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Low Dose MDCT with Tube Current Modulation: Role in Detection of Urolithiasis and Patient Effective Dose Reduction

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ABSTRACT

Introduction: Urolithiasis is one of the major, recurring problem in young individuals and CT being the commonest diagnostic modality used. In order to reduce the radiation dose to the patient who are young and as stone formation is a recurring process; one of the simplest way would be, low dose CT along with tube current modulation.

Aim: Aim of this study was to compare the sensitivity and specificity of low dose (70mAs) with standard dose (250mAs) protocol in detecting urolithiasis and to define the tube current and mean effective patient dose by these protocols.

Materials and Methods: A prospective study was conducted in 200 patients over a period of 2 years with acute flank pain presentation. CT was performed in 100 cases with standard dose and another 100 with low dose protocol using tube current modulation. Sensitivity and specificity for calculus detection, percentage reduction of dose and tube current with low dose protocol was calculated.

Results: Urolithiasis was detected in 138 patients, 67 were examined by high dose and 71 were by low dose protocol. Sensitivity and Specificity of low dose protocol was 97.1% and 96.4% with similar results found in high BMI patients. Tube current modulation resulted in reduction of effective tube current by 12.17%. The mean effective patient dose for standard dose was 10.33 mSv whereas 2.92 mSv for low dose with 51.13–53.8% reduction in low dose protocol.

Conclusion: The study has reinforced that low-dose CT with tube current modulation is appropriate for diagnosis of urolithiasis with significant reduction in tube current and patient effective dose.

Keywords: Body mass index, Diagnostic imaging, Low dose

INTRODUCTION

Diagnostic imaging has been a key part in evaluation of urolithiasis with plain radiograph being the initial imaging modality followed by ultrasonography. Due to low sensitivity of these modalities, unenhanced helical Computed Tomography (CT) was first used in 1995 for the detection of urolithiasis [1]. Though CT has a high sensitivity and has an additional advantage of suggesting an alternate diagnosis, the drawback is increased radiation dose to the patient, which is three to five times higher than that by Intravenous Urography (IVU) with three views [2]. To overcome this, low dose CT was introduced along with technical innovations like Tube Current Modulation (TCD) to reduce radiation exposure. TCD reduces effective dose without compromising on image quality by modulating the tube current continuously thereby adapting to the patients' anatomic characteristics during scanning [3,4].

AIM

Aim of our study was to compare the diagnostic performance of low dose (70mAs) unenhanced helical CT protocol with standard dose (250mAs) protocol with tube current modulation technique in detecting the presence of urolithiasis. We also compared the performance of low dose CT examination with regard to Body Mass Index (BMI). The mean effective tube current and dose delivered by low dose and standard dose CT protocol with tube current modulation was determined.

MATERIALS AND METHODS

This prospective study was conducted over a period of 2 years from January 2011 to December 2013 after obtaining institutional ethical committee clearance. Two hundred patients with acute flank pain/haematuria or with clinical suspicion of urolithiasis underwent unenhanced CT scan after obtaining informed consent. The body mass index was calculated in all patients and they were grouped according to the recommendations of the National Institute of Health [3] as follows: underweight (BMI <18.5 kg/m^2), normal (BMI range 18.5–24.9 kg/m^2), overweight (BMI range 25.0–29.9 kg/m^2), obese (BMI range 30.0–39.9 kg/m^2) and extremely obese (BMI >/= 40 kg/m^2).

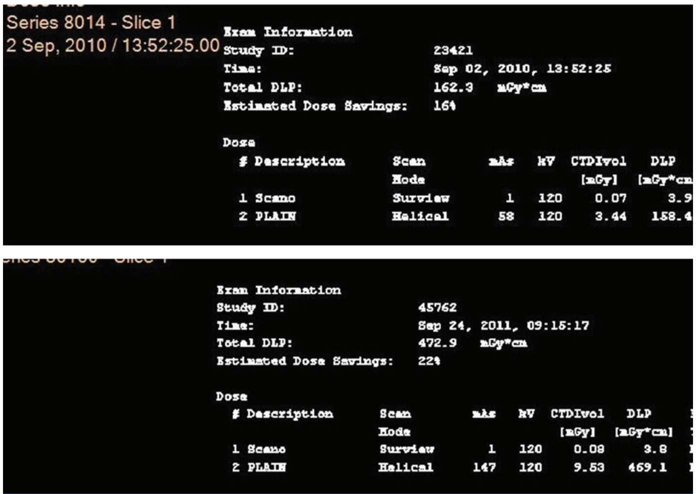
All underwent unenhanced CT on 64 slice (Brilliance 64- MDCT, Phillips) scanner with tube current modulation. Out of 200 patients, the first 100 patients were evaluated with low dose protocol (a tube current – 70mAs, tube voltage – 120 kV) and subsequent 100 patients with standard dose protocol (250mAs and 120 kV). Images were reconstructed in axial and coronal planes with 5mm thickness and 5mm interval.

All examinations were performed with a tube current modulation system (Z- DOM, Phillips Brilliance MDCT) which combined both z axis and x-y axis (angular) modulation. For each slice position, the CT system calculates the average tube current, expressed as average effective tube current throughout the exposure. The effective tube current is determined by dividing the product of tube current and rotation time by the pitch [4-6]. The mean effective tube current of the examination was displayed at the scan console which was recorded. The Brilliance 64- MDCT unit calculates CT Dose Index (CTDI) and DLP in each case and these values were displayed on the screen at the end of the examination [Table/Fig-1a&b].

Effective radiation dose was calculated by using conversion factors for a general anatomic region as described by the European Guidelines on Quality Criteria for Computed Tomography [7] which is based on the work of Jessen et al., [8]. In this approach, the Dose Length Product (DLP) is multiplied by a region specific conversion factor to estimate the effective dose. Conversion factor is 0.015 for abdomen and pelvis.

Data Collection and Image Analysis

Both the standard and low dose CT images were interpreted, in separate sessions, on PACS (Picture Archiving and Communication



[Table/Fig-1a&b]: (a) Display at the CT console giving CTDI, DLP and mean effective tube current (mAs) at the end of each examination in a patient examined under low dose protocol; and (b) standard-dose protocol.

System) by a junior resident (Reviewer A) and a senior radiologist (Reviewer B) of 2 and 5 years of experience respectively. The reviewers were aware of history of renal colic but were not aware of the side of pain, patient's BMI and the protocol used.

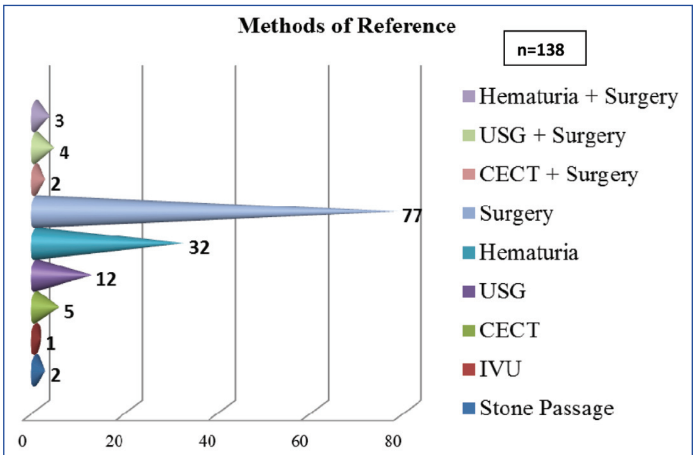
The following information was recorded:

1) Location of calculus - intrarenal or ureteric. Ureteric calculi were classified as proximal, mid, distal ureteric or VUJ calculus [Table/Fig-2]; 2) Presence of indirect signs like renal enlargement, hydronephrosis, perinephric or periureteric fat stranding and rim sign were documented. Rim sign is defined as an area of soft-tissue attenuation surrounding a suspended ureteral calculus that appears calcified [9]; 3) Presence of an alternative or additional diagnosis which could explain the patient's symptom; 4) Individual patient effective dose and tube current per examination for both low and standard dose protocols.

		Ureter			
	Renal	Proximal	Mid	Distal	VUJ
Right	119	5	5	11	11
Left	102	12	13	9	11

[Table/Fig-2]: Distribution of calculi.

The calculus was considered present if one of these gold standard methods of confirmation are met like surgical retrieval of stone, depiction of a calculus by IVU, standard-dose CT or both or on ultrasound within 24 hours and history of passing calculus followed by relief of pain or haematuria [Table/Fig-3].



[Table/Fig-3]: Various methods of confirmation of calculus disease.

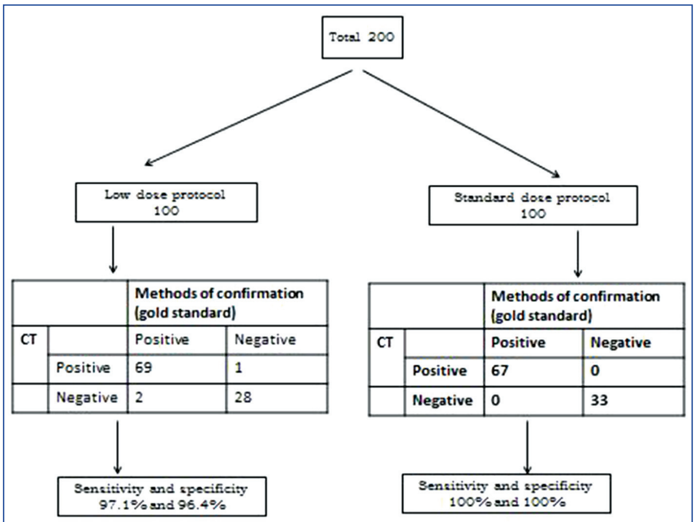
The calculus was considered absent if there was a negative microscopic urine analysis and relief of pain with no treatment or no history of passing calculus in urine and CT depiction of an alternative diagnosis and relief of pain after a specific treatment or a laboratory based alternative diagnosis e.g. pancreatitis.

STATISTICAL ANALYSIS

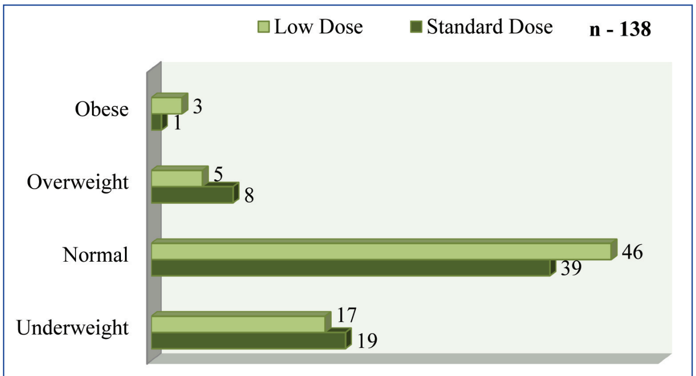
Statistical analyses were performed using Statistical Package for Social Sciences (SPSS) version 17. The intraobserver and inter-observer agreements were evaluated using kappa statistics. Sensitivity, specificity, negative predictive value, positive predictive value, and accuracy were calculated for both reviewers in both protocols. Percentage reduction in tube current with low dose protocol was calculated and patient effective dose in low and standard dose protocols were compared.

RESULTS

Unenhanced CT was done in 200 patients and 138 (69%) cases were found to be positive for calculus disease by final methods of confirmation and 62 were negative. Of the 138, 67 were examined by standard dose and 71 by low dose protocol [Table/Fig-4]. This difference in number was not statistically significant (Fisher's exact test, p = 0.67). The age of the patients ranged from 1 to 72 years with a mean age of 39.25 years. An 82% of the patients with urinary stone disease were in the age group of 21 to 40 years. Male to female ratio was 3.7:1. According to the recommendations of the National Institute of Health, [3] BMI was calculated and categorized [Table/Fig-5].



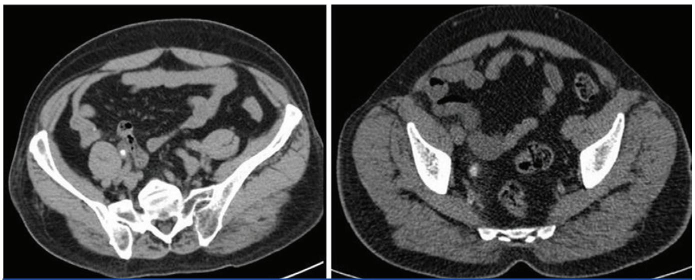
[Table/Fig-4]: CONSORT diagram of the study.



[Table/Fig-5]: Patient distribution with respect to BMI.

Hydronephrosis was seen in 82 patients out of 138. A total of 46 patients had no hydronephrosis but had calculus disease suggesting non obstructive calculus. In 10 patients (6 in standard 4 in low-dose protocol) with hydronephrosis, calculus was not detected on CT or confirmed by a method of reference. The causes were like megaureter, purulent flakes in ureter, emphysematous pyelonephritis. One case with distal ureteric stricture, missed on both low and standard dose. Rest of the patients likely had passed off calculi and was considered as true negatives.

Renomegaly found in 5 cases, (3 scanned by standard dose and two by low dose) 3 had ureteric calculus, while two had an alternative diagnosis of emphysematous pyelonephritis. Twenty 5 patients had perinephric-periureteric fat stranding. 3 did not have calculi and 2 had emphysematous pyelonephritis. Rim Sign was present in 7 patients with ureteric calculus out of which five patients scanned with low dose and two with standard dose [Table/Fig-6a&b]. Perinephric collection was seen in two patients and both patients had calculus disease, one each was scanned by standard and low dose protocol. Alternate or additional diagnosis was made in 29 patients of which 16 were scanned with standard dose protocol and 13 with low dose protocol [Table/Fig-7].



[Table/Fig-6a,b]: Distal right ureteric calculus in standard (a) and low (b) dose CT protocols showing rim sign on low dose CT image. Also note image quality was comparable.

Low Dose	
Alternate Diagnosis	**Frequency**
Ureteral Stricture	2
Megaureter	1
Inguinal hernia	1
Adnexal lesion	1
Osteitis condensa ilei	1
Pelviureteric junction obstruction	1
Emphysematous pyelonephritis	1
Ectopic Kidney	1
Cholelithiasis	1
Calcified lymphnodes	1
Bilateral pleural effusion	1
Acute pancreatitis	1

[Table/Fig-7]: Alternate diagnosis on low dose CT.

Tube Current Modulation, Effective Tube Current and Effective Radiation Dose

With the use of tube current modulation technique, mean effective tube current decreased in the standard-dose group to 211.5 mAs compared with reference level of 250 mAs and to 62.95 mAs in low dose group compared with reference level of 70 mAs. Tube current modulation reduced overall effective tube current by 12.17% in all examinations. The tube current modulation, however resulted in an increase in the effective tube current in 4 patients in high BMI low dose group which ranged from 107 to 175 mAs. If these patients were excluded, effective tube current would be in the range of 51–69 mAs. In 20 patients of high BMI, standard dose group effective tube current ranged from 257 to 341 mAs. If these patients were excluded, the effective tube current range would be 124-250 mAs. Spearman' correlation coefficient of 0.829 ($p<0.001$) for standard-dose and 0.856 ($p<0.001$) for low-dose examinations suggested good correlation between the mean effective tube current and BMI in each examination [Table/Fig-8].

The mean effective patient dose with standard and low dose protocol was 10.33 mSv and 2.92 mSv respectively. Low dose protocol reduced effective patient dose by 51.1%–53.8%. Paired T-test = 23.63 and $p<0.001$ suggesting statistically significant.

Tube current modulation reduced mean effective patient dose by 0-36 % in all examinations. Paired t-test = 3.729 and $p<0.001$ suggesting statistically significant.

Diagnostic Performance of Standard and Low-dose Protocols

The sensitivity, specificity of low dose protocol in detection of urolithiasis were similar to standard dose protocol [Table/Fig-9].

The interobserver agreement between Reviewer 1 and Reviewer 2 was excellent in both protocols. For the low dose protocol, kappa values were 0.821 ($p<0.001$) and overall kappa values were 0.977 ($p<0.001$). Overall image quality was comparable.

There were two false negative cases in low dose protocol and presence of a stone was confirmed by surgery in one case and by the presence of haematuria in the other. In one of the false negative patient the stone was misinterpreted as a phlebolith [Table/Fig-10a]. In the other due to a positive urine analysis and haematuria, it was considered as definitely having a stone and had likely been recently passed. No alternative diagnosis was shown during the follow up period. Only one false positive case reported where a calculus of ~2mm seen in the upper pole of kidney [Table/Fig-10b].

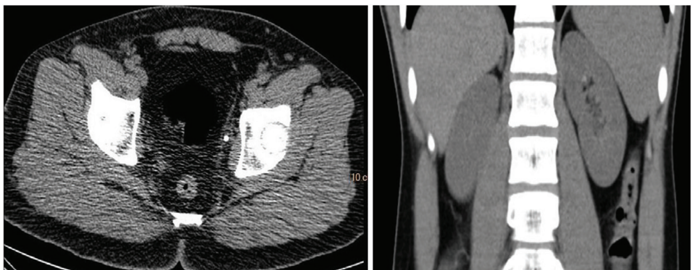
A total of 22 patients having high BMI underwent scanning with low dose CT. A total of 16 out of 22 patients showed calculi, of which 2 were in distal ureter and 2 at VUJ [Table/Fig-11a&b]. The sensitivity and specificity were 100%.

Protocol	Effective Tube Current (mAs)		BMI		Correlation between effective tube current and BMI
	Mean	Range	Mean	Range	
Standard Dose	211.5	124 - 341	22	15.7-35	0.829
Low Dose	62.95	51 - 175	21.7	16.5-35.3	0.856

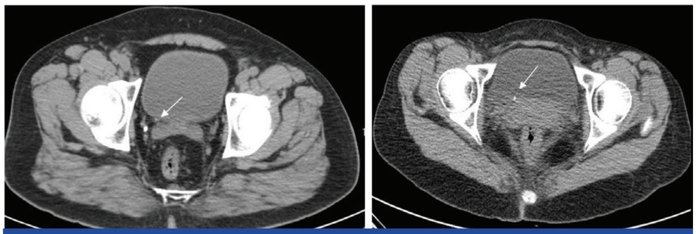
[Table/Fig-8]: Correlation effective tube current and BMI in both protocols.

Performance Characteristic	Reviewer 1			Reviewer 2		
	Standard Dose	Low Dose	Overall	Standard Dose	Low Dose	Overall
True Positive	66	68	134	67	69	136
False Positive	0	1	1	0	1	1
True Negative	33	28	61	33	28	61
False negative	1	3	4	0	2	2
Sensitivity(%)	98.5	95.7	97.1	100	97.1	98.5
Specificity(%)	100	96.4	98.5	100	96.4	98.4
PPV(%)	100	90	93.7	100	93.1	96.7
NPV(%)	97.05	87.1	92.3	100	90	95.2

[Table/Fig-9]: Comparison of performance of low and standard dose protocols.



[Table/Fig-10a,b]: Low Dose CT in 39 and 22 year old male with BMI 20 and 21.5, a) a hyperdense focus in the left hemipelvis was reported as a phlebolith. However, distal ureteric stone was found on surgery (False negative case) and, b) Hyperdensity (~2mm in size) in the upper pole of the left kidney was reported as a calculus, however, was not confirmed by a method of reference (False positive case).



[Table/Fig-11a,b]: (a) Right VUJ calculus of 2 mm clearly shown in standard; and (b) low dose protocol (BMI-29.20).

DISCUSSION

Unenhanced CT is preferred modality over excretory urography in detecting urolithiasis because of higher sensitivity and specificity, short procedure time and absence of contrast reactions with added advantage of detecting alternative or additional diagnosis. To reduce patient effective dose, tube current modulation technique was used along with low dose of 70 mAs which was found to be sensitive even in high BMI patients. We compared low-dose with standard-dose CT and used tube current modulation in both protocols. Using the Fisher's-exact test it was found that the difference in the number of stones detected by the standard-dose and low-dose groups was not statistically significant (p=0.67).

In patients with suspected renal colic, low dose protocol showed a sensitivity and specificity (Sensitivity: 97.1%; Specificity: 96.4%) which is comparable to that of standard dose protocol (Sensitivity: 100%; Specificity: 100%) with good interobserver correlation. This is similar to previous studies using single detector CT [1,10-13] or MDCT [14-17] with variable range of tube current.

In our study, there were two false negative cases both of which were assessed by low dose protocol. One was misinterpreted as phlebolith but was found to be calculus in distal ureter on surgery. In other case, no calculus was detected on CT and because of haematuria and positive urine analysis, it was considered as passed off calculus. This was similar to study by Mulkens et al., who reported phlebolith to be the cause of false positive and false negative causes, especially in distal ureter and VUJ [17]. There was another case with hyperdensity in kidney which was categorized as false positive. This could be because of heterogeneity of renal stroma causing it difficult to differentiate between hyperdense pyramids and small calculus [18].

Various studies have described low dose MDCT protocols for calculus detection using tube currents ranging from 30mAs to 70mAs [14,18]. In our study, the reference effective tube current level was decided on a subjective good quality image at low dose for normal BMI patients by consensus (by an experienced radiologist and technologist) at the start of the study. Tack et al., and Mulkens et al., concluded that low dose MDCT with 70 mAs was appropriate for diagnosis of stones and could be used as a standard procedure [15,17].

We evaluated 22 patients having high BMI using low dose CT, out of which calculus was found in 4 cases (18%). Mulkens et al., using low dose CT, found high sensitivity (97%) and specificity (100%) for overweight and obese patients (n-96) out of which 35 cases had ureteral calculus in pelvis or at VUJ [17]. Polleti et al., suggested to use standard dose CT in high BMI patients especially in distal ureteric or VUJ calculus because he found low sensitivity on low dose protocol [18]. However, they used tube current of 30mAs without tube current modulation.

The mean effective dose in our study was 2.92 mSv for low dose examinations as compared to 10.3 mSv for standard dose, thereby, showing a reduction of mean effective dose by approximately 51.14-54.32%. Paired t-test showed statistically significant difference (p<0.001) [11,18]. The mean effective dose was within the same range as that of the study by Mulkens et al., (51.2–64.3%) and Kalra et al., (43–66%). This is important as calculus disease is common in young individuals and is also a recurring disease, hence, radiation dose to the patient should be as low as possible. So low dose CT along with tube current modulation technique helped in reducing patient dose by 4-5 times without compromising the sensitivity and specificity for calculus detection. Patient dose was equal or slightly less than standard IVP procedure which is an important aspect [19,20].

Many of previous studies inferred that low dose protocols were not suitable for large or obese patients as they used a fixed tube current, hence, for obese patients it was recommended to use standard dose CT to achieve adequate image quality or to obtain additional acquisitions especially of the pelvis with high tube current [4,14,16,21] .

The use of automatic exposure control mechanism such as tube current modulation as in our study helped in optimizing radiation dose as was done in few previous studies [4,21]. The tube current modulation system reduced mean tube current by 12.17 %. There is a linear correlation between patient size and image quality, hence, the uniform reduction in radiation dose for all category patients cannot produce acceptable image quality. Although tube current modulation yields an overall reduction in the mean tube current, the mean tube current goes above the reference tube current for obese patients. The energy imparted in CT increases with patient size, but the corresponding effective dose is higher for smaller organs than for larger ones. Since pelvic organs (bladder, colon and gonads) account for a considerable part of the effective dose and are close to the center of pelvis, the effective dose should be lower in obese patients than in underweight ones. Hence, an increase in effective tube current settings in patients with a high BMI may not result in a higher effective radiation dose [15,17,22]. In our study, the highest effective dose (9.5mSv) in the low dose protocol was seen in an obese patient who underwent examination with an effective tube current of 175 mAs. However, this dose is lower than if standard dose protocol was used.

Mulkens et al., found good relation between the mean effective tube current of each examination and BMI and a wide dynamic range of mean effective tube current values in both low and standard dose groups [17]. The present study also found a good relation between the BMI and mean effective tube current values in each examination, however, the number of cases were less.

One of the major advantages of CT is to provide alternative and supplementary diagnoses [23].

In the present study, we correctly established the presence of alternative or additional diagnoses. However, the presence of a distal ureteric stricture can be missed on low as well as on standard dose, as happened in our study (n-1) which can be explained because of difficulties in tracing ureter and identifying subtle findings due to less abdominal fat. But, in high BMI patients in spite of good pelvic fat, it is difficult to identify subtle findings because of artifacts or grainy images.

LIMITATION

There were few limitations in our study. We did not compare standard- and low-dose protocols in the same patient at the same time. Similarly, low-dose protocols with and without tube current modulation in the same patient were also not compared. Using a supplemental radiation in a population with a large number of young and otherwise healthy patients is not ethical.

CONCLUSION

The performance of low dose protocol in detecting urolithiasis was comparable to that of standard dose protocol. Tube current modulation resulted in an additional reduction in effective tube current and effective dose without significant change in accuracy in detection of urolithiasis. Hence, we would like to reinforce that low-dose unenhanced MDCT with tube current modulation is appropriate for diagnosis of urolithiasis and does not obscure alternative or supplementary diagnoses, even in overweight and obese patients.

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