e-ISSN: 0975-1556, p-ISSN:2820-2643

Available online on www.ijpcr.com

International Journal of Pharmaceutical and Clinical Research 2024; 16(2); 1531-1538

Original Research Article

Size-Specific Dose Estimate – A Tool for Radiation Dose Quantification and Assessment Among Renal Colic Patients in a Tertiary Care Hospital in Southern India

Nikhil Kumar[1], Pulagam Vamsidhar Reddy[2], Prakashini K[2], Priya PS[2]*, Arun Chawla[3], Ranjitha S Shetty[4], Basima Maisoon[5]

[1]Gupta Diagnostic Clinic, Burla, Odisha, India
[2]Department of Radiodiagnosis & Imaging, Kasturba Medical College, Manipal, Manipal Academy of Higher Education, Manipal, India, 576104
[3]Department of Urology, Kasturba Medical College, Manipal, Manipal Academy of Higher Education, Manipal, India, 576104
[4]Department of Community Medicine, Kasturba Medical College, Manipal, Manipal Academy of Higher Education, Manipal, India, 576104
[5]Prasanna School of Public Health, Manipal Academy of Higher Education, Manipal, India, 576104

Received: 25-12-2023 / Revised: 23-01-2024 / Accepted: 18-02-2024
Corresponding Author: Dr. Priya P. S.
Conflict of interest: Nil

Abstract:

Background: The demand for well-defined CT protocols with reduced radiation dose to the patients without compromising the accuracy of the diagnostic study has been growing.

Aim: The study aimed to assess and compare patient radiation dose in low and standard-dose Computed Tomography protocol by size-specific dose estimates in renal colic patients and to determine the quality and diagnostic worth of obtained images.

Materials and Methods: A prospective study was conducted among180 adult patients comprising 90 cases and 90 controls over a period of 2 years. Cases included patients with renal colic who underwent low-dose Computed Tomography of Kidneys, Ureters and Bladder (CT KUB) and controls were those who underwent plain CT abdomen and pelvis as a part of contrast study for other clinical indications. Both the groups were further divided into two groups based on their computed effective diameter (< or > 25cm). The radiation dose parameters, including size-specific dose estimate and effective dose, and image quality were tabulated and assessed using SPSS version 16.0.

Results: There was a significant reduction in radiation dose descriptors in the case groups as compared to control groups by 35.6% in the group with effective diameter less than 25cmand 15.8% in the group with effective diameter more than 25 cm, in terms of effective dose, while a reduction of 30% and 7.4% was noted in terms of size-specific dose estimate, respectively without compromise in the diagnostic image quality.

Conclusion: Size-specific dose estimates can be used as a standard dose descriptor of a patient's absorbed radiation dose and has potential use in helping formulate newer CT protocol for renal colic based on the patient's body habitus.

Keywords: Computed Tomography; Radiation Dosage; Renal Colic; Diagnostic Imaging.

Introduction

Renal colic is a common indication for a patient undergoing diagnostic imaging with urolithiasis being one of the most common causes of renal colic. Currently, the unenhanced Computed Tomography (CT) is the investigation of choice for evaluating urolithiasis due to its higher sensitivity compared to plain radiography, intravenous urography, and ultrasound (Smith et al. 1995; Smith et al. 1996). [1] CT is a rapid and non-invasive imaging modality useful in diagnosing renal calculi as it can help localize calculi, their size, and their obstructive potential and provide alternative diagnoses. However, there has been growing concern over radiation exposure during CT scans in recent years, leading to increased demand for clear protocols that reduce radiation dose without compromising diagnostic accuracy (Poletti et al. 2007). [2] The amount of radiation a patient receives from a CT scan depends on their body habitus and the output of the scanner. The CT Dose Index (CTDI) and Dose-Length Product (DLP) are used to estimate a patient's radiation exposure, but they measure scanner output rather than absorbed dose (McCollough et al. 2008). [3]

Prior published studies have reported that CTDI phantoms have led to an underestimation of dose to the patient by about 40-70% in pediatric and adult torsos (Boone et al. 2011; McCollough 2008). [4] If the CTDI is integrated with the patient's size estimates and the anatomy of the region to be scanned, the accuracy of dose estimation can be improved. The 'size-specific dose estimate' described by the American Association of Physicists in Medicine (AAPM) (Valentin 2007), [5] considers the rectifications which are based on the body habitus (or size) of the patient, for better estimation of the radiation dose to the patient (McCollough et al. 2008). [6]

There is an increase in demand for well-defined CT protocols in which the dose to the patient can be reduced without compromising the accuracy of the diagnostic study. Only a few studies have assessed patient radiation exposure in modified CT protocols based on their body habitus (Rob et al. 2017; Denton et al. 1999). [7] Moreover, very few studies have used the size-specific dose estimate as the metric of radiation dose absorbed by the patient.

Hence, the present study was carried out to estimate size-specific dose estimates among patients with renal colic and compare with routine dose CT protocol followed for any other clinical indications. The study also aimed to compare the quality of images obtained in the renal colic group with that of routine dose CT protocol.

Methods

This study was a prospective observational study conducted over a two-year period from November 2018 to October 2020. The study was conducted in the Department of Radiodiagnosis and Imaging of a tertiary care hospital situated in southern India.

Study Subjects

The study comprised 180 adult patients with equal number of cases and controls. The sample size was derived based on the frequency of renal colic patients presenting to our department for CT study.

The case group consisted of 90 patients with complaints of renal colic who were referred for Computed Tomography of Kidneys, Ureters and Bladder (CT-KUB) study. The control group included 90 patients referred for plain and contrast-enhanced CT study for other clinical indications, such as infection or inflammation in organs other than the kidneys, ureters, and bladder. Plain study of the scan was considered for comparison.

The cases included adult patients (above 18 years of age) of both sexes with clinically suspected renal colic referred to the Department of Radiodiagnosis and Imaging for a Non-Contrast CT (NC-CT) KUB study. The controls consisted of adult patients (above 18 years of age) of both sexes who underwent a CT abdomen and pelvis study for other clinical indications. Post-operative cases with DJ stents in situ were excluded from the study.

Instrumentation

Images were acquired using Computed tomography: (model) - Philips Incisive 128-slice CT scanner.

Study Procedure

Among the cases, a localized scannogram was taken before the CT scan, followed by a localized plain CT scan from L1 to L3 vertebra level in minimal possible dose settings (70kvP and 120mAs) and the effective diameter was calculated at the maximum girth, using the formula,

Effective diameter = √ (AP ×LAT), where AP is the Anterior-posterior diameter and LAT is the lateral diameter (Boone et al. 2011).

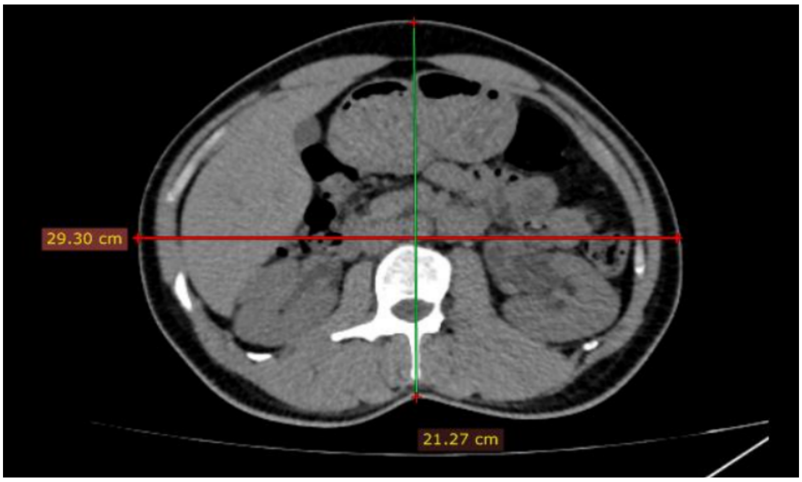

Figure 1: Maximum AP and Lateral dimensions are measured in the acquired plain sections, calculated effective diameter ~24.8cm.

Based on the effective diameter, the cases were divided into two groups, Those with an effective diameter <25cm and those with an effective diameter >25cm. The lower effective diameter brackets used in this study were based on the general body morphometrics of Indian patients.

In both case groups, the scans were acquired with a tube voltage of 100 kVp, while the tube current was fixed at 90 mAs for patients with an effective diameter <25cm (38 patients), and 160 mAs for those with an effective diameter >25cm (52 patients).

Dose information of the scan was sent to Picture Archiving and Communication System (PACS), and 'the volume CT dose index' (CTDIvol, in milligrays) and the 'dose-length product' (DLP; milligrays times centimetres) were documented.

The control group of 90 patients underwent Contrast-Enhanced Computed Tomography (CECT) of the abdomen and pelvis in routine dose protocol with 120 kVp and automated tube current modulation (ranging from 230-280mAs) and were also categorized into two groups of effective diameter more than 25 cm and less than 25cm. The plain study series was considered for comparison. The automatic exposure control or 3D dose modulation settings were enabled in the control group protocol only.

The radiation dose information was acquired from the machine after each study, and the CT dose index (CTDI) and dose length product (DLP) were obtained. The effective dose was calculated using the conversion factors stated by the International Commission on Radiological Protection (ICRP) 103 (Valentin 2007).

Also, the size-specific dose estimates were quantified from patient dimensions and scanner output (CTDIvol), using conversion factors as described by the American Association of Physicists in Medicine (AAPM) (Brady and Kaufman 2012) as follows.

Size-specific dose estimates = f size x CTDIvol, where the AAPM report gives f size.

Radiological Assessment

The objective image analysis was done by positioning circular regions of interest (ROI) of the liver, spleen & and psoas manually at three different areas and an average of HU values was considered. The quantified ROI diameter was ~1.3cm, with an area measuring ~1.4cm^2. ROIs were placed in uniform tissue areas to exclude adjacent structures and artifacts. CT attenuation values were measured in three sections, and the average CT attenuation (HU) and standard deviation (SD) within the ROIs were considered.

The following formulae were used to quantify the SNR and the CNR:

SNR= Average attenuation value in the organ of interest/ Average noise in the image.

CNR= (Average attenuation value in the organ of interest - Average attenuation value in the other organ)/ Average noise in the background organ. The background organ considered in our study was psoas muscle.

The subjective image analysis was performed by two experienced radiologists independently by assessing the visibility of the ureter at abdominal, pelvic, and vesicoureteric junctions. The grading was done on a 3-point scale where, 3=Good visibility; 2=Fair visibility, the uncertainty of ureter position in a 1 cm wide region; 1= Poor visibility, ureter not distinctly visualized or uncertainty in ureter position in more than 1cm wide region.

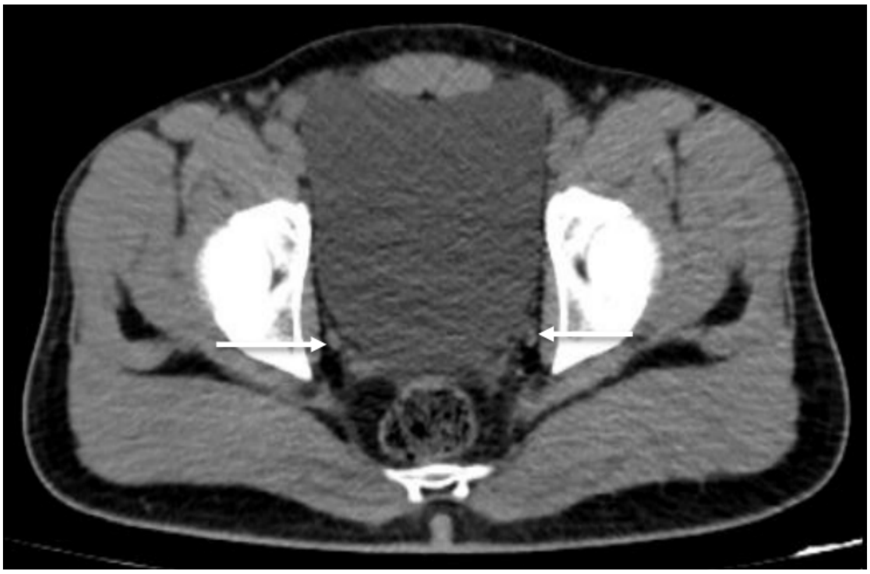

Figure. 2: Plain axial section at the vesico-ureteric junction, with white arrows depicting good visibility.

Ethical Considerations: The study protocol was approved by the Institutional Ethics Committee prior to initiation of the study (IEC- 761/2018). Purpose and objectives of the study were explained to the participants and a written informed consent was obtained from every patient before their recruitment into the study.

Statistical Analysis

Data was entered into a Microsoft excel sheet and were analyzed using the SPSS version 16.0 (Statistical Package for the Social Sciences (SPSS) for Windows, Version 16.0. SPSS Inc. Released 2007, Chicago, IL, USA). Categorical data was presented as frequencies and proportions. The chi-square test was used as a test of significance for qualitative data. Continuous data were represented as mean and standard deviation (SD). Independent t-test or Mann-Whitney U test was used as a test of significance to identify the mean difference between two quantitative variables and qualitative variables, respectively. A p-value <0.05 was considered as statistically significant after assuming all the rules of statistical tests.

Results

The study included 180 adults with 90 cases and 90 controls. Majority of cases were in the younger and middle-age group between 29 – 38 and 39-48 years (21% each), and among controls, the majority were older between 59-68 years (29%).

Proportion of males were higher in both the groups with 61% among cases and 55% among controls. Similarly, in the group with effective diameter > 25 cm, (52 cases and 52 controls); 42.3% of the cases and 53.8% of the controls were in the older age group (59-78 years). Most of the cases (73%) and controls (62%) were males in this group too.

As for the diagnoses, of the 90 cases, 35% had bilateral renal calculi, followed by left-sided renal calculus (24%) and right-sided renal calculus (19%) while 22% had diagnoses other than urolithiasis, like pyelonephritis and cholelithiasis.

Table 1: Mean effective diameter, CTDI, DLP and SSDE comparison between cases and control groups

Parameters	Effective diameter <25cm		p-value	Effective diameter >25cm		P value
	Cases n=38	Controls n=38		Cases (n=52)	Controls (n=52)	
	Mean (±SD)	Mean (±SD)		Mean (±SD)	Mean (±SD)	
SSDE	7.4 ±0.8	10.7 ± 1.6	0.001*	10.2 ± 1.1	10.8 ± 1.5	0.003*
CTDI	4.3 ± 0.1	6.4 ± 1.0	< 0.001*	7.7 ± 0.01	7.8 ± 1.3	0.46
DLP	250.9 ± 24.9	383.6 ± 96.7	< 0.001*	424.6 ± 52.3	496.9 ± 105.9	< 0.001*
Effective diameter	22.6 ± 1.4	21.9 ± 2.1	0.17	27.2 ± 1.5	26.7 ± 1.5	0.08

The assessment of radiation dose descriptors in this group of patients showed a significant reduction in mean SSDE, DLP, and CTDI in the cases compared to controls (p<0.001). However, no significant difference was observed in mean effective diameter between the cases and controls (Table 1).

Table 2: Objective image analysis for diagnostic quality of the study

	Parameters, ROI Site of lesions	Effective diameter <25cm		p-value	Effective diameter >25cm		p-value
		Cases n=38	Controls n=38		Cases n=52	Controls n=52	
		Mean (±SD)	Mean ±SD)		Mean (±SD)	Mean ±SD)	
Attenuation Value (HU)	Liver	56.4 ± 7.2	53.7± 8.6	0.14	47.1±9.0	49.5±7.0	0.132
	Spleen	49.9 ± 3.2	46.9± 2.8	< 0.001*	49.2±3.2	46.3±3.9	< 0.001*
	Psoas muscle	52.3 ± 3.8	49.2± 5.0	0.003*	50.9±5.4	48.2±4.5	0.013*
Noise (SD in ROI)	Liver	9.3 ±1.2	5.1± 1.0	< 0.001*	9.9±2.7	6.0±1.0	< 0.001*
	Spleen	8.9 ±1.4	4.9± 0.9	< 0.001*	10.0±2.9	5.8±1.1	< 0.001*
	Psoas muscle	10.2 ±1.6	5.7± 1.6	< 0.001*	12.1±3.4	7.2±1.4	< 0.001*
Signal to noise ratio (SNR)	Liver	6.2±1.2	10.9± 2.7	< 0.001*	5.1±1.7	8.5±1.9	< 0.001*
	Spleen	5.7±0.9	9.8± 2.1	< 0.001*	5.3±1.6	8.3±1.7	< 0.001*
	Psoas muscle	5.2±0.8	9.1± 2.5	< 0.001*	4.6±1.6	6.9±1.6	< 0.001*
Contrast to noise ratio (CNR)	Liver-Spleen	0.7±0.9	1.3± 1.6	0.024*	-0.2±0.9	0.4±0.9	0.001*
	Liver-Psoas muscle	0.4±0.9	0.9± 1.4	0.094	-0.4±1.0	0.1±0.9	0.013*
	Spleen-Psoas muscle	-0.2±0.4	-0.4± 0.9	0.281	-0.2±0.4	-0.3±0.6	0.135

As represented in Table 2, objective image quality analysis showed a statistically significant difference in the mean liver, spleen, and psoas muscle noise and signal-to-noise ratio (SNR) between cases and controls, with superior visibility in the controls. No significant difference in mean Contrast to noise ratio (CNR) was found for the spleen-psoas muscle and liver-psoas muscle, while a significant difference was found for the liver-spleen CNR, possibly due to variable amounts of fatty infiltration in the liver.

Table 3: Subjective image analysis for diagnostic quality of study

Ureter visibility	Effective diameter <25cm		p-value	Effective diameter >25cm		p-value
	Cases N=38	Controls N=38		Cases N=52	Controls N=52	
	Mean (±SD)	Mean (±SD)		Mean (±SD)	Mean (±SD) n	
Abdominal ureter	2.9+0.2	2.9+0.2	0.343	3+0	2.9+0.1	0.32
Pelvic ureter	2.6+0.4	2.3+0.7	0.026*	2.8+0.3	2.5+0.6	0.002*
VUJ	2.6+0.5	2.3+0.7	0.036*	2.8+0.4	2.6+0.6	0.09

As shown in Table 3, subjective image analysis revealed no statistically significant difference in abdominal ureter visibility between the cases and controls, but the cases had better visibility of the pelvic ureter and VUJ as compared to that in controls in both the groups (effective diameter <25cm and >25cm).

Table 4: Effective dose and SSDE comparison between cases and controls of two groups

Dose descriptor	Effective diameter <25cm		Effective diameter >25cm	
	Cases (38) Mean (±SD)	Controls (38) Mean (±SD)	Cases (52) Mean (±SD)	Controls (52) Mean (±SD)
Effective dose (mSv)	3.8 ± 0.4	5.9 ± 1.5	6.4 ± 0.8	7.6 ± 1.6
SSDE (mGy)	7.4 ± 0.8	10.6 ± 1.6	10.3 ± 1.1	10.8 ± 1.5

It is shown in table 4 that there was a reduction in effective dose in the case group by 35.6% as compared to the controls with an effective diameter of less than 25cm. There was a significant reduction in SSDE by 30.2% in the case group as compared to controls. For cases with an effective diameter greater than 25cm, there was a reduction of effective dose by 15.8% compared to controls, and a 4.6% reduction in SSDE in the cases compared to controls.

Effective dose and SSDE are two different radiation parameters. Effective dose estimates the dose by considering organ-specific radio sensitivities, whereas SSDE estimates the dose by considering the body habitus.

Discussion

In the present study, 180 participants were recruited and were divided into two subgroups based on their effective diameter, i.e., less than 25cm and more than 25cm. The division was made based on prior measurements of the effective diameter of patients who underwent CT studies of the abdomen and pelvis in the radiology department. In a similar study conducted by Waszczuk et al. (2015) [8] in Poland, the patients were divided into three subgroups based on their effective diameter asless than 30cm, 30-35cm, and more than 35cm. The lower effective diameter brackets considered in the current study was based on the body morphometrics of Indian patients.

The case group with effective diameters less than 25cm had a 30 % decrease (1.4 times reduction) in SSDE, while the case group with effective diameters greater than 25cm had a 7.4 percent decrease (1.1 times reduction) in SSDE compared to the control group. As the absorbed radiation dose depends on the patients' dimensions, the errors due to size dependence were eliminated by matching the effective diameter. The study by Waszczuk et al. (2015) [9] showed a significant decrease in SSDE by factors of approximately 2.7, 3.4, and 2.8 among the renal colic subgroups, i.e., those with less than 30cm, 30-35cm, and more than 35cm respectively. Our results are in contrast with the report of a study by Christner et al. (2012), [10] in the USA, in which the SSDE was independent of size. However, in the other published studies (Poletti et al. 2007; [11] Kim et al. 2005; [12] Moore et al. 2015), [13] the SSDE was not considered.

Using the ICRP 103-based conversion factors (Valentin 2007), [14] the case group had a 35.6% reduction in effective dose compared to the control group with an effective diameter of less than 25cm, while SSDE was reduced by 30.2% among cases. For cases with an effective diameter greater than 25cm, there was a 15.8% reduction in effective dose compared to controls, and a 4.6% reduction in SSDE was observed. Notably, the effective dose and SSDE are different parameters for determining the radiation dose.

The effective dose considers the organ-specific radio sensitivities to estimate the dose and is based on an idealized phantom which merges the relative weightage of individual radiosensitive organs to estimate the dose to the patient. The SSDE estimates the dose based on body habitus, body wall thickness, and organ placement, using linear dimensions obtained from acquired images and yields a more appropriate estimate of the absorbed dose rather than presuming an absolute linear relationship between the CTDI and the absorbed dose measured with a 32cm-phantom (Boone et al. 2011). [15] SSDE is a patient radiation dose estimate and applies to individuals, whereas the effective dose can be applied to a population group.

Also, the effective dose represents the dosage to a patient population and was formulated to be applied on a population of varied range, but which would require similar scanning parameters to maintain image quality, rather than an individual, whereas the SSDE can be used as a modality for estimation of individual radiation exposure (Brink and Morin 2012). [16]

In the study conducted by Brady and Kaufman (2012) on phantom models, it was concluded that CTDIvol values resulted in errors in calculations of radiation dose in different weight categories ranging from 28-66 percent. Since the weight of the patients was not assessed in the current study, the comparison of the variation in SSDE and CTDIvol with respect to weight categories was not feasible. The current study yielded that there was a significant difference in the radiation dose in SSDE and CTDIvol among the cases and controls when the effective diameter was considered, ranging from 28-60 percent. [17]

The current study assessed the subjective image quality based on attenuation values, noise, and SNR variation in abdominal organs. The case group had higher image noise while the control group had higher SNR, likely due to reduced dose causing increased noise and heterogeneity of the obtained images in the case group. The contrast evaluated by using CNR showed a significant difference in the liver-spleen in both groups, possibly due to varying levels of fatty infiltration in the liver resulting in heterogeneous attenuation values. A similar study conducted by Waszczuk et al. (2015) assessed subjective image quality and concluded that although SNR was higher in the control group, there was no significant difference in CNR. The reduction in dose can cause increased image noise and SNR reduction, but this is acceptable if the clinical diagnosis remains unaffected by the protocol. In the current study, the subjective image analysis was performed by two experienced radiologists, and the visibility of parts of the ureter was graded as good for 72% among the cases with less than 25cm effective diameter, and 67% for the corresponding control group, with visibility of pelvic ureter and VUJ being superior in the case group. Similarly for the group with effective diameter of >25 cm, ureter visibility was graded as good for 91% and 84% among the cases and controls respectively, with visibility of the pelvic ureter being better in the case group.

In the current study, the case groups received a tube voltage of 100 kVp, whereas the control group was subjected to a tube voltage of 120 kVp, ensuring that the subjects weren't irradiated twice. Studies by Poletti et al. (2007), Waszczuk et al. (2015), and Kim et al. (2005) employed a tube voltage of 120 kVp for both standard and low dose protocols. The study by Moore etal. (2015) used a tube voltage of 120 kVp for the standard dose protocol and 80-100kVp for the low dose protocol.Koteshwar et al. (2016) employed 120 kVp for both low dose and standard dose. Patients in studies by Poletti et al. (2007), Kim et al. (2005), and Moore et al. (2015) received double radiation exposure. Mulkens et al. (2007), classified their patients based on their body mass index and the routine dose protocol employed a tube voltage of 130 kVp while reduced dose protocol employed a tube voltage of 110 kVp with the 6-MDCT (Emotion 6, Siemens) machine. With the 16-MDCT (Sensation 16, Siemens) machine, both the protocols employed 120 kVp.

For the cases in the current study, a tube current of 90mAs was fixed for the case group with an effective diameter of 25cm. In the control group, automatic tube current modulation was used. Waszczuk et al. (2015), in their study also utilized automated tube current modulation with a fixed noise index for both low-dose and standard-dose groups. However, Moore et al. (2015), in their study employed automatic tube current modulation for standard doses only, while the low-dose group received 50-150mAs.Kim et al. (2005) administered 260mAs for the standard group and 50mAs for the control group, while Poletti et al. (2007) used 180mAs for the standard group and 30mAs for the control group. In a study by Koteshwar et al. (2016), the tube voltage for the standard dose was 250mAs, while 70mAs was used for the low-dose protocol.

The current study did not calculate the sensitivity and specificity of SSDE based low dose protocol, as the patients were not irradiated twice. Similar study by Kim et al. (2005) found that their low-dose protocol had the same diagnostic performance as the standard dose for alternative diagnoses, but it had a smaller number of such cases (7%). Further, the study by Moore et al.(2015) concluded that elderly patients had a higher chance of alternative diagnosis than younger patients, and hence low or ultra-low dosage should be more useful in the younger group of patients. Additionally, the study by Poletti et al. (2007) reported that although the low dose CT was able to pick up an alternative diagnosis, the percentage of them was too low (4.8%) for statistical comparison.The study by Koteshwar et al (2016) found that the low dose protocol was as sensitive as the standard dose for detecting alternative diagnoses.

In the current study, the patients were stratified into two subgroups, based on their effective diameter (those with <25cm and >25cm). Cases from both the subgroups showed reductions in mean SSDE by factors of 1.4 and 1.1 times, respectively, with the maximum reduction seen in the <25cm group. Similarly, in the Waszczuk et al.(2015) study, the renal-colic group had lower radiation dose descriptors compared to the standard-dose CT group, and the three subgroups (<30cm, 30-35cm and >35cm) within the renal colic group showed reductions in mean SSDE (2.7, 3.4, and 2.8 times, respectively) with the maximum reduction being observed in the 30-35cm group.

Very few prospective studies have been published in India considering SSDE as radiation dose descriptor in CT done for renal colic patients.The study had a few limitations. The comparison between the study population was made on the body habitus (effective diameter) paired population and not on the same individuals twice due to ethical considerations. The case and control population were subjected to different exposure parameters, automatic exposure being enabled in the control group only, which could have affected the results.

Conclusion

Our study showed that using SSDE as a measure of absorbed radiation dose in renal colic patients was more effective than the usual CT radiation dose descriptors. Our study also showed that there was an increase in image noise and reduction in SNR due to the use of low dose protocols, however itcan be tolerated if the clinical diagnosis is not affected by the protocol. Our findings suggest that further adjustments in radiation dose parameters can be done for patients with smaller effective diameters.

It is imperative to reduce the radiation dose if there is a tolerable increase in image noise, and the diagnostic information of the images is acceptable. The SSDE can be used as a standard descriptor of patient's absorbed radiation dose, especially for patients with relatively less effective diameter, where the CTDIvol is described to cause underestimation of dose (Boone et al. 2011). The SSDE has a potential use in helping formulate newer CT protocols based on the patient's body habitus.

References

1. Boone JM, Strauss KJ, Cody DD, McCollough CH, McNitt-Gray MF, Toth TL, Goske MJ. 2011. Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations. Maryland: American Association of Physicists in Medicine. Report No. 204 Available from: https://aapm.org/pubs/reports/rpt_204.pdf
2. Brady SL, Kaufman RA. Investigation of American Association of Physicists in Medicine Report 204 Size-specific Dose Estimates for Pediatric CT Implementation. Radiology. 2012; 265(3):832–840.
3. Brink JA, Morin RL. 2012. Size-specific Dose Estimation for CT: How Should It Be Used and What Does It Mean? Radiology. 265(3): 666–668.
4. Christner JA, Braun NN, Jacobsen MC, Carter RE, Kofler JM, McCollough CH. 2012. Size-specific Dose Estimates for Adult Patients at CT of the Torso. Radiology. 265(3):841–847.
5. Denton ERE, Mackenzie A, Greenwell T, Popert R, Rankin SC. Unenhanced helical CT for renal colic - is the radiation dose justifiable? Clinical Radiology. 1999; 54(7):444–447.
6. Kim BS, Hwang IK, Choi YW, Namkung S, Kim HC, Hwang WC, Choi KM, Park JK, Han TI, Kang W. Low-dose and standard-dose unenhanced helical computed tomography for the assessment of acute renal colic: prospective comparative study. Acta Radiol. 2005; 46(7): 756–763.
7. Koteshwar P. Low Dose MDCT with Tube Current Modulation: Role in Detection of Urolithiasis and Patient Effective Dose Reduction. JCDR. 2016.
8. McCollough CH. CT Dose: how to measure, how to reduce. Health Physics. 2008; 95(5): 508–517.
9. McCollough CH, Cody D, Edyvean S, Geise R, Gould B, Keat N, Huda W, Judy P, Kalender W, McNitt-Gray M, Morin R, Payne T, Stern S, Rotherberg L, Shrimpton P, Timmer JT. 2008. The Measurement, Reporting, and Management of Radiation Dose in CT. New York: American Association of Physicists in Medicine. Report No. 96.
10. Moore CL, Daniels B, Ghita M, Gunabushanam G, Luty S, Molinaro AM, Singh D, Gross CP. Accuracy of Reduced-Dose Computed Tomography for Ureteral Stones in Emergency Department Patients. Annals of Emergency Medicine. 2015;65(2):189-198.e2.
11. Mulkens TH, Daineffe S, De Wijngaert R, Bellinck P, Leonard A, Smet G, Termote J-L. Urinary Stone Disease: Comparison of Standard-Dose and Low-Dose with 4D MDCT Tube Current Modulation. American Journal of Roentgenology. 2007;188(2):553–562.
12. Poletti P-A, Platon A, Rutschmann OT, Schmidlin FR, Iselin CE, Becker CD. Low-Dose Versus Standard-Dose CT Protocol in Patients with Clinically Suspected Renal Colic. American Journal of Roentgenology. 2007; 188(4):927–933.
13. Rob S, Bryant T, Wilson I, Somani BK. Ultra-low-dose, low-dose, and standard-dose CT of the kidney, ureters, and bladder: is there a difference? Results from a systematic review of the literature. Clinical Radiology. 2017; 72(1):11–15.
14. Smith RC, Rosenfield AT, Choe KA, Essenmacher KR, Verga M, Glickman MG, Lange RC.. Acute flank pain: comparison of non-contrast-enhanced CT and intravenous urography. Radiology. 1995;194(3):789–794.
15. Smith RC, Verga M, McCarthy S, Rosenfield AT. Diagnosis of acute flank pain: value of unenhanced helical CT. American Journal of Roentgenology. 1996;166(1):97–101.
16. Valentin J. The 2007 recommendations of the International Commission on Radiological Protection. Oxford: International Commission on

Radiological Protection. 2007. Publication No.103. Available from https://www.icrp.org/docs/ICRP_Publication_103-Annals_of_the_ ICRP_37(2-4)-Free_extract.pdf

17. Waszczuk ŁA, Guziński M, Czarnecka A, Sąsiadek MJ. Size-Specific Dose Estimates for Evaluation of Individual Patient Dose in CT Protocol for Renal Colic. American Journal of Roentgenology. 2015;205(1):100–10 5.