthcare, GE Medical Systems, Milwaukee, USA) have become commercially available. In addition to incorporating modelling of photon and noise statistics, pure IR algorithms such as MBIR use a more complex system of prediction models including modelling of optic factors such as tube and detector response, and the exact geometric features of the focal spot, CT cone beam and absorbing voxels[18]. It is ~~necessary~~preferable, however, to evaluate the diagnostic quality of images reconstructed with MBIR before availing of the potential dose reductions it is purported to provide. These data would also be informative for the development of low dose scanning protocols in the clinical setting, which would likely assist in the granting of ethical approval.~~introduction of the technique into widespread clinical practice.~~

Several strategies may be used to compare the efficacy of reconstruction techniques in noise reduction including technical and anthropomorphic phantoms[19, 20] the split-dose technique or the artificial addition of image noise to conventional dose images to simulate low dose images[21]. Technical and anthropomorphic phantoms provide a safe, objective and reproducible method of assessing the image quality of different reconstruction algorithms over a range of radiation dose levels. Preliminary phantom experiments with MBIR report a significant reduction in image noise and streak artifact, with significant improvements in image quality compared to FBP and ASIR[22, 23].

Many phantom models do not accurately reflect the complex relationship that exits between anatomical variability and image quality, and results of phantom studies may not be entirely applicable to the clinical setting. However, patient studies to assess the performance of reconstruction algorithms at different dose levels can often be problematic to implement, as imaging large numbers of patients at different dose settings introduces confounding factors in addition to ethical challenges. To date, clinical studies assessing the use of MBIR in abdominopelvic CT are limited[22, 24].

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The use of radiological images acquired from cadavers for research[23], teaching[25], and training[26] purposes has been well described in the literature. Cadavers also provide an excellent model with which to compare reconstruction algorithms by facilitating the repeated scanning of one subject over a range of radiation dose settings without movement artefact or dose concerns. This method has been used in thoracic CT imaging to demonstrate maintenance of acceptable image quality despite 82% dose reduction using MBIR[27]. To the best of our knowledge, this is the first study to assess the image quality of cadaveric abdominopelvic CT scans reconstructed with MBIR.

The aim of this study was to use cadaveric imaging to determine ~~the dose range at which MBIR~~if MBIR improved image quality compared with ASIR and FBP, to~~he~~ quantify the extent of this improvement and to assess if there was a benefit to MBIR over conventional methods for low dose image reconstruction. ~~had the greatest efficacy for noise reduction while maintaining acceptable image quality. These data will provide essential information that will help guide the development of safe protocols which are~~

~~more likely to be granted ethical approval for validation trialsperformance of reduced dose CT using MBIR~~.

Methods

Subjects

The study was conducted under the auspices of a ‘License to Practice Anatomy’ granted to the Chair of the Department of Anatomy and Neuroscience of our institution under the Anatomy Act 1832. Donors premorbidly signed written consent for the use of their bodies for the purposes of education and research. Five human cadavers (4 male, 1 female) were included in the study. The median time from death to CT scanning was 38 days (range, 8 to 180). The cadavers were fresh frozen at -4°C and thawed for the purpose of the study as per standard practice. Cadaver body-mass index (BMI) was not measured directly but was estimated from effective diameter measurements taken from the CT images and the regression equation in the Boos et al 2016 study[28]; mean cadaver BMI was estimated to be 30kg/m^2.

CT technique

All subjects were scanned with a 64-slice GE Discovery 750HD CT scanner (General Electric Healthcare, Waukesha, WI, USA). Each cadaver was scanned without intravenous or oral contrast in the supine position enclosed in a body bag without any metallic fasteners. Scans were performed with the arms by the side~~ to minimise cadaver manipulation.~~due to the affects of rigor mortis.

The protocol was employed with varying tube voltage (kV) and current (mA) settings of 80kV/225mA, 120kV/100mA, 100kV/225mA, and 120kV/200mA; the resultant CTDI$_{vol}$~~, resulting in mean ~~, mean dose length products (DLP~~)/~~) and mean size specific dose estimates (SSDE) ~~of 238.7±12.41mGy.cm/5.36~~4~~±0.62mGy, 315.5~~6~~±16.4mGy.cm /7.09~~1~~±0.82mGy, 447.2±23.35mGy.cm /10.04±1.16~~2~~mGy and 630.9~~1~~±3~~3~~2.7mGy.cm/14.17~~2~~±1.64mGy respectively. ~~can be seen in Table 1. T~~T~~he radiation exposure resultant from the CT localizer radiographs was excluded from the dose calculations.

The 120kV/200mA protocol was used as a reference conventional dose (CD) protocol following a review of the radiation dose of 100 standard abdominopelvic CT studies performed at our institution (mean DLP of 640~~.4~~±27~~2.8~~3mGy.cm). The 80kV/225mA, 120kV/100mA, and 100kV/225mA low dose protocols were given the names low dose 1 (LD1), low dose 2 (LD2), and low dose 3 (LD3), respectively. The gantry rotation time (0.8 seconds), collimation (40 x 0.62mm), pitch factor (0.98), and slice thickness (0.625 mm) were kept constant for all acquisitions.

CT image reconstruction

All images were reconstructed from the raw-data acquisitions. Each cadaver was scanned at four different dose levels as detailed above and each of these data sets was reconstructed using three different reconstruction techniques: filtered back projection; our standard departmental reconstruction technique, hybrid iterative reconstruction (60% FBP and 40% ASIR), labelled ASIR40; and pure iterative reconstruction (MBIR), resulting in a total of 12 series per cadaver. Images were reconstructed from an acquisition thickness of 0.625mm to a final slice thickness of 1.25mm for all series.

Quantitative analysis of image noise

Objective image quality analysis was performed independently on a dedicated workstation (Advantage Workstation VolumeShare 2, Version 4.4, GE Medical Systems, Milwaukee, WI) by two operators (FM, 5 years experience and DF, 1 year experience). Attenuation values in Hounsfield units (HU) were measured at five levels using circular regions of interest (ROIs) ~~histograms~~ of equal size (diameter 10mm). The ~~regions of interest (~~ROIs~~)~~ were placed in the following anatomical structures: most superior portion of liver parenchyma just inferior to ~~liver parenchyma at~~ the level of the right hemi-diaphragm; liver parenchyma at the level of the porta hepatis; erector spinae at the right renal hilum; psoas muscle at the iliac crest; and gluteus maximus muscle at the roof of the acetabulum. The ROIs were placed in as homogenous an area as possible, taking care to avoid fat planes and blood vessels. The standard deviation of the mean attenuation in the ROI served as an objective measure of image noise[29]. The signal-to-noise ratio (SNR) of each ROI was calculated by dividing the mean HU by its standard deviation[30]. Each operator took measurements independently and the mean measurement was used for analysis. The operators were blinded to the scanning protocol and reconstruction technique used and the order of the series was randomized.

Qualitative analysis

Subjective image quality assessment was performed independently on the Advantage Workstation by two readers (FM, 5 years experience and MT, 6 years experience). Subjective image noise, diagnostic acceptability, and contrast resolution were graded on a 10-point scale at 5 anatomical levels: right hemi-diaphragm, porta hepatis, right renal hilum, iliac crest, and roof of the acetabulum. Image noise was graded as acceptable (score of 5) if average graininess was seen with satisfactory depiction of small anatomical structures such as blood vessels and tissue interfaces, unacceptable (score of 1) if graininess interfered with structure depiction, and excellent (score of 10) if there was no appreciable mottle. Diagnostic acceptability was graded as acceptable (score of 5), unacceptable (score of 1), or excellent (score of 10) if depiction of solid organs, large bowel, small bowel, peri-colonic fat, and peri-enteric fat for diagnostic interpretation and degree of image degradation by beam hardening artifacts was satisfactory, unsatisfactory or considerably superior, respectively. Contrast resolution was also graded at the liver, spleen and buttock musculature using a 10-point scale in which a score of 10 represented superior contrast between different abdominal soft tissues, a score of 1 indicated the poorest contrast, and a score of 5 indicated acceptable contrast. Streak artifact was also graded at each level using a 3-point scale: 0, no streak artifact present; 1, streak artifact present but not interfering with image interpretation; and 2, streak artifact present and interfering with image interpretation.

The parameters of image quality were selected on the basis of previous studies and the *European Guidelines on Quality criteria for Computed Tomography* [31, 32]. The authors had used these methods previously and trained the other readers before analysis with a set of 5 practice scans[33]. The order of the data sets was randomized and the readers were blinded to the scanning protocol and reconstruction technique. The readers used a combination of axial and coronal reformats for interpretation and altered the CT level and window width at their discretion.

Statistical analysis

Data was exported from Microsoft Office Excel 2010 (Microsoft Corporation, CA, USA) into GraphPad Prism version 6.0 (GraphPad Software Incorporated, San Diago, USA) and Statistical Package for the Social Sciences (SPSS) version 22 (IBM, Chicago, Illinois, USA) for further analysis. Distribution of variables was assessed using D'Agostino-Pearson omnibus normality test. Inter-observer concordance was assessed with Cohen's k test.

Two-way analysis of variance was used to compare three or more groups of parametric indices. Tukey's multiple comparisons test was used to assess differences between reconstruction techniques at each dose level for quantitative and qualitative parameters. Mean differences between reconstruction algorithms and their 95% confidence intervals were calculated at each dose level. Percentage noise and dose reduction compared with FBP and ASIR40 was determined for the MBIR data sets. Dunnett's test was used to compare the quantitative and qualitative parameters of the low dose MBIR series with CD ASIR40 series. P values less than 0.05 were considered to be statistically significant.

Results

Quantitative analysis of image noise

Objective image noise was significantly different at each dose level (p<0.0001) and between each reconstruction algorithm at every dose level (p<0.0001 for all comparisons) with the greatest levels of image noise at LD1 (Figure 1a). MBIR reconstructions had significantly lower measures of objective image noise compared with both FBP and ASIR40 reconstructions at all dose levels (p<0.0001 for all comparisons) with the greatest mean difference observed for both at the LD1 level; mean differences of 34.~~26~~3HU (CI, 30.~~19~~2 to 38.~~35~~4) and 20.~~5~~6HU (CI, 16.~~47~~5 to 24.6~~4~~) compared with FBP and ASIR40, respectively.

MBIR facilitated percentage noise reductions of 68.1%, 69.2%, 61.02%, and 65% compared with FBP and 56.2%, 57.9%, 52.6%, and 56.6% compared with ASIR40 at the LD1, LD2, LD3, and CD levels, respectively.

SNR for MBIR data sets was significantly higher than both FBP and ASIR40 data sets at each dose level (p<0.0001) with the greatest mean difference compared with FBP at LD2 (2.6~~2~~ (CI, 1.~~6~~7 to 3.~~5~~6)) and compared with ASIR40 at CD (2.~~26~~3 (CI, 1.3 to 3.2)) (Figure 1b). No significant difference was observed in SNR between FBP and ASIR40 data sets at all dose levels.

Qualitative analysis

There was excellent agreement between the two raters for the assessment of diagnostic acceptability and presence of streak artifact (k, 0.824 and 0.868, p<0.001) with moderate agreement for the assessment of subjective image noise and contrast resolution (k, 0.795 and 0.623, p<0.001). Using mean scores for further analysis it was shown that subjective image noise, diagnostic acceptability, and contrast resolution scores were significantly different between each reconstruction algorithm at each dose level (p<0.0001 for all comparisons).

MBIR reconstructions had significantly higher qualitative scores compared with both FBP and ASIR40 reconstructions at all dose levels (p<0.0001 for all comparisons) with the greatest mean differences observed for all qualitative measures at the LD1 level (Figures 2, 3 and 4) . Figure 5 is an example of the images obtained following reconstruction with FBP, ASIR and MBIR at the LD1 dose level (80kV, 225mA).

MBIR reconstructions had significantly lower levels of streak artifact compared with FBP (p<0.001) and ASIR40 (p<0.01) at the lowest dose level only (LD1). All other comparisons were non-significant (Figure 6).

No statistically significant difference in image noise or SNR was seen between the MBIR reconstructed images at the various dose levels (Figures 1 and 2). An example of the MBIR reconstructed images at the four dose levels can be seen in Figure 7.

Comparison of low dose MBIR with conventional dose ASIR40

Our standard practice currently is to use conventional dose ASIR40 in the clinical setting. LD MBIR series were acquired with a mean dose reduction compared with CD ASIR40 of 62.~~17~~2%, 50%, and 29.1~~2~~% for LD1 MBIR, LD2 MBIR, and LD3 MBIR series, respectively. All LD MBIR reconstructions had significantly lower levels of objective image noise compared with the CD ASIR40 protocol (p<0.0001 for all comparisons).

All low dose MBIR series and conventional dose ASIR40 series had above average to excellent subjective image noise, diagnostic acceptability, and contrast resolution scores.

Diagnostic acceptability and contrast resolution scores were superior for all LD MBIR series compared with CD ASIR40 ($p<0.0001$ for all comparisons). LD2 MBIR and LD3 MBIR had superior subjective image noise scores compared with CD ASIR40 ($p<0.0001$ for both comparisons) with no significant difference in subjective image noise between LD1 MBIR and CD ASIR40 reconstructions (Figure 2). Streak artifact was similar between all of the LD MBIR and the CD ASIR40 reconstructions (Figure 6) with no statistically significant difference observed.

Discussion

Iterative reconstruction algorithms serve to improve image quality by noise reduction and improved spatial resolution over filtered back projection. Blending ASIR with FBP is less computationally intense than MBIR, modelling only photon and electronic noise statistics in order to reduce computational time. MBIR incorporates modelling of certain parameters previously omitted from blended or hybrid iterative reconstruction algorithms. These include a system model that addresses the nonlinear, polychromatic nature of x-ray tubes by modelling the photons in the data set, a statistical noise model that considers the focal spot and detector size, and a prior model that corrects unrealistic situations in the reconstruction process to decrease the computational time[34]. The incorporation of system optic information enables reductions in image noise and artifacts with improvements in spatial resolution. The major limitation of these additional data processing steps is the prolonged reconstruction time required (45 minutes in one series[35]), compared with FBP and ASIR, and *although this may preclude its use in the emergency setting, it is unlikely to be a significant issue for most routine abdominopelvic CT examinations. Reconstruction times were many hours for such examinations only a few years ago. With improved computational efficiency reconstruction times will likely continue to improve and allow MBIR to be used in all clinical settings. Anecdotally it was been noted that greater dose reductions required longer reconstruction times.*~~although this may preclude its use in the emergency setting, it is unlikely to be a significant issue for most routine abdominopelvic CT examinations. With improved computational efficiency, this time will likely reduce significantly and allow MBIR to be used in all clinical settings.~~

MBIR has been shown to reduce image noise and improve image quality at conventional dose levels compared with~~to~~ both FBP and ASIR[13, 18]. The utility of MBIR at preserving image quality at lower radiation dose levels has also been investigated. ~~Many studies have demonstrated ~~S~~s~~uccessful use of MBIR in chest CT has been demonstrated with reported~~ing~~ dose reductions of up to 79% with~~and~~ preserved image quality[36]. However, few studies have investigated the utility of MBIR in abdominopelvic CT[22, 24] or the dose range at which MBIR has the greatest efficacy for noise reduction.

In the present paper~~our study~~, MBIR datasets had significantly lower levels of objective image noise compared with both FBP and ASIR40 at both conventional and low dose levels with the greatest absolute noise reduction observed at the lowest radiation dose level. A similar finding was observed for the qualitative indices with the greatest improvement in image quality also observed at the lowest dose level. In addition, MBIR significantly reduced streak artifact at the lowest dose level only.

Compared with ~~our current~~the ~~standard~~ conventional dose CT protocol reconstructed with ASIR40, MBIR facilitated the acquisition of images with lower levels of image noise, higher diagnostic quality and contrast resolution scores, and comparable subjective image noise and streak artifact scores, while enabling a 62% dose reduction. Findings suggest that the greatest utility of MBIR in abdominopelvic CT is reduced image noise which helps maintain image quality in spite of low radiation dose acquisition, thus enabling the creation of diagnostic quality studies at substantially reduced radiation doses.

Cadaveric study has been used in the past to assess CT dose optimization in chest[27, 37, 38] and orthopaedic CT[39, 40], however this is the first multi-specimen cadaveric study in the literature to assess radiation dose optimization in abdominal CT. A cadaver more closely simulates actual body composition than a phantom and ethical concerns over live human radiation dose experiments are not present with cadaveric study. A further advantage of cadaveric study is the ability to utilize cadavers of different body habitus; with a phantom study this would involve acquiring multiple (often very expensive) CT phantoms. Cadaveric study allows experimentation with a near perfect simulation for live human tissue and allows the use of multiple different radiation exposures to assess for differences in radiation dose and image quality. Decreasing radiation dose in clinical studies ~~in live humans~~ introduces a risk to patients regarding suboptimal images leading to impaired diagnostic confidence of the radiologist and therefore these studies often use small increments of radiation reduction to minimize this. With cadaveric study,

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large reductions in radiation dose can be instituted and ~~the~~ images assessed for quality without ~~the same~~ concerns over missed diagnosis. This type of study also obviates additional radiation exposure to a patient, which may occur due to additional research scanning or from the requirement for repeat scanning due to *insufficient diagnostic confidence in the original images. Having confirmed the ability of MBIR to maintain image quality in a low-dose setting, the present results help support ethical applications to allow validation of these methods of radiation dose reduction in clinical practice.*~~decreased diagnostic confidence from the original images. Having confirmed the ability of MBIR to maintain image quality in the low-dose setting, we can now confidently set up CT protocols with markedly reduced radiation dose to confirm the applicability of these findings to clinical practice.~~

MBIR ~~reconstructed~~ images have an impasto appearance different to FBP- and lower percentages of blended ASIR/FBP-reconstructed images[14]. Initial studies of ASIR also reported a similar phenomenon[41], but partial blending with FBP and further technological advancements in the algorithm have minimized this effect. Other studies have reported new artifacts in MBIR ~~reconstructed~~ images such as a ‘staircase effect’ at bone interfaces and a ‘bordering blacked-out artifact’ on skin surfaces[18]. Although these artifacts were visible in all planes, predominantly on axial reformations, the overall effect on image quality was deemed to be minor. In the present paper, the readers were familiar with the altered appearance of MBIR ~~reconstructed~~ images and believed this phenomenon did not interfere with diagnostic acceptability and was minimized in the coronal plane.

~~We recognize the~~The limitations of this study are recognised~~our study~~. ~~We studied the~~ I~~i~~mage quality characteristics of abdominopelvic CT scans reconstructed with three different reconstruction algorithms were studied. A~~n a~~ssessment of the utility~~ability~~ of MBIR~~ reconstructed~~ images ~~to detect~~for the detection ~~-~~and characterization~~e~~ of pathological findings was not made and further clinical studies are required to validate its diagnostic ability. Cadavers were scanned with ~~the ~~arms by their sides ~~and this may have resulted in~~in which had potential to ~~-~~decrease~~d~~ overall image quality compared with clinical image datasets; nonetheless, ~~we feel that ~~comparison between ~~the ~~different ~~reconstruction~~reconstruction algorithms on the same cadavers should remain~~remains~~ valid. ~~C~~

Evaluation of the impact of MBIR on contrast resolution of liver and other solid organs following intravenous contrast administration was not possible. ~~Furthermore, cadaveric imaging precludes the administration of intravenous and oral contrast media.~~ Low dose clinical images reconstructed with MBIR have not been deemed adequate for the assessment of solid organ lesions but adequate for assessment of retroperitoneal adenopathy or acute complications of Crohn's disease. It is important therefore to emphasise that the use of cadaveric imaging should only be undertaken if it provides an appropriate substitute for clinical imaging. Quantitative analysis needs to be supplemented with a qualitative assessment of image acceptability in the anticipated application. Although cadaveric imaging may show promise, validation through careful conducted clinical studies remains essential.

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Previous clinical studies using intravenous and oral contrast have reported a reduction in streak artifact with the use of MBIR[13, 18]. In the present paper reduced streak artifact was only observed on MBIR images compared with alternative reconstruction techniques at the lowest dose level only. This suggests that the improved performance of MBIR for streak artefact removal occurs mainly in the low dose setting. This will require further assessment. ~~This is particularly relevant to the assessment of streak artifact. Also, evaluation of the impact of pure IR on contrast resolution of liver and other solid organs post contrast was not possible; it is important to acknowledge this as this is a vital factor in abdominal imaging. Previous clinical studies using intravenous and oral contrast have reported a reduction in streak artifact with the use of MBIR[13, 18]. However, in the present paper reduced streak artifact was only observed in MBIR-reconstructed images at the lowest dose level only, indicating a possible under evaluation of the ability of MBIR to reduce streak artifact in our study.~~ Furthermore, due to the inherent difference in the appearance of MBIR~~ reconstructed~~ images described above, readers may have not been completely blinded to the reconstruction algorithm during subjective analysis. ~~However, blinding to the imaging protocol was satisfactory.~~ Finally, the results of our study may not be completely applicable to pure iterative reconstruction algorithms available from other venders and independent validation of these techniques would~~may also~~ be required.

Conclusion

In conclusion, this cadaveric study demonstrates that MBIR can facilitate the acquisition of abdominopelvic CT scans with lower levels of image noise and greater image quality compared with conventional dose images reconstructed with FBP or ASIR40, while enabling ~~up to 62%~~significant radiation dose reduction. These data will provide essential information that will help guide the development of safe protocols which are more likely to be granted ethical approval for the purposes of clinical validation.~~Further analysis of low dose imaging reconstructed with MBIR will focus on the clinical utility of MBIR at this dose range.~~

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Table & Figure Legend

Table 1.

CTDI$_{vol}$, DLP and SSDE for each of the different CT protocols

Figure 1.

a) Variation in objective image noise and b) SNR with choice of reconstruction algorithm at each low dose (LD) and conventional dose (CD) protocol. Data are plotted as mean and standard deviation. FBP (filtered back projection); ASIR40 (40% adaptive statistical iterative reconstruction); MBIR (model based iterative reconstruction).

Figure 2.

Variation in subjective noise scores with choice of reconstruction algorithm at each low dose (LD) and conventional dose (CD) protocol. Data are plotted as mean and standard deviation. FBP (filtered back projection); ASIR40 (40% adaptive statistical iterative reconstruction); MBIR (model based iterative reconstruction).

Figure 3.

Variation in diagnostic acceptability scores with choice of reconstruction algorithm at each low dose (LD) and conventional dose (CD) protocol. Data are plotted as mean and standard deviation. FBP (filtered back projection); ASIR40 (40% adaptive statistical iterative reconstruction); MBIR (model based iterative reconstruction).

Figure 4.

Variation in contrast resolution scores with choice of reconstruction algorithm at each low dose (LD) and conventional dose (CD) protocol. Data are plotted as mean and standard deviation. FBP (filtered back projection); ASIR40 (40% adaptive statistical iterative reconstruction); MBIR (model based iterative reconstruction).

Figure 5.

An example of the images obtained through FBP, ASIR and MBIR reconstructions at the LD1 dose level (80kV, 225mA).

Figure 6.

Variation in streak with choice of reconstruction algorithm at each low dose (LD) and conventional dose (CD) protocol. Data are plotted as mean and standard deviation. FBP (filtered back projection); ASIR40 (40% adaptive statistical iterative reconstruction); MBIR (model based iterative reconstruction).

Figure 7.

An example of the MBIR reconstructed images at the four dose levels CD, LD1, LD2 and LD3.