Original Article

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Comparison Between Low-Dose and Standard-Dose Computed Tomography for Diagnosis of Urolithiasis

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Abstract

Background: Urolithiasis is the condition where there are calculi in the urinary system and the current study was implemented to evaluate the diagnostic performance of low-dose Computed Tomography (CT) with standard-dose CT for detection of urolithiasis. **Subjects & Methods:** Eight hundred thirty-seven individuals Individuals with clinically/sonographically suspected urolithiasis and referred for Computed Tomography (CT) evaluation at the Radiodiagnosis department were screened for the study. The study was conducted in two stages. During the first stage, individuals underwent an NCCT scan (Philips 16 slice CT scanner) with the standard-dose protocol as per the current management strategy. Individuals with CT evidence of urolithiasis were included in the second stage of the study where they were given with low dose CT. After excluding many subjects, 148 patients underwent standard-dose CT for the evaluation of urolithiasis. Additionally, 23 patients were referred directly for CT due to high clinical suspicion of urolithiasis, constituting 171 patients who underwent NCCT KUB. Among patients who underwent CT scan 16 patients were excluded from the study as no calculus was detected on NCCT. **Results:** Urolithiasis was seen in 155 patients who met the inclusion criteria. Among these, 26 patients declined for low-dose CT, nine patients had BMI > 35 kg/m^2 and 16 patients were of age <18 years and hence were excluded from the study. Finally, 104 patients underwent low-dose CT and were included in the final analysis. The use of low tube potential setting by tube voltage reduction of 15% significantly reduced radiation dose by approximately 31% in patients undergoing CT for evaluation of urolithiasis, irrespective of their BMI. **Conclusion:** A combination of reduced tube potential and AEC helps to achieve optimum results for the diagnosis of urolithiasis. The study strongly supports the use of low-dose CT for diagnosis and follow-up of urolithiasis in patients who are not morbidly obese.

Keywords: Urolithiasis, low-dose CT, standard-dose CT, Body mass index, Diagnostic accuracy.

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Introduction

Urolithiasis can be defined as the occurrence of calculi in the urinary tract, which includes kidneys, ureters, bladder and urethra. Patients who present with renal calculi often undergo multiple imaging studies before, during, and after treatment. Additionally, these patients are at high risk of recurrence, with recurrence rates as high as 75% in 20 years3,1. Conventional radiography and sonography do not have a high diagnostic yield. Alternatively, excretory urography, although an excellent investigation, is invasive, sometimes painful, and potentially time-consuming. It does not have high sensitivity and specificity as compared with computed tomography (CT) scan. In comparison, CT has shown high sensitivity of 94-100% and specificity of 97%4. However, among its disadvantages, the risk of ionizing radiation is perhaps the most significant. CT is a major contributor towards medical radiation and barring natural background sources, it is the largest source of radiation to mankind. Standard-dose CT for urolithiasis is associated with radiation exposure ranging from 8 to 16 mSv. A significant dose reduction is plausible due to the high contrast difference between the majority of urinary tract calculi and the surrounding soft tissue. Various studies have compared the efficacy of low dose CT with standard-dose CT for evaluation of urolithiasis. The results from all these studies have shown that low-dose CT is effective for the detection of urolithiasis and these studies recommend the use of low-dose CT for the detection of urolithiasis considering the reduced risk of radiation without affecting specificity and sensitivity as compared with standard-dose CT scan.[1–9] However, to our knowledge, there are very few studies conducted in the Indian subcontinent comparing standard-dose and low-dose CT. It is therefore necessary to obtain data on the use of low-dose CT when compared with standard-dose CT in this population. Hence, the current study has been planned to assess the efficacy and potentiality of low-dose CT with standard-dose CT for the detection of urolithiasis and to help formulate appropriate strategies for diagnosis and follow-up of urolithiasis.

Subjects and Methods

Source of data: Individuals with clinically/sonographically suspected urolithiasis and referred for CT evaluation at the Department of Radiodiagnosis, GITAM Institute of Medical Sciences and Research, Visakhapatnam were screened for the study. Informed consent was taken from individuals for their willingness to participate in the study. Individuals who met the inclusion/exclusion criteria were included in the study. The study was conducted over a period of 18 months from January 2018 to June 2019. All the patients underwent standard-dose CT before entering the study.

Inclusion Criteria:

- Individuals aged 18 years and above.
- Patients in whom renal/ureteric calculi are seen on standard-dose CT

Exclusion Criteria:

- Pregnancy.
- Women of childbearing age, unless they have undergone appropriate sterilization.
- BMI >35 kg.m^{-2}.
- Presence of suspected co-morbidities such as acute appendicitis.
- Moribund patients.

The concern with this study evaluating the efficacy of low-dose vs standard-dose CT for evaluation of urolithiasis is the risk of additional radiation with the low-dose protocol. The American Association of Physicists in Medicine (AAPM) has stated that ”Risks of medical imaging at effective doses below 50 mSv for single procedures or 100 mSv for multiple procedures over short time periods are too low to be detectable and may be non-existent. Hence this study is well within acceptable limits for risks associated with radiation exposure. Additionally, patients with BMI > 35 kg.m^{-2} were not included as current guidelines do not recommend low-dose CT in morbidly obese patients.

Method of collection of data: This study was approved by the institutional review board and informed consent was taken from all the individuals before inclusion in the study. The study was conducted in two stages. During the first stage, individuals underwent an NCCT scan (SIEMENS® SOMATOM EMOTION® 16) with the standard-dose protocol as per the current management strategy. Individuals with CT evidence of urolithiasis were included in the second stage of the study. Individuals, who did not demonstrate urolithiasis on standard-dose CT were excluded from Stage 2 and not included in the study. During Stage 2, for individuals in whom the standard-dose CT showed the presence of urolithiasis, an additional NCCT with the low-dose protocol was performed. Both the scans were performed in a single setting. The mAs delivered to the patient and the dose received by the patient were accurately provided by the CT equipment after the completion of each protocol and this data was recorded. Baseline demographic data was collected, which included the gender and BMI status and the patients were grouped based on the BMI to evaluate whether BMI has any impact on the detection of calculi with low-dose CT protocol.[10]

Computed tomography protocol: The following were the parameters for standard-dose and low-dose CT protocol. Standard Dose CT

- kV – 130 kV
- Tube current – Based on the BMI the tube current varied as per the CARE Dose 4D®, the AEC software present in our current CT scanner.
- Slice thickness – 5 mm acquisition reconstructed to 1.2 mm slice thickness
- Multiplanar reconstruction using the standard algorithm as and when required

Low Dose CT

- kV – 110 kV
- Tube current – Based on the BMI the tube current varied as per the CARE Dose 4D®, the AEC software present in our current CT scanner
- Slice thickness – 5 mm acquisition reconstructed to 1.2 mm slice thickness
- Multiplanar reconstruction using the standard algorithm as and when required

Calculation of Effective Dose:

The effective dose was calculated as the product of DLP X f (the conversion factor). The CT scanner provided the DLP data. The conversion factor for CT abdomen and pelvis is 0.015 mSv/mGy cm. Hence the effective dose was calculated using Microsoft Excel® based on the following formula

Effective dose (in mSv) = DLP (in mGy cm) X 0.015 mSv/mGy cm.

Image Assessment:

Two experienced radiologists reviewed the scans. The radiologists were blinded to the type of scans (130 kVp and 110 kVp) and they assessed the studies independently. The radiologists were however aware of the clinical history and probable diagnosis in all the patients. Each study was evaluated by both the radiologists in random order and the results were compared. The confidence level of each radiologist was also evaluated on 3-point scale (1 = no confidence, 2 = confidence with reservation and 3 = highly confident). The radiologists evaluated the studies concerning the number, location and size of urolithiasis, and the presence of hydronephrosis/hydroureteronephrosis independently in each data set.

Statistical Analysis: Data was recorded into Microsoft Excel and was analyzed using Open Epi software. All the data were presented as mean ± SD. For radiation dose and mean mAs delivered, a paired t-test was performed to compare both the groups. Since each patient served as his/her own control, the results obtained in the standard-dose group were considered as standard and findings from the low-dose group were compared with the standard-dose group. Sensitivity and specificity for the low-dose group were compared with results obtained from the standard-dose group. A p-value of <.05 was considered statistically significant. The interobserver agreement among both the radiologists was evaluated for both the groups using kappa (κ) statistics: $\kappa \leq 0.2$ indicated poor agreement; κ of 0.21 to 0.40 indicated fair agreement, κ of 0.41 to 0.60 indicated moderate agreement, κ 0.61 to 0.80 indicated good agreement and κ of 0.81 to 1.00 indicated excellent agreement.

Results

A total of 837 individuals with clinically suspected urolithiasis who underwent ultrasonography were screened for the study. Among these, 603 patients were excluded from the study due to the absence of ultrasonography features of renal and/or ureteral/vesicoureteral junction calculus (evidenced by the absence of renal calculus, hydronephrosis/ hydro ureteronephrosis), and were treated symptomatically. Nearly thirty-five patients had ureteric/vesicoureteric junction calculus or renal calculus, which was diagnostic and therefore they were not referred for CT and underwent further management for calculi. Fifty-one patients who had ultrasonography features suggestive of calculus refused for CT scan and were therefore treated conservatively. Thus a total of 689 patients did not undergo CT evaluation. A total of 148 patients underwent standard-dose CT for the evaluation of urolithiasis. Additionally, 23 patients were referred directly for CT due to high clinical suspicion of urolithiasis, constituting a total of 171 patients who underwent NCCT KUB. Among patients who underwent CT scan 16 patients were excluded from the study as no calculus was detected on NCCT. Urolithiasis was seen in 155 patients who met the inclusion criteria. Among these, 26 patients declined for low-dose CT, nine patients had BMI > 35 kg/m^2 and 16 patients were of age <18 years and hence were excluded from the study. Finally, 104 patients underwent low-dose CT and were included in the final analysis.

A total of 104 patients were included in this study. In our study, most of the patients were in the BMI category of 25-30 kg/m^2 (40.4%) and 18‑25 kg/m^2 (36.5%) [Table 1]. There were only 11 patients in the BMI category <18 kg/m^2 (10.6%). In our study most of the patients were males (n = 85; 81.7%) and few are females (n=19; 18.3%)

Table 1: Distribution of Patients Based on BMI Category

BMI Category (kg/m^2)	No of patients	%
<18	11	10.6
18-25	38	36.5
25-30	42	40.4
30-35	13	12.5
Total	104	100

A total of 428 calculi were observed across 104 patients in both the standard- and low-dose groups (range: 1 to 19 calculi/patient). None of the calculi seen in the standard-dose CT scan was missed by the low-dose CT scan. A size correlation for calculi was performed on the basis that any calculus less than 3 mm is unlikely to cause symptoms and therefore is not significant. Therefore, calculi of size 2 mm or more has been considered for comparison. There was an excellent correlation concerning the size of calculus in both groups. Calculi size ranged from 2 mm to 23 mm, largest was a staghorn calculus. The sensitivity for detection of calculi in both the standard- and low-dose groups was considered to be 100% as none of the calculi seen on standard-dose CT were missed on low-dose CT. Similarly, there was an excellent inter-observer agreement with a κ value of 0.99. None of the calculus seen by radiologist 1 was missed by radiologist 2 and vice versa [Table 2].

[Table 3] shows the location and distribution of calculi seen at different locations. The majority of the calculi were in kidneys (53.4%) and least in the urinary bladder (2.4%) (Table-3). All the cases with PUJ calculus demonstrated hydronephrosis and all the cases with ureteric and VUJ calculus demonstrated hydroureteronephrosis. Hydronephrosis was seen in seven patients on the right side and six patients on the left side and hydroureteronephrosis were seen in 35 patients on the right side and 41 patients on the left side. One patient had both right PUJ and right ureteric calculus and one patient had both ureteric and VUJ calculus on the right side. One patient had both ureteric and VUJ calculus on the left side. Eight patients had bilateral hydroureteronephrosis and one patient

Table 2: Interobserver Sensitivity for Detection of Calculi in Standard- and Low-Dose Groups

Reader	Standard-dose CT (sensitivity)	Low-dose CT (sensitivity)	% difference in sensitivity	p-value
1	428/428 (100%)	428/428 (100%)	Nil	NS
2	428/428 (100%)	428/428 (100%)	Nil	NS
1 and 2	856/856 (100%)	856/856 (100%)	Nil	NS

NS = not significant

Table 3: Location and Distribution of Calculi

Location of calculus		Number of patients	%
Right	Renal	60	28.8
	PUJ	8	3.8
	Ureteric	30	14.4
	VUJ	6	2.9
Left	Renal	51	24.5
	PUJ	6	2.9
	Ureteric	31	14.9
	VUJ	11	5.3
Vesical	Vesical	5	2.4

PUJ = pelviureteric junction; VUJ = vesicoureteric junction

had bilateral hydronephrosis [Figure 1].

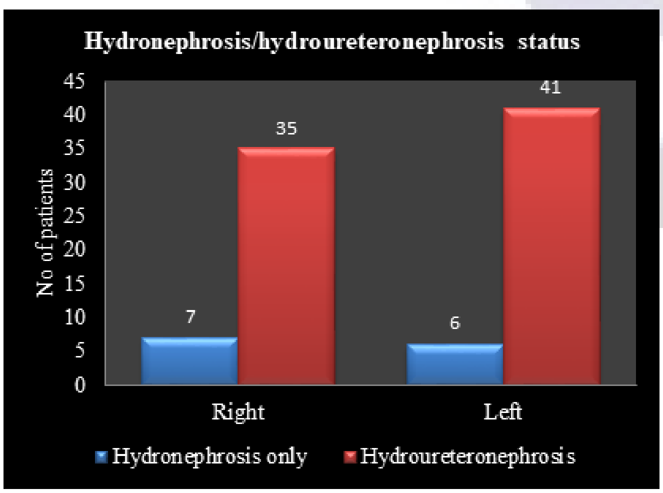

Figure 1: Status of hydronephrosis and hydroureteronephrosis

The mean effective radiation dose in the standard-dose group was 6.04 ± 2.11 mSv (mean ± SD) (range: 2.63 to 15.39 mSv) mSv is Milli Sievert and in the low-dose group was 4.16 ± 1.47 mSv (mean ± SD) (range: 1.84 to 9.86 mSv) with a mean difference of 1.88 ± 0.69 mSv (mean ± SD) (range: 0.71 to 5.53 mSv) between the groups [Figure 2].

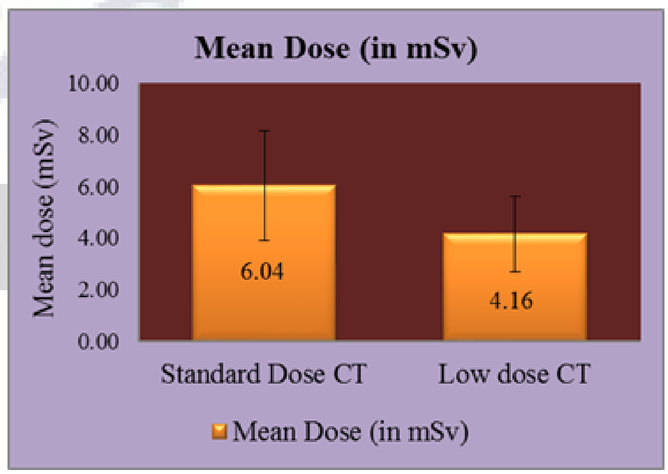

Figure 2: Mean CT radiation dose (in mSv) across standard-dose and low-dose groups.

There was an overall reduction of radiation dose by 31.21 ± 3.15% (mean ± SD) (range: 22.45% to 41.4%) in the low-dose group compared with the standard-dose group, which was statistically significant ($p<.0001$).

The mean mAs (Milli Ampere second) delivered in the standard-dose group was 129.4 ± 47.15 mAs (mean ± SD) (range: 61 to 244 mAs) and across the low-dose group was

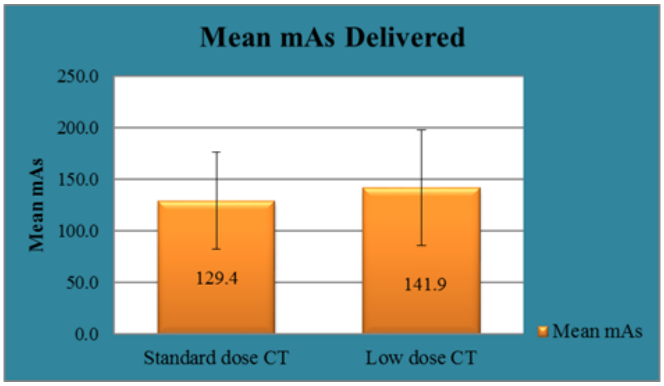

Figure 3: Mean mAs delivered across standard-dose and low-dose groups.

141.9 ± 55.95 mAs (mean ± SD) (range: 63 to 310 mAs). There was an increase in the mean mAs in the low-dose group by about 8.83 ± 5.48% (mean ± SD) (range: 3.28% to 53.46%); however, this difference was not statistically significant (p = .08) across the study [Figure 3].[Table4 & Table5]

Similarly, a comparison between the increase in tube current with both standard and low dose CT was evaluated across BMI groups. [Table 6] shows the mean mAs delivered across the BMI categories. There was a non-significant increase in tube current with low-dose CT protocol in the BMI categories <18 and 18-25 group, whereas the difference in tube current in BMI categories 25-30 and 30-35 group assumed statistical significance (P = .03 and P = .008 respectively). Figure-4 shows the various locations of calculi.

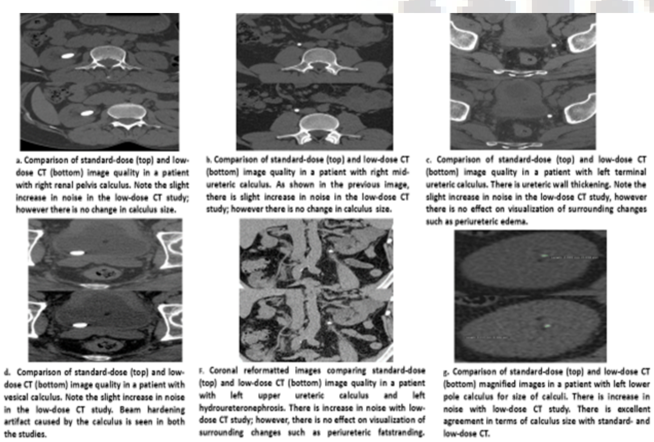

Figure 4: CT images show the location of calculi at various sites

Discussion

In urology practice, diagnostic evaluation and management of renal calculi account for a sizeable portion of day-to-day practice. Patients with renal calculi have a high risk of recurrence and often need to undergo multiple imaging studies before, during, and after treatment.[2] The increasing use of CT has made it the commonest cause of medical radiation.[5,6] The increase in several CT studies being conducted every day indicates that the background radiation from CT studies is going to increase. It is therefore necessary to reduce radiation from CT wherever possible.[10] A multicentric study by Ferrandino et al. (2009),[11] evaluated the effective radiation dose received due to CT studies in individuals with acute renal calculi episodes and short-term follow-up. They observed that up to 20% of patients received a radiation dose of > 50 mSv, which is the recommended annual dose limit for short term studies.[2] Various studies have shown the efficacy of low-dose CT protocol for diagnosis of urolithiasis,[7,12,13] There are very few studies, which have systematically compared low-dose CT protocol with standard-dose CT protocol in the same patient population and these studies have shown high sensitivity and specificity (up to 100%) for diagnosis of urolithiasis with low-dose CT. All the studies recommend the use of low-dose CT for the diagnosis of urolithiasis.[13–15]

In our study, we have compared the diagnostic yield with a low-dose CT scan when compared with a standard-dose CT scan in the same patient population. This model is better compared with randomizing patients to either standard-dose or low-dose study as was performed in the study of Mulkens et al. (2007),[16] Our study also has certain advantages over other evaluation models, which have employed artificial introduction of noise to mimic low-dose CT images. In those studies, it is possible that other factors that influence scan quality such as kVp, pitch, manufacturer, and important effect of tube current modulation may not be evaluated.[17]

The study utilized an automated tube current setting based on CARE Dose 4D software (Siemens®), which modulated tube current based on the patient's body habitus both in standard-dose and low-dose studies. Although, this model has not been explored fully for diagnosis of urolithiasis it holds significant promise.

In our study of 104 patients with 428 calculi, none of the calculi seen in the standard-dose CT were missed on low-dose CT. There was an excellent calculus size agreement. The dose reduction was similar across all the subgroups studied, irrespective of the BMI status. These results are comparable to the theoretical dose reduction, which states that the dose reduction is approximately proportional to the square of tube voltage change. In our study, the tube voltage reduction would have resulted in approximately 28.4% reduction in radiation dose. There are seen several studies, which have shown a

Table 4: Mean radiation dose (mSv) across all BMI category groups

BMI Category (kg/m^2	Standard dose		Low dose		P -value
	Mean dose	Standard deviation	Mean dose	Standard deviation	
<18	3.49	0.36	2.44	0.25	<.0001
18-25	4.53	0.69	3.07	0.51	<.0001
25-30	6.88	0.68	4.77	0.56	<.0001
30-35	9.88	1.86	6.79	1.19	<.0001
BMI = body mass index; mSv = milli Sievert					

Table 5: Mean Dose Reduction Across Subgroups vs Overall Study

BMI Category (kg/m^2)	Mean dose reduction	SD
<18	29.94	2.98
18-25	32.26	3.20
25-30	30.66	2.35
30-35	31.03	4.29
Overall*	31.21	3.15
*P>.05, BMI = body mass index; SD = standard deviation		

Table 6: Mean mAs Across all BMI Category Groups

BMI	Standard dose		Low dose		P -value
	Mean mAs	Standard deviation	Mean mAs	Standard deviation	
<18	77.55	18.57	82.00	19.32	0.59
18-25	95.34	25.59	102.21	27.56	0.26
25-30	150.24	26.18	163.62	29.11	0.03
30-35	205.62	21.99	238.77	34.98	0.008
BMI = body mass index					

higher reduction in radiation dose compared to our study.[18,19] A study by Fulghum et al. (2012) evaluated the reduction in radiation dose in abdominal CT when performed at 120 kV and 90kV using a phantom model. In their study, they observed that low-dose CT results in approximately 35% reduction in radiation dose compared to standard-dose CT.[20] All these study results have shown radiation dose reduction comparable to that obtained in our study, which is based on a reduction in tube potential together with AEC. The other techniques in which dose reduction can be achieved in the modern CT scanners include tube current modulation and using iterative reconstruction models. Currently, almost all of the CT scanner vendors have automatic tube current modulation or AEC. This allows the machine to modulate the radiation dose by changing the tube current-time product (mAs) depending on the patient's size and attenuation. This helps to optimize attenuation in various organs, such as the abdomen, which requires lower attenuation compared to other body parts such as shoulders.[19] The AEC used in our study is the CARE Dose 4D® (Siemens®). This technique makes use of effective mA and compensates helical pitch for given tube mA. It assesses the size and shape of the patient and automatically adapts the radiation dose based on these parameters. This dose optimization is achieved in two ways. The tube current is modified based on the program, where the machine compares the actual patient size to a ”standard-sized” patient. Additionally, AEC also takes into account the body part under evaluation as different body parts may require different mAs. Therefore, a smaller patient receives a smaller mAs dose and a heavier patient receives a larger mAs dose. Lastly, our study design was based on the AEC model, which can vary from machine‑to‑machine and is manufacturer specific. Some old generation machines may not have AEC modulation technology. Nonetheless, most of the scanners employ similar technology and the results can be extrapolated to other machines as well.[2,19]

Conclusion

We conclude that the use of low tube potential setting by tube voltage reduction of 15% significantly reduced radiation dose by approximately 31% in patients undergoing CT for evaluation of urolithiasis, irrespective of their BMI. Although there is an increase in the mAs to offset the increase in noise at lower tube potential settings, the use of AEC helps to achieve optimal dose reduction. AEC also helps to personalize the radiation dose received by each patient based on their BMI, thereby optimizing image quality. Therefore, a combination of reduced tube potential and AEC helps to achieve optimum results for the diagnosis of urolithiasis. We strongly support the use of low-dose CT for diagnosis and follow-up of urolithiasis in patients who are not morbidly obese.

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