Comparative Study of Image Quality and Radiation Dose between 120kvp Filtered Back Projection and 80kvp Iterative Reconstructed Computed Tomography Images

Sweta Joshi[1], Sharma Paudel[2], Sundar Suwal[1], Shanta Lall Shrestha[3], Benu Lohani[3], Shashi Shekhar Singh[4]

[1]Lecturer, [2]Associate Professor, [3]Professor; [4]Clinical Registrar;
Department of Radiology and Imaging, Tribhuvan University Teaching Hospital, Maharajgunj, Kathmandu, Nepal

Corresponding author: Dr. Sharma Paudel. Email: sharmapaudel@gmail.com Contact Number: 9841393486

ABSTRACT

Background: Iterative Reconstruction techniques have been shown to produce diagnostically acceptable images at low doses to the patient. This study aimed to compare the image quality and radiation dose between 120kVp Filtered Back Projection and 80kVp Iterative Reconstructed (SAFIRE) CT images.

Methods: This cross-sectional study was performed on patients referred for CT Urography examinations for various clinical indications to the Department of Radiology and Imaging, Tribhuvan University Teaching Hospital. Data were collected for a period of four months (From August to November 2019) after approval from the Institutional Review Committee of the Institute of Medicine. Convenience sampling was employed and a total of 96 examinations were included. Among them 48 were male and 48 were female. Data were obtained from the 128-slice MDCT Siemens Somaton Definition AS+ CT scanner. Venous phase scans were obtained with Protocol A (120kVp and Filtered Back Projection) and non-contrast scans were obtained with Protocol B (80kVp and SAFIRE). The mAs (tube current-time product) was fixed at 200 for both protocols.

Results: There was a 72.5% reduction in Size Specific Dose Estimate (SSDE) in Protocol B compared to Protocol A. However, there was a 13.17% increase in noise in Protocol B compared to Protocol A. Image quality evaluation showed a 98.95% acceptability for the low dose i.e. Protocol B images.

Conclusion: CT using low kVp (80kVp) and low current (200mAs) along with an iterative reconstruction algorithm (SAFIRE) can provide diagnostically acceptable images at very low doses for examinations of the Urinary tract

Keywords: Filtered Back Projection, Iterative Reconstruction, Radiation Dose, Size Specific Dose Estimate.

INTRODUCTION

Ionizing radiation has been used for diagnostic purposes in medicine for more than a century. Its benefits are immense and certainly exceed the risks. Computed Tomography (CT), X-ray, and nuclear medicine imaging studies have improved patients' lives and revolutionized modern medicine. However, the rapid increase in the use of these modalities has resulted in a disproportionate increase in the population's overall exposure to ionizing radiation.[1]

Computed tomography (CT) is one of the most frequently used medical imaging modalities for a variety of clinical indications. There is, however, great concern about the potential risks related to radiation-induced cancer. In one study, investigators found an increase in the estimated cancer risk from CT radiation ranging from 0.4% (in 1996) to 1.5%–2.0% (in 2007) for all cancers in the United States.[2] Pediatric CT radiation has been associated with the development of malignancies in children, such as leukemia and brain cancer.[3] Therefore, CT radiation exposure must be as low as reasonably achievable (the ALARA principle).[4]

There is increasing use of CT for the diagnosis of several urinary tract pathologies. This increases concerns about the radiation doses received by patients. Iterative reconstruction methods have been proven to provide diagnostically acceptable images at fairly lower radiation doses. In this study, we aimed to compare the image quality and radiation dose between the 120kVp Filtered Back Projection and the 80kVp Iterative reconstructed CT images.

METHODOLOGY

This cross-sectional study was performed on patients referred for CT Urography examinations for various clinical indications to the Department of Radiology and Imaging,

Article information		
Received: 13 September 2023	**Accepted:** 20 December 2023	**Published online:** 31 December 2023

 https://doi.org/10.61814/jkahs.v6i3.857

Tribhuvan University Teaching Hospital, Maharajgunj, Nepal. Data were collected for a period of four months (From August to November 2019) after approval from the Institutional Review Committee of the Institute of Medicine [Ref.: 491(6-11)E^2/076/077)]. The patients were explained about the examination in detail. A written informed consent was obtained from each patient meeting the inclusion criteria.

Convenience sampling was employed and a total of 96 examinations were included. The study was conducted on adult patients (above 18 years) of both sexes. The height and weight of the patients were recorded for the calculation of BMI. Patients were divided into four BMI classes i.e. underweight (BMI<18.5 kg/m^2), normal (BMI between 18.5 and 24.9 kg/m^2), overweight (BMI between 25 and 29.9 kg/m^2), and obese (BMI≥30 kg/m^2). Among them, patients with BMI≥25 kg/m^2 were excluded from the study, as the lower kilovoltage that is used for Protocol B might not be sufficient for adequate penetration in larger patients.

CT Protocols: CT examinations were performed on the 128-slice MDCT Siemens Somaton Definition AS+ CT scanner. Two protocols were prepared for the examination.

Protocol A: This was the routine CT urography protocol i.e. 120kVp images reconstructed with Filtered Back Projection. Venous phase scans were obtained using this protocol.

Protocol B: The kilovoltage was reduced to 80kVp and the images were reconstructed with SAFIRE. Non-contrast scans were obtained with this protocol.

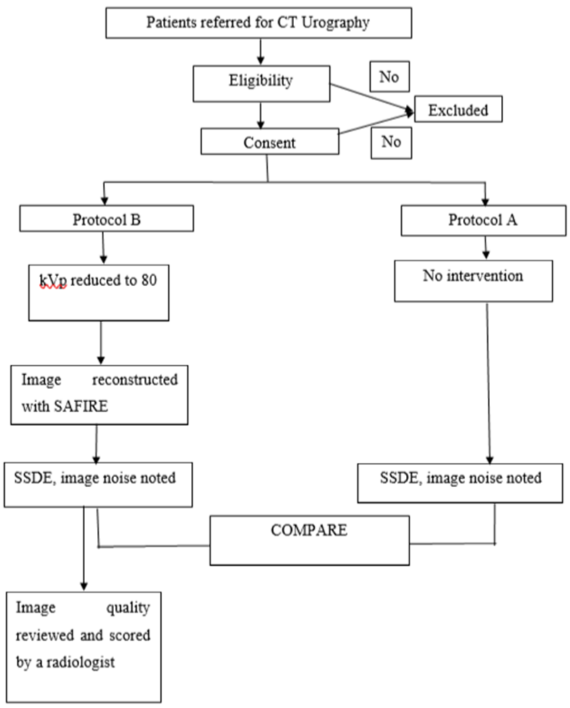


Figure 1: Flow chart of the study

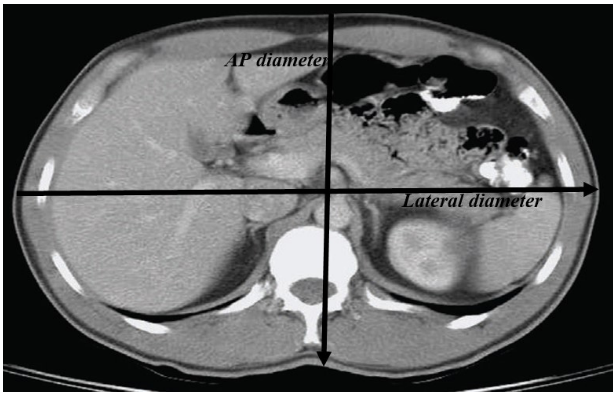
The scan coverage was kept identical for protocols A and B. The mAs were fixed at 200 for both protocols. The outline of the study design is shown in Figure 1.

Quantitative analysis of radiation dose & image noise:

a. Size Specific Dose Estimate (SSDE) calculation: $CTDI_{vol}$ was calculated by the scanner using the average tube current throughout the entire scan and was recorded for each scan series. For each patient, anteroposterior (AP) and lateral (Lat) dimensions at the mid-liver region i.e. at the level of the portal vein were measured from axial CT images by using digital calipers on the scanner console. (Figure 2) These values were used to calculate the effective diameter. The AAPM Report 204[5] provides tables based on the effective diameter that were used to find the f-size that, when multiplied by $CTDI_{vol}$, yields SSDE. SSDE was calculated for the non-contrast scans and the venous phase scans of each patient.

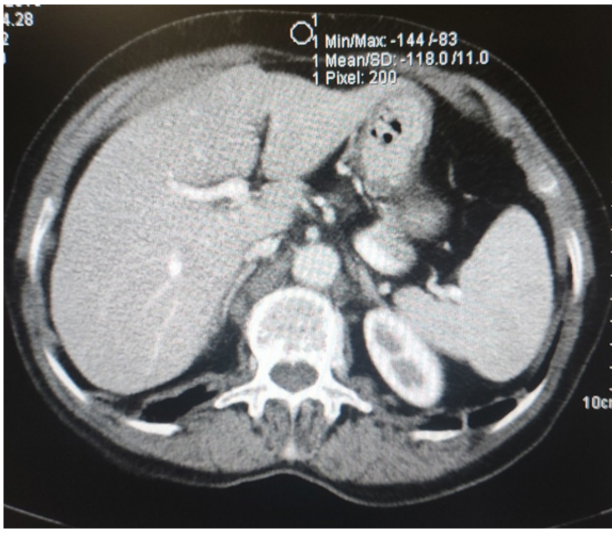
Effective diameter = SSDE = $CTDI_{vol}$ X f-size

Figure 2: Measurement of anteroposterior and lateral diameters



b. Noise calculation: For the 80kVp SAFIRE and 120kVp FBP, image noise was measured as the standard deviation of the pixel values from a uniform circular ROI (200 pixels) drawn in a homogeneous region of the subcutaneous fat of the anterior abdominal wall. (Figure 3)

Figure 3: CT image showing noise measurement



Evaluation of overall image quality: The overall image quality of the non-contrast scans (Protocol B) was assessed and given a score by an experienced radiologist (SS) who had many years of experience in body imaging. The radiologist was blinded to the techniques used to acquire the image. The images were reviewed on the syngo.via workstation. Scoring was done on a 4-point scale ranging from 1 to 4, (1=Excellent, 2=Very Good, 3=Fair image quality deteriorated but there is no diagnostic limitation, 4=Poor image quality deteriorated with diagnostic limitation). The reviewer reviewed the images in the workstation for quality score based on the criteria given by European guidelines.[6]

Statistical Analysis: The relevant data of the examinations were collected in predesigned proforma, data entry was done in a Microsoft Excel spreadsheet and data analysis was done with SPSS version 25. Mean, standard deviation, minimum, and maximum values were obtained. Paired t-tests were applied for analytical study to determine if:

a. There was a significant reduction in radiation dose in the non-contrast phase (obtained with Protocol B) compared to the venous phase (obtained with Protocol A) scans of the same patient.

b. There was a significant change in noise levels in the non-contrast phase (obtained with Protocol B) compared to the venous phase (obtained with Protocol A) scans of the same patient.

RESULTS

Background Characteristics of the patient

A total of 96 patients were selected for the study. Among them 48 were male and 48 were female. The description of population statistics can be found in Table 1.

Table 1: Descriptive statistics of the population (n=96)

Patient Parameters	Minimum	Maximum	Mean	SD
Age (years)	18	75	38.73	17.28
BMI (kgm^2)	15.1	24.9	21.27	2.48
Effective diameter (cm)	18	32	24.16	2.95
f-size value	1.19	1.91	1.53	0.16

Radiation dose: For Protocol A, the mean SSDE was 20.47±2.18 mGy. The minimum and maximum SSDE were 15.87 and 25.47 mGy respectively. For Protocol B, the mean SSDE was 5.63±0.6 mGy. The minimum and maximum SSDE were 4.36 and 7 mGy respectively. (Table 2)

There was a radiation dose reduction of 72.5% when the kV was reduced from 120 to 80 kV keeping the mAs constant. This radiation dose reduction was statistically significant as given by the paired t-test (t=91.95, p=0.001).

Table 4: Frequency and percentage of participants receiving different image quality scores (Protocol B)

Score	Interpretation	Frequency	Percentage (%)
1	Excellent	1	1
2	Very Good	54	56.3
3	Fair	40	41.7
4	Diagnostic limitation	1	1
Total		96	100

Noise: For Protocol A, the mean noise was 6.76±2.9 with the minimum and maximum noise being 3.6 and 19.9 respectively. For Protocol B, the mean noise was 7.65±2.78 with the minimum and maximum noise being 4.1 and 21.1 respectively. (Table 3) There was a mean increase in noise of 13.17% when the KV was reduced from 120KV to 80KV despite the use of SAFIRE for reconstructing the 80KV images for Protocol B. This increase was statistically significant as given by the paired t-test (t=4.48, p=0.001).

Result of image quality evaluation: Image Quality scoring of non-contrast scans (Protocol B) was done on a 4-point scale ranging from 1 to 4, (1= Excellent, 2= Very Good, 3= Fair, image quality deteriorated but there is no diagnostic limitation, 4= Poor, image quality deteriorated with diagnostic limitation). Considering scores 1-3 to be diagnostically acceptable, 98.95% of image sets were found to be acceptable. (Table 4)

DISCUSSION

The alarming increase in the number of CT examinations performed today raises concern about the high radiation doses associated with it. Embracing the principle of ALARA, all possible measures should be applied to reduce the radiation dose in CT examinations. One of the heavily promoted dose reduction strategies given by various CT manufacturers is the use of Iterative reconstruction methods. In this study, we tried to evaluate the diagnostic acceptability of the low kV (80kVp) and low mAs (200 mAs) CT images of the urinary tract reconstructed with SAFIRE. Protocol A which was the routine protocol of our department (120kVp FBP) was used to obtain the venous phase scans and Protocol B i.e. the low dose protocol (80kVp SAFIRE) was used to obtain the non-contrast scans. The two protocols A and B were also compared for differences in Size-specific dose estimates (SSDE) and

Table 2: Radiation Dose in Protocol A and Protocol B

Parameter	Protocol A				Protocol B			
	Min	Max	Mean	SD	Min	Max	Mean	SD
SSDE (mGy)	15.85	25.47	20.47	2.18	4.36	7	5.63	0.6

SSDE: Size Specific Dose Estimate; SD: Standard Deviation

Table 3: Noise in Protocol A and Protocol B

Parameters	Protocol A				Protocol B			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Noise	3.6	19.9	6.76	2.9	4.1	21.1	7.65	2.78

https://doi.org/10.61814/jkahs.v6i3.857

noise. SSDE have been used as a measure of radiation dose in this study because absorbed organ doses are very close to SSDE in CT exams of the abdomen and pelvis.[7]

A straightforward reduction in the dose by simply lowering the kilovoltage would severely hamper image quality due to increase in noise. So, the SAFIRE reconstruction algorithm was applied to reduce the noise by smoothing the low kVp image. Radiation dose reduction of 72.5% was achieved in Protocol B compared to Protocol A. This is because of the lower kVp used for Protocol B compared to Protocol A (120 v/s 80kVp).

The noise was calculated as the standard deviation of an ROI (consisting of 200 pixels) placed on the anterior abdominal fat. There was a mean increase in noise of 13.17% in Protocol B compared to Protocol A. This can be attributed to the lower kV used in Protocol B. Decreasing the x-ray tube voltage increases the image noise/mottle, as reflected by the observed increase in the measured standard deviation. The increase in noise would have been much higher if the Protocol B images hadn't been reconstructed with SAFIRE.

Our study results are in good agreement with the results of the previous study by Hur S et al.[8] which demonstrated that the iterative reconstruction algorithms provided better image quality compared to standard filtered back projections at lower radiation doses. However, there was a difference between the two studies: the present study used a low tube current-time product (200 mAs) whereas an intermediate tube current-time product (340 mAs) was used in the previous study.[8] Had we selected a higher tube current to offset the higher image noise, further reduction in image noise could have been possible at the cost of an increased radiation dose. They found a mean effective dose reduction of 57.41%. This lower dose reduction was due to the use of higher mAs (340mAs v/s 200mAs in our study). They applied the low-tube-voltage (80kVp), with the Iterative Reconstruction in Image Space (IRIS) algorithm for better detection of hepatocellular carcinomas (HCC). The present study used low doses on the non-contrast scans of the urinary tract, with the goal of detecting calcifications and hemorrhage which are more readily visualized. So, we opted for a more aggressive dose reduction strategy.

Solomon J et al.[9] tried to determine the effect of radiation dose reduction and reconstruction algorithm on image noise, contrast, resolution, and detectability of subtle hypoattenuating liver lesions. They concluded that SAFIRE allowed imaging at a 16±13% reduced dose while maintaining low contrast detectability of subtle hypoattenuating focal liver lesions. We aimed at a much higher dose reduction strategy principally because non-contrast scans in CT urography are obtained to look for calcifications and hemorrhages which are more easily detected compared to hypoattenuating liver lesions.

Ciaschini et al.[10] also tried to assess the acceptability of low-dose CT images of the urinary tract. Our study attempted a 72. 5% dose reduction which is similar to the 75% dose-reduced examinations of their study.[10] Unlike the prospective nature of our study, the previous study was retrospective and utilized simulation software that enabled them to reconstruct CT examinations at lower tube current levels in the same patients. They found that while sensitivity for all calculi decreased by approximately 27% with a 75% reduction in tube current, sensitivity for calculi greater than 3 mm fell only 5.8% with a 75% dose reduction.

The low-dose (Protocol B) images were reviewed by an experienced radiologist to assess their diagnostic acceptability (Table 4). Considering scores 1-3 to be diagnostically acceptable, 98.95% of image sets were found to be acceptable. Among those, 56.84% of image sets scored very good, 42.1% of images scored fair, and only 1.05% of images scored excellent. One image set was given a score of 4 i.e. Poor image with deterioration of image quality. The Protocol B images showed an underwhelming overall image quality score, which was based on the subjective impression of the image by the observer. This low score may be the result of the unfamiliarity of plastic-like image impressions of iterative reconstruction.[11] The possibility that this unfamiliarity generated by iterative reconstruction may negatively influence the interpretation of radiologists should be considered before the implementation of SAFIRE into routine clinical abdominal imaging. Also, the scores depended largely on other patient factors including the amount of perirenal fat present, the presence of ascites, or other fluid collections in the abdomen. It was noted that patients with abundant perirenal fat scored better than others in the quality score. Moreover, patients with excess fluid collections in the vicinity of the kidneys failed to obtain a good quality score. Thus, this dose reduction technique needs to be used with caution in patients with a history of ascites or other fluid collections.

Limitations and recommendations

There were certain limitations in our study. We only included patients having a BMI less than 25kg/m^2 because the lower kVp would not be sufficient for patients with larger body habitus. Thus, a modified study, perhaps with a slightly increased kVp or mAs may be suitable for patients with BMI≥25kg/m^2. We only used one scanner and hence, only one iterative reconstruction method i.e. SAFIRE, was evaluated. SSDE values were calculated using the effective diameter and not the water equivalent diameter which would have been ideal. Another limitation was that only adults were included in the study. Pediatric patients were excluded since the scanner in use makes use of the 32cm PMMA phantom for the $CTDI_{vol}$ measurement for the pediatric abdomen whereas the AAPM report has strictly mentioned the need for a 16 cm PMMA phantom if SSDE were to be calculated using the f-size factors provided in the report.[5] Finally, the sample size was small due to the time constraints and demanding inclusion criteria. So, a larger scale study including the pediatric population and employing random sampling is recommended.

CONCLUSION

The quantitative analysis showed that compared to the 120kVp FBP images, the 80kVp IR images allowed a drastic 72.5% dose reduction. However, with an increase of 13.17% in noise as a penalty. The overall image quality evaluation showed that the iterative reconstruction algorithm yielded diagnostically acceptable images at low tube voltage (80kVp) and low tube current-time product (200mAs) setting and thus may be a valuable tool for reducing radiation dose in CT examinations of the urinary tract.

Data Availability: Supporting information is available from the authors on request.

Source of Funding / Support: There was no external source of support for this research.

Conflict of Interest: None declare.

Author COntribution: SJ conceptualised the research, collected, analysed and interpreted the data and drafted the manuscript; SP reviewed the literature, drafted, reviewed the manuscript and corresponded to the journal. SS reviewed the literature, interpreted the data, reviewed the drafts of the manuscript; SLS reviewed the literature, designed the research, reviewed the drafts of the manuscript; BL reviewed the literature, reviewed the drafts of the manuscript; SSS reviewed the literature analysed the data and review the drafts of the manuscript; All authors approved the final version of draft manuscript.

REFERENCES

1. Amis ES Jr, Butler PF, Applegate KE, Birnbaum SB, Brateman LF, Hevezi JM, Mettler FA, Morin RL, Pentecost MJ, Smith GG, Strauss KJ, Zeman RK; American College of Radiology. American College of Radiology white paper on radiation dose in medicine. J Am Coll Radiol. 2007 May;4(5):272-84. https://doi.org/10.1016/j.jacr.2007.03.002 [PubMed] [Google Scholar]
2. Brenner DJ, Hall EJ. Computed tomography--an increasing source of radiation exposure. N Engl J Med. 2007 Nov 29;357(22):2277-84. https://www.nejm.org/doi/full/10.1056/NEJMra072149 [PubMed] [Google Scholar]
3. Pearce MS, Salotti JA, Little MP, McHugh K, Lee C, Kim KP, Howe NL, Ronckers CM, Rajaraman P, Sir Craft AW, Parker L, Berrington de González A. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet. 2012 Aug 4;380(9840):499-505. https://doi.org/10.1016/S0140-6736(12)60815-0 [PubMed] [Google Scholar]
4. United States Nuclear Regulatory Commission. ALARA. 2013. Available from:https://www.nrc.gov/reading-rm/doc-collections/commission/orders/2013/2013-06cli.pdf
5. American Association of Physicists in Medicine. Size Specific Dose Estimates in pediatric and adult body CT examinations (Task Group 204). ; 2011. Available from: https://www.aapm.org/pubs/reports/rpt_204.pdf
6. European guidelines on quality criteria for Computed Tomography. [Online]. Available from www.drs.dk/guidelines/ct/quality/htmlindex.htm
7. Supanich M, Peck D. Size Specific Dose Estimate as an indicator of Organ dose in CT abdomen and pelvis studies. RSNA Scientific assembly and annual meeting. 2012 November. Available from: https://archive.rsna.org/2012/12023193.html
8. Hur S, Lee JM, Kim SJ, Park JH, Han JK, Choi BI. 80-kVp CT using Iterative Reconstruction in Image Space algorithm for the detection of hypervascular hepatocellular carcinoma: phantom and initial clinical experience. Korean J Radiol. 2012 Mar-Apr;13(2):152-64. https://doi/10.3348/kjr.2012.13.2.152 [PubMed] [Google Scholar]
9. Solomon J, Marin D, Roy Choudhury K, Patel B, Samei E. Effect of Radiation Dose Reduction and Reconstruction Algorithm on Image Noise, Contrast, Resolution, and Detectability of Subtle Hypoattenuating Liver Lesions at Multidetector CT: Filtered Back Projection versus a Commercial Model-based Iterative Reconstruction Algorithm. Radiology. 2017 Sep;284(3):777-787. https://doi.org/10.1148/radiol.2017161736 [PubMed] [Google Scholar]
10. Ciaschini MW, Remer EM, Baker ME, et al. Urinary Calculi: Radiation Dose Reduction of 50% and 75% at CT— Effect on Sensitivity. Radiology. 2009; 251(1): 105-111. https://pubs.rsna.org/doi/10.1148/radiol.2511081084 https://doi.org/10.1148/radiol.2511081084 [PubMed] [Google Scholar]
11. Sameer T, Ashok R, Walter H, Andrew H, Joseph S, Philip C, Thomas F, Martin S. Iterative reconstruction in image space (IRIS) and lesion detection in abdominal CT. Proc. SPIE 7622, Medical Imaging 2010: Physics of Medical Imaging, 2010 March. https://doi.org/10.1117/12.843787 [Google Scholar]