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Enhancement of abdominal Low-Dose CT image quality utilizing Clear View reconstruction technique at Mzuzu Central Hospital, Malawi

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Abstract

Objective

This study aimed to investigate the impact of Clear View dual-domain iterative reconstruction (IR) technology on the quality of low-dose abdominal CT images and to determine the optimal weight ratio to optimize image quality.

Methods

We studied 40 patients (28 males, 12 females, aged 19-69) undergoing low-dose abdominal CT scans (CTDI = 5.32 ± 0.89 mGy). The scanning parameters were set as follows: tube voltage of 120 kVp, tube current modulation based on Signal to Noise Ratio (SNR) at 0.5 mode (O-Dose automatic tube current modulation technology), pitch of 0.9, rotation time of 0.6 s/r, matrix size of 512 × 512, and collimation width of 16 × 1.25 mm. We applied Clear View IR with four weight ratios (20%, 40%, 60%, 80%) and filtered back projection (FBP). Conventional scanning uses with 120 kVp, 280 mAs, pitch of 0.9, rotation time of 0.6 s/r, matrix size of 512 × 512, and collimation width of 16 × 1.25 mm. Conventional dose abdominal CT scans (CTDI = 11.95 ± 0.00 mGy).CT values, standard deviations (SD), signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR) were measured for liver, spleen, pancreas, kidneys, and erector spinae muscles. Two deputy chief physicians blindly evaluated image quality on a 1-5 scale. Statistical analysis was done using SPSS 22.0 with $P < 0.05$ considered significant.

Results

Subjective evaluations revealed the highest diagnostic score with a 40% Clear View reconstruction weight ratio. Higher weight ratios significantly reduced subjective image noise, with the highest noise scores at 80%. Moreover, compared to FBP, especially Clear View reconstruction weight ratios of 20% to 60%, significantly improved the image quality of abdominal solid organs, reducing image artifacts and improving diagnostic acceptability ($P < 0.05$). Objective evaluation showed that with increasing Clear View reconstruction weight ratios, image noise SD values decreased, while SNR and CNR values increased, and the differences in SD, SNR, and CNR for different reconstruction weight ratios of abdominal solid organs were statistically significant ($P < 0.05$).

Conclusion

Compared to FBP algorithm, Clear View demonstrates greater potential in low-dose abdominal CT, effectively reducing image noise and artifacts while maintaining image clarity. Based on combined subjective and objective evaluations, a 40% Clear View reconstruction weight ratio provides optimal image quality for abdominal solid organs.

Keywords: Clear View dual-domain IR technology; abdomen; image quality; image noise; Computed Tomography

Introduction

In recent years, computed tomography (CT) imaging has played a crucial role in screening and diagnosing abdominal diseases, owing to its high resolution and accuracy, making it a key tool for physicians in disease assessment and treatment planning[1]. Abdominal CT scans are renowned for their coverage of vital organs and extensive scan range, potentially exposing patients to relatively high risks of radiation-related diseases[2]. Therefore, investigating post-processing optimization strategies to simultaneously reduce patient radiation dose while enhancing abdominal image quality holds significant clinical value[3].

Previous studies on low-dose abdominal CT imaging often employed techniques such as tube current modulation, automatic exposure control, and automatic tube voltage modulation[4]. However, research suggests that these methods may result in increased noise levels and decreased image quality. While filtered-back projection (FBP) has long been considered the "gold standard" for CT image reconstruction, its effectiveness in low-dose CT scanning is limited due to issues such as excessive noise, significant artifacts, and unclear image details[5]. Efforts to reduce radiation dose during examinations may directly impact image quality. Therefore, striking a balance between reducing radiation dose and meeting diagnostic requirements remains a continuous research focus.

To address this challenge, iterative reconstruction (IR) has emerged as a new CT image reconstruction algorithm, showing promising results in noise reduction, artifact suppression, and radiation dose reduction, and is now widely applied in clinical practice[6,7]. Clear View dual-domain iterative reconstruction technology is a relatively new iterative reconstruction algorithm that initiates iterations from the intersection of time and frequency domains, accelerating the iteration process, addressing some of the edge problems in IR algorithms, and effectively improving image divergence at high subset levels[8]. Recent studies have indicated the potential of Clear View in reducing radiation dose, enhancing image quality, and improving lesion detection capabilities[9].

However, there is limited literature on the optimal iteration reconstruction level of Clear View for various abdominal solid organs (such as the liver, pancreas, spleen, and kidneys) in low-dose abdominal CT imaging. Therefore, this study aims to investigate the impact of different reconstruction weight ratios based on Clear View dual-domain IR technology on the quality of low-dose CT images of the abdomen and to determine the optimal weight ratio, thus simultaneously improving image quality and reducing patient radiation dose.

Materials and Methods

General Information

A total of 50 patients who underwent abdominal CT examinations at Mzuzu Central Hospital, Malawi, from March 2024 to May 2024 were randomly selected. The inclusion criteria were: age > 18 years old; no gender restrictions. Exclusion criteria included: (1) severe cardiac or pulmonary dysfunction, inability to lie flat and hold breath; (2) history of abdominal surgery, contraindications for CT examination. Ultimately, 40 patients (28 males, 12 females) were included in the analysis, with ages ranging from 19 to 69 years old and a mean age of (51.25 ± 15.42) years. The body mass index (BMI) ranged from 18.5 to 24.9 kg/m2. This study was approved by Mzuzu University Research Ethics Committee (MZUNIREC) (Approval Number: MZUNIREC/DOR/24/153). Patient informed consent was waived due to retrospective nature of the study.

Data Acquisition and Reconstruction

A 16-slice helical CT scanner (Neusoft CT, Neusoft Medical Systems Co, Ltd.) was used for all abdominal low-dose CT scans. Patients were positioned supine with their feet first, arms raised and crossed above the head, and were instructed to hold their breath after inhalation for a few seconds before scanning. The scanning range was from the diaphragm to the symphysis pubis. The scanning parameters were set as follows: tube voltage of 120 kVp, tube current modulation based on Signal to Noise Ratio (SNR) at 0.5 mode (O-Dose automatic tube current modulation technology), pitch of 0.9, rotation time of 0.6 s/r, matrix size of 512 × 512, and collimation width of 16 × 1.25 mm. The slice thickness and interval were both set at 5 mm. Image reconstruction was performed using both filtered back projection (FBP) and iterative reconstruction at four different levels (20%, 40%, 60%, and 80%). Other reconstruction parameters were kept consistent across all reconstructions. The reconstructed images were then transferred to an AVW2.0 post-processing workstation for evaluation.

Image Evaluation

Objective Assessment: The CT images at different iterative reconstruction (IR) levels were measured using the AVW2.0 workstation, with all tasks performed by the same radiologist. Regions of interest (ROIs) were manually delineated, sized 50-60 mm², avoiding artifacts and edge areas. Specifically, ROIs were selected at the level of the right lobe of the liver at the first hepatic portal, the middle portion of the pancreas, the splenic hilum level of the spleen, the lower poles of both kidneys, and the paraspinal muscles bilaterally at the level of the first hepatic portal, while avoiding large vessels and pathological regions, specific measurement planes are illustrated in Figure 1. To ensure consistency in measurements across different reconstruction levels, ROIs were placed using a copy-paste method. Each ROI was measured three times on consecutive slices, and the average was used for analysis. CT values and standard deviation (SD) of the ROIs were recorded. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of the ROIs were calculated as follows: SNR = CT value of ROI/SD value of ROI, CNR = (CT value of ROI — CT value of paraspinal muscle at the same level)/SD value of paraspinal muscle at the same level.

Subjective Assessment: Two radiologists with over 5 years of experience in abdominal CT diagnosis conducted a blinded subjective assessment of the images. The window width was set at 350 Hounsfield Units (HU), and the window level was set at 40 HU. A five-point scale was used for scoring based on the following criteria[10]: 5 points, clear visualization of anatomical structures, good sharpness, and no apparent noise; 4 points, relatively clear visualization of anatomical structures with some slight blurring of details, slightly reduced sharpness, and increased noise; 3 points, most structures in the image are diagnostically acceptable, relatively low sharpness, and noticeable noise; 2 points, most structures in the image are unclear with low sharpness and significant noise; 1 point, image does not meet diagnostic requirements.

Radiation Dose Recording of Patient Dose Parameters

This includes the CT Dose Index Volume (CTDIvol) and Dose-Length Product (DLP), and the calculation of the Effective Dose (ED) using the formula ED = k × DLP, where the conversion factor k is referenced from the European Commission's Quality Criteria for Abdominal CT, with k = 0.015[11].

Statistical Analysis

Data were analyzed using SPSS 20.0 statistical software. Continuous data were presented as mean ± standard deviation (`x ± s), and normality of the data was assessed. A significance level of $P < 0.05$ was considered statistically significant. Pairwise comparisons were performed using paired sample t-tests, and multiple group comparisons were conducted using one-way analysis of variance (ANOVA). The consistency of subjective ratings between the two physicians was assessed using Kappa tests, categorized as follows: consistency (0.75 ≤ Kappa ≤ 1), moderate consistency (0.40 ≤ Kappa < 0.75), poor consistency (Kappa < 0.40)12.

Results

Objective Evaluation Results

Statistically significant differences were observed in the standard deviation (SD), signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR) of abdominal organs among different reconstruction weight ratios of FBP and Clear View ($P < 0.05$), as shown in Tables 1, 2, and 3. SNR and CNR increased with increasing Clear View reconstruction weight ratio, while SD decreased. Compared to FBP reconstruction, the SD of abdominal organs decreased by 0.49~52% with 80% Clear View reconstruction, while SNR and CNR increased by 0.50~52% and 0.47~52%, respectively.

Table 1: Comparison of Noise Values of Various Abdominal Parenchymal Organs under Different Reconstruction Weights

Reconstruction Algorithm	liver	pancreas	spleen	kidneys	Erector spinae
FBP	16.12 ± 1.12	15.08 ± 2.09	14.80 ± 1.08	14.27 ± 1.52	14.87 ± 1.54
20%	12.33 ± 0.82	11.98 ± 1.66	11.46 ± 0.73	11.04 ± 0.92	11.83 ± 1.14
40%	11.16 ± 0.78	10.81 ± 1.57	10.34 ± 0.70	9.98 ± 0.88	10.69 ± 1.16
60%	9.11 ± 0.74	8.84 ± 1.58	8.47 ± 0.64	8.19 ± 0.82	8.94 ± 0.95
80%	7.74 ± 0.65	7.55 ± 1.43	7.15 ± 0.75	6.97 ± 0.72	7.53 ± 0.98
F	244.78	60.43	276.92	154.93	115.97
P	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Table 2: Comparison of SNR of Various Abdominal Parenchymal Organs under Different Reconstruction Weights

Reconstruction Algorithm	liver	pancreas	spleen	kidneys
FBP	3.54 ± 0.52	3.17 ± 0.84	3.19 ± 0.47	2.44 ± 0.38
20%	4.59 ± 0.59	3.95 ± 1.01	4.10 ± 0.51	3.12 ± 0.47
40%	5.08 ± 0.68	4.38 ± 1.13	4.56 ± 0.57	3.45 ± 0.52
60%	6.23 ± 0.89	5.38 ± 1.50	5.61 ± 0.71	4.19 ± 0.66
80%	7.32 ± 1.06	6.31 ± 1.82	6.63 ± 0.89	4.92 ± 0.78
F	71.66	17.69	84.61	55.16
P	< 0.001	< 0.001	< 0.001	< 0.001

Table 3: Comparison of CNR of Various Abdominal Parenchymal Organs under Different Reconstruction Weights

Reconstruction Algorithm	liver	pancreas	spleen	kidneys
FBP	0.64 ± 0.19	0.54 ± 0.14	0.41 ± 0.16	0.89 ± 0.41
20%	0.80 ± 0.19	0.67 ± 0.19	0.50 ± 0.20	1.13 ± 0.49
40%	0.89 ± 0.24	0.74 ± 0.21	0.56 ± 0.21	1.25 ± 0.53
60%	1.03 ± 0.27	0.83 ± 0.27	0.65 ± 0.26	1.56 ± 0.60
80%	1.27 ± 0.37	1.03 ± 0.28	0.75 ± 0.31	1.80 ± 0.70
F	16.24	14.30	6.16	8.28
P	< 0.001	< 0.001	< 0.001	< 0.001

Table 4: Comparison of Subjective Evaluation of Various Abdominal Parenchymal Organs under Different Reconstruction Weights ($\bar{x} \pm s$)

Clear View	Subjective noise	Visibility	Artefacts	Diagnosis acceptability
FBP	3.95 ± 0.60	4.07 ± 0.64	4.37 ± 0.67	3.72 ± 0.74
20%	4.15 ± 0.67	4.35 ± 0.54	4.45 ± 0.51	4.19 ± 0.48
40%	4.35 ± 0.61[a]	4.80 ± 0.49[a]	4.87 ± 0.35[a]	4.60 ± 0.51[a]
60%	4.45 ± 0.51[a]	4.60 ± 0.50[a]	4.73 ± 0.45[a]	4.47 ± 0.51[a]
80%	4.80 ± 0.41	3.93 ± 0.58	4.33 ± 0.66	4.24 ± 0.45
P value [b]	< 0.001	< 0.001	< 0.001	< 0.001

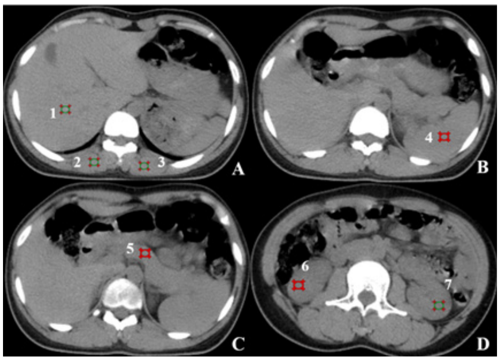

Figure 1. Regions of Interest for Abdominal Organs. ROI 1 corresponds to the liver; ROI 2 and 3 correspond to the spinal muscles (A); ROI 4 corresponds to the spleen (B); ROI 5 corresponds to the pancreas (C); ROI 6 and 7 correspond to the kidneys (D)

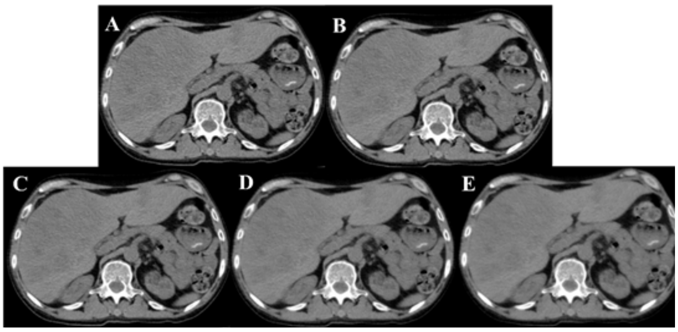

Figure 2. Transverse non-enhanced abdominal CT images of a 50 year-old male with a body mass index of 23.07 kg/m². A~E represent different scenarios of reconstructed images: FBP reconstruction (A), 20% Clear View (CV) iterative reconstruction (B), 40% Clear View (CV) iterative reconstruction (C), 60% Clear View (CV) iterative reconstruction (D), 80% Clear View (CV) iterative reconstruction (E)

Subjective Evaluation

All images in this study met diagnostic criteria, with subjective quality ratings by both physicians exceeding 3 points (Table 4). Subjective noise, visibility, artifacts, and diagnosis acceptability scores of Clear View images at any weight ratio were higher than those of FBP images ($P < 0.001$), and increased with increasing Clear View weight. The inter-rater agreement between the two physicians was relatively high (Kappa = 0.80~0.88). With increasing reconstruction weight ratio, subjective evaluation scores of abdominal organs continued to improve, but wax-like texture and suboptimal display of fine structures were more pronounced in 80% weight ratio images. Both physicians considered the image quality of abdominal organs to be highest at 40% reconstruction weight, with statistically significant differences among groups ($P < 0.05$); differences among different reconstruction weight ratios were also statistically significant ($P < 0.05$); see Table 4 and Figure 2.

Radiation Dose

The average CTDIvol, DLP, and ED values for the 40 patients were 5.32 ± 0.89 mGy, 257.44 ± 41.15 mGy/cm, and 3.86 ± 0.62 mSv, respectively.

Discussion

Abdominal computed tomography (CT) stands as a cornerstone among clinical imaging techniques. Due to its extensive scan range, it entails elevated X-ray radiation doses, consequently amplifying the risk of radiation-related ailments in patients. Therefore, adherence to the ALARA (As Low As Reasonably Achievable) principle is imperative, aiming to minimize CT radiation dosage while ensuring clinical diagnostic efficacy in abdominal cases, bearing significant clinical and societal implications[12,13].

With the advancement of CT technology, CT reconstruction algorithms play a pivotal role in reducing radiation exposure. Conventional filtered back projection (FBP) reconstruction algorithms, albeit simple, necessitate more raw data, leading to increased scanning doses. In contrast, Clear View dual-domain iterative reconstruction (IR) technology notably enhances image clarity in abdominal CT scans, rendering visceral organ structural details more discernible. Research by Hou Ping et al. indicates that, compared to FBP reconstruction, Clear View enhances the objective image quality across all ultra-low-dose tests, regardless of body size or model[14].

In this study, four reconstruction weights (20%, 40%, 60%, 80%) were set to subjectively and objectively evaluate abdominal image quality, aiming to elucidate the significance of Clear View technology in enhancing image quality and to discern the optimal reconstruction weight. Compared to FBP reconstruction, Clear View significantly reduces structural details and image noise in abdominal visceral organs, enhancing Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR)[15]. Moreover, as the Clear View reconstruction weight increases, objective noise in the images gradually decreases, while CNR and SNR progressively increase, consistent with findings by Wang Ning et al.[16]. Although the SD value of image noise for abdominal visceral organs gradually decreases, higher reconstruction weights do not necessarily yield better results, as they may lead to a more pronounced wax-like appearance in images, with suboptimal display of fine structures, resulting in decreased subjective ratings. This analysis suggests that the Clear View algorithm at higher weights may shift the frequency spectrum of image noise leftward, resulting in image blurring and unclear tissue boundaries, thereby compromising the discernibility of different anatomical structures and boundary sharpness, a viewpoint that warrants validation in subsequent foundational research.

For abdominal visceral organs, adopting the optimal reconstruction level in the later stages of image reconstruction is crucial to obtaining the highest-quality images of target organs. This holds significant value in image quality interpretation and lesion detection, aligning with the findings of other scholars[17,18].

This study also confirms that, compared to FBP reconstruction, increasing Clear View iteration weights lead to a noticeable reduction in image noise. For instance, with reference to the reported standard dose level (CTDIvol = 10.28 ± 1.57 mGy)[19], an 80% Clear View reconstruction yields reductions of 0.49% to 52% in SD values for abdominal visceral organs, along with respective increases of 0.50% to 52% in SNR and CNR. Leveraging Clear View dual-domain IR technology, based on multi-model dual-domain iterative techniques, facilitates the transformation of nonlinear problems into linear iterative problems, enabling 100% deep iteration. Combining both time and frequency domains initiates rapid iteration, coupled with features like a million-pixel platform (1024 × 1024 large matrix), enhancing image detail resolution, thereby yielding clearer and more accurate diagnostic images, with radiation dose reduction of up to 70%[8].

Limitations of this study include the relatively small sample size, which cannot entirely eliminate selection bias, necessitating further expansion of the sample size. Additionally, the study did not evaluate the application value of this reconstruction technology in the diagnosis of abdominal diseases, warranting more related research in the future to enhance clinical application value.

Conclusion

In conclusion, Clear View emerges as a novel image reconstruction method, boasting rapid computation speed and high image quality. It significantly enhances the clarity and contrast of adult abdominal CT images, providing more accurate and reliable radiological information for clinical medical diagnosis, thereby holding promising prospects for widespread clinical application.

Declarations

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Conflicts of interest / Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and material

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical approval

This study was approved by Mzuzu University Research Ethics Committee (MZUNIREC/DOR/24/153).

Consent for publication

The manuscript is approved by all authors for publication.

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