DOI: 10.7860/IJARS/2023/58851.2873

Radiology Section

Original Article

Evaluation of Renal/Ureteric Calculus Composition using Dual-Energy Computed Tomography: A Cross-sectional Study

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ABSTRACT

Introduction: Urolithiasis is a commonly encountered health problem, and knowledge of the chemical composition of stones is crucial in deciding the management approach and preventing recurrence. Pre-operative assessment of stone composition has become possible after the introduction of Dual-Energy Computed Tomography (DECT).

Aim: To compare the accuracy of DECT with biochemical analysis of postoperative stone samples.

Materials and Methods: A cross-sectional study was conducted in the Department of Radiodiagnosis, Mysore Medical College and Research Institute, Mysore, Karnataka, India, between January 2020 to June 2021 on 35 patients who met the inclusion and exclusion criteria. All the patients underwent a non contrast DECT scan of the Kidneys, Ureters and Bladder (KUB) on a 128-slice twin beam single-source DECT scanner. The stone composition was determined using pre-programmed software and was correlated with biochemical analysis. Proportions were compared using chi-square test of significance. The sensitivity and specificity of DECT was determined.

Results: Amongst the total 35 patients (mean age of 45.7±14.89 years, 23 patients males and 12 patients females) and 36 calculi analysed, The most frequently encountered calculus in the urinary tract was calcium oxalate n=24 (66.7%). The second most common calculus was Uric Acid (UA) n=5 (13.9%). The DECT findings regarding chemical composition of calculus were confirmed by Fourier Transformation Infrared Spectroscopy (FTIRS). The mean Dual-Energy (DE) ratio for oxalate, UA, hydroxyapatite, cystine and mixed stones was found to be 1.18, 1.01, 1.39, 1.09 and 1.11, respectively. DECT was found to be highly sensitive and specific in the diagnosis of calculi composition based on their DE ratio. It was found to be 95.8% sensitive and 100% specific for differentiating calcium oxalate stones from non oxalate stones and 100% sensitive and 96.8% specific for differentiating UA stones from non UA stones.

Conclusion: DECT has high diagnostic accuracy in the pre-operative determination of urinary calculus composition which will guide in management, as UA stones are open to medical therapy while most of the non UA stones need surgical intervention.

Keywords: Biochemical analysis, Calcium oxalate, Stones, Uric acid, Urolithiasis

INTRODUCTION

Urolithiasis is a common problem among people living in temperate climates and is associated with patient morbidity and hospital costs. The tendency for stone formation is lifelong. It is seen three times as often in men as in women [1]. It has been estimated that approximately 10% of affected patients will have a recurrence within 2 years and nearly 40% within 15 years [1]. Apart from the high incidence and recurrence rates, the study of urolithiasis is important because of complications like renal failure secondary to obstruction and hydronephrosis, urinary tract infections [2].

Management involves initial diagnosis, stone removal and prevention of recurrence. Treatment options may be conservative or surgical depending on the chemical composition, location and size of calculi, presence of anatomic and functional anomalies in the upper urinary tract [3].

Stones are of various mineral compositions and can either be relatively hard or soft depending on their fragility. Calcium oxalate monohydrate and dihydrate represent more than 80% of all urinary stones. The other components are UA, cystine, magnesium ammonium phosphate (struvite) and calcium hydrogen phosphate dihydrate (brushite). UA stones are known for being soft and are amenable to Medical Dissolution Therapy (MDT) or can be easily fragmented with Extracorporeal Shock Wave Lithotripsy (ESWL) [4]. ESWL is minimally invasive and is the preferred treatment but it is not effective for all stone types. Brushite and cystine stones are harder and hence resistant to lithotripsy. Thus, knowledge of the chemical composition is crucial in choosing the right management option and in predicting the treatment results. Also, the data on the chemical composition and contents of various uroliths may be useful in taking preventive measures for reducing the risk of prevalence and recurrence of urolithiasis in patients with metabolic disturbances [5].

Until recently, the authors did not have a diagnostic method to obtain such data before spontaneous expulsion or surgical removal of the calculus. This situation has changed after the introduction of DECT. Earlier, abdominal radiograph, ultrasound and intravenous urogram were used for the diagnosis of renal stones, but over the years, Non Enhanced Computed Tomography (NECT) using single energy and DE has taken the superior place [6].The advantage of DECT is its ability to provide material-specific information that is unavailable with single-energy CT without significantly increasing the radiation dose. It helps the clinician to decide the optimal treatment modality thus decreasing the financial burden on society due to unnecessary surgical procedures [7].

In the present study, the authors utilized a single-source twin-beam split-filter DECT at 120 kVp energy level with gold (Au) and tin (Sn) filters as compared to most of the previous studies which had used either dual-source DECT or single-source DECT with fast kV switching [2,6,8]. In this study, the primary aim was to determine the chemical composition of urinary stones using DECT attenuation values and to compare the accuracy of DECT with biochemical analysis of postoperative stone samples.

MATERIALS AND METHODS

A cross-sectional study was done at the Department of Radiology in Krishna Rajendra tertiary care hospital attached to Mysore Medical College and Research Institute, Mysore, Karnataka, India from January 2020 to June 2021. Approval from Institute Ethics Committee was obtained (EC REG: ECR/134/Inst/KA/2013/RR-16). Based on the inclusion and exclusion criteria, a total of 35 patients of either sex were included in the study after obtaining informed consent.

Inclusion criteria: Patients of all age groups referred from Urology/ Surgery Department to the Department of Radiodiagnosis for CT-KUB for urolithiasis were included in the study.

Exclusion criteria: Pregnant women, those patients in whom surgical stone extraction was not done and those patients who lost to follow-up were excluded from the study.

Procedure

Scanning protocol

All patients were subjected to a non contrast DECT scan of the kidneys, ureters, and bladder (CT KUB). The study was performed on a 128-slice Twin Beam Single Source DECT scanner (Somatom Definition Edge, Siemens Healthcare, Germany) as per our hospital protocol. The following imaging parameters were used: 120 kV, 150-250 mAs, 0.33 sec gantry rotation time and 128x 0.6mm collimation. A filter composed of gold (Au) and tin (Sn) is placed in front of the X-ray output which splits the 120 kV X-ray beam into a low energy (80 kV) and high energy (140 kV) x-ray spectrum before it reaches the patient.

Assessment

A total of 35 patients who were referred to the Department of Radiodiagnosis for CT KUB were studied using twin-beam DECT to determine the composition of urinary tract calculi. After image acquisition, the DE dataset was subjected to pre-programmed DE algorithmic software and analysed by syngo.via software. The images were read by an experienced radiologist. After placing the stone marker on the desired stone, the authors were able to get the DE ratio at Au/Sn120 kVp which was very accurate in further classification of non UA stones into calcium oxalate, cystine, hydroxyapatite and mixed type. The DE ratio was calculated as the ratio of the stone's CT attenuation at low- and high-energy spectra, after prior subtraction of a kidney-equivalent baseline value of 30 HU. This process is quick and it takes hardly less than a minute to characterise the stone after the acquisition.

They were followed-up to surgery and the 36 calculi extracted from these patients (one of the patients was operated for bilateral ureteric calculi) were subjected to biochemical analysis using Fourier Transformation Infrared Spectroscopy (FTIRS). According to FTIRS, the calculi were classified into five types- oxalate, hydroxyapatite, UA, cystine, and mixed stones. The biochemical composition of the stones was compared with the DECT composition.

STATISTICAL ANALYSIS

The sensitivity and specificity of DECT and FTIRS to the clinical diagnosis were determined. In addition to sensitivity and specificity, the positive and negative predictive values were calculated. Data analysis was carried out using Statistical Package for Social Sciences (SPSS) version 18.5 software.

RESULTS

The age of the patients ranged from 18 to 72 years with a mean age of 45.7±14.89 years. The highest numbers of patients were in the age group of 46-60 years (n=15) and the lowest number of patients were in the age group of 61-75 years (n=4) [Table/Fig-1]. Of the total 35 patients included in the study, 23 patients were males (65.7%) and 12 patients were females (34.3%).

Among 36 calculi analysed from 35 patients, 12 (33.4%) in the ureters and 2 in the urinary bladder (5.6%) [Table/Fig-2].The mean calculus size was 15.36±10.121 mm.

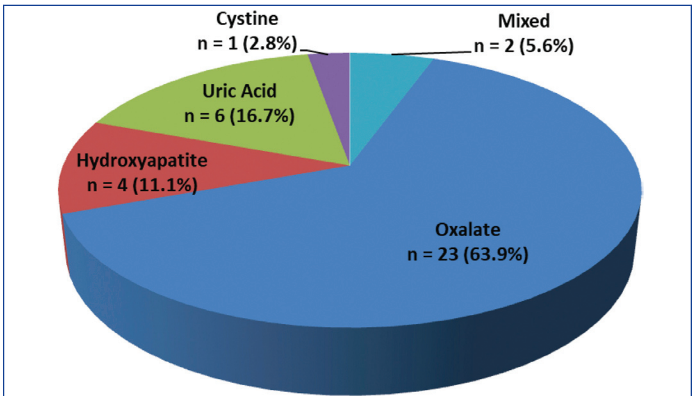
Age group (in years)	Frequency	Percentage
15-30	6	17.1
31-45	10	28.6
46-60	15	42.9
61-75	4	11.4
Total	35	100.0

[Table/Fig-1]: Age Distribution among the study population (n=35).

Site	Frequency	Percentage
Right kidney	12	33.3
Left kidney	10	27.8
Right ureter	6	16.7
Left ureter	6	16.7
Urinary bladder	2	5.6
Total	36	100.0

[Table/Fig-2]: Urinary stone distribution (Total calculi=36).

Out of 36 calculi analysed by DECT, the majority belonged to the non UA category (83.3%), and only 16.7% were UA calculi. 23 (63.9%) were calcium oxalate stones, 6 (16.7%) were UA stones, 4 (11.1%) were hydroxyapatite, 1 (2.8%) was cystine and 2 (5.6%) were mixed types of stones [Table/Fig-3].



[Table/Fig-3]: Distribution of type of calculus as per Dual-Energy Computed Tomography (DECT).

Post-extraction FTIRS revealed the chemical composition of stones as oxalate in the maximum number of cases (66.7%) followed by UA (13.9%), hydroxyapatite (8.3%), mixed (8.3%) and cystine (2.8%), respectively [Table/Fig-4].

Calculus type	Frequency	Percentage
Oxalate	24	66.7
Hydroxyapatite	3	8.3
Uric Acid	5	13.9
Cystine	1	2.8
Mixed	3	8.3
Total	36	100.0

[Table/Fig-4]: Type of calculus as per Fourier Transformation Infrared Spectroscopy (FTIRS).

On DECT, the mean CT attenuation values for low energy (Au filter) and high energy (Sn filter) were 1084.13±194.386 HU and 934.54±163.409 HU, respectively, for calcium oxalate (mean DE ratio= 1.18) [Table/ Fig-5,6].

Type of Stone	HU at Au120					HU at Sn120	
	N	Mean±SD	Min.	Max.	Mean±SD	Min.	Max.
Calcium oxalate	24	1084.13±194.39	768	1542	934.54±163.41	662	1231
Hydroxy apatite	3	1191.67±118.15	1100	1325	980.67±110.39	856	1066

Uric acid	5	520.20±29.11	472	546	492.60±27.55	453	530
Cystine	1	602.00±0.00	602	602	555.00±0.00	555	555
Mixed type	3	886.00±376.92	468	1200	761.00±276.72	450	980

[Table/Fig-5]: Comparison of mean HU of different calculi at 120kvp using Gold (Au) and tin (Sn) filters.
HU: Hounsfield unit

Type of stone	Dual-energy (DE) ratio				
	N	Mean	SD	Min.	Max.
Calcium oxalate	24	1.18	0.038	1.08	1.25
Hydroxyapatite	3	1.39	0.023	1.36	1.40
Uric acid	5	1.01	0.024	0.98	1.03
Cystine	1	1.09	.	1.09	1.09
Mixed type	3	1.11	0.137	0.95	1.20
Total	36	1.16	0.102	0.95	1.40

[Table/Fig-6]: Computed Tomography number ratios (Dual-Energy (DE) Ratios) of different stones.

On comparing the DECT findings with FTIRS, out of 4 cases diagnosed as hydroxyapatite, 3 were true positive while one was false positive (diagnosed as oxalate calculus on FTIRS). Of the 6 cases diagnosed as UA by DECT, 5 were true positive while one was false positive (diagnosed as mixed type by FTIRS). Both DECT and FTIRS diagnosed 23 cases as oxalate, one case as cystine calculus and 2 cases as mixed type [Table/Fig-7].

DECT-Detected Composition	Chemical Composition (IR Spectroscopy)				
	Calcium Oxalate	Hydroxy Apatite	Uric Acid	Cystine	Mixed
Calcium Oxalate	23				
Hydroxy Apatite	1	3			
Uric Acid			5		1
Cystine				1	
Mixed					2
Total	24	3	5	1	3

[Table/Fig-7]: Comparison between DECT-Detected Composition and Chemical Composition of Calculi.

The sensitivity and specificity of DECT for hydroxyapatite, cystine and mixed type stones were 100% and 97%, 100% and 100% and 66.7% and 100%, respectively [Table/Fig-8].

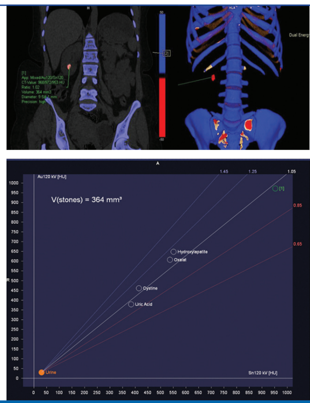
Chemical Composition	Diagnostic Efficacy of DECT				
	Sensitivity (%)	Specificity (%)	PPV	NPV	Accuracy (%)
Calcium Oxalate	95.8%	100.0%	100.0%	92.3%	97.2%
Hydroxy Apatite	100.0%	97.0%	75.0%	100.0%	97.2%
Uric Acid	100.0%	96.8%	83.3%	100.0%	97.2%
Cystine	100.0%	100.0%	100.0%	100.0%	100.0%
Mixed	66.7%	100.0%	100.0%	97.1%	97.2%

[Table/Fig-8]: Diagnostic Efficacy of DECT.
PPV: Positive predictive value; NPV: Negative predictive value

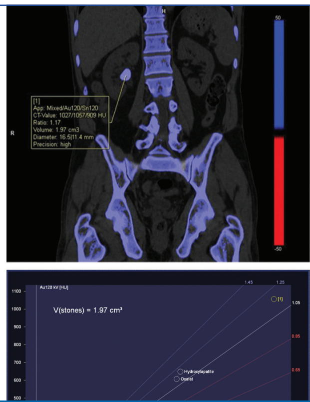
The sensitivity and specificity of DECT in differentiating calcium oxalate from non oxalate calculus was 95.8% and 100.0%, respectively. The sensitivity and specificity in the differentiation of UA from non UA calculi were found to be 100% and 96.8, respectively.

DISCUSSION

Urinary stones are now-a-days being routinely evaluated using unenhanced CT, and the DE protocols have an added benefit by clearly indicating the composition of the urinary stones [9]. DECT can differentiate among oxalate and non oxalate calculi, UA, and non UA calculi with very high sensitivity and specificity. Three material decomposition algorithm that assumes every voxel includes a component of water, calcium and/or UA is used in the latest DECT machines for the determination of the composition. The voxels are then colour-coded based on the quantity of each of these components [10]. In present study, preprogrammed software was used on a twin-beam DECT machine to evaluate the stone type. In final map, colour coding differentiated UA (red colour) from non UA (blue colour) very accurately [Table/Fig-9,10] [11].



[Table/Fig-9]: Uric Acid (UA) calculus in lower pole calyx of right kidney.



[Table/Fig-10]: Calcium oxalate calculus in right renal pelvis.

In this study, 36 stones were extracted from 35 patients. Of the total 35 patients included in the study, males (65.7%) were affected more than the females (34.3%) and most commonly affected age group was 46-60 years. The age and gender distribution of urinary tract calculi found in the present study were similar to that conducted by Singh A et al., where the mean age of patients was 45.6±11.7 years and the majority (59%) of patients were males [2]. In the present study, calcium oxalate (66.7%) was the most common calculus followed by UA with a very low incidence of cystine calculus. Similarly, in the study conducted by Ilya M et al., Jammu and Kashmir, calcium oxalate (78.4%) was the predominant stone type [6] while hydroxyapatite was the predominant calculus (48%) in another study conducted by Singh A et al., in Lucknow, Uttar Pradesh, India [2]. Thus, the authors can conclude that the stone composition is variable with the geographical location. In present study, pure UA stones had attenuation values that were significantly lower than most calcium stones. The results were also consistent with the study done by Ilya M et al., where UA stones had attenuation values that were significantly lower than most calcium stones and other stone subtypes had a wide range of attenuation values spanning from 600 HU to 2800 HU [6].

The present study strongly supports the diagnostic accuracy of DECT in determining the urinary stone composition and the results are in conformity with similar studies [2,6,8,12,13] conducted previously [Table/Fig-11]. In a study conducted by Ilya M et al., the overall sensitivity and specificity of DECT to differentiate a calcium oxalate calculus from a non calcium oxalate calculus was 97.8% and 92.3%, respectively. To differentiate a UA stone from a non UA stone, the sensitivity and specificity of DECT was 100% both [6].

Variable	Singh A et al., [2]	Ilya M et al., [6]	Basha MAA et al., [8]	Bonatti M et al., [12]	Kapanadze LB et al., [13]	Current Study
Place of Study	Lucknow, Uttar Pradesh, India	Jammu and Kashmir	Egypt	Italy	Russia	Mysore, Karnataka, India
Year of Study and Sample Size	2019, n=100	November 2015 to October 2016, n=53	January 2020 to January 2021, n=48	October 2012-April 2014, n=30	n=91	January 2020 to June 2021, n=35
Age group	45.6±11.7 years	31-45 years	42±10.3 years (22–68 years)	56 years (34–86 years)	42.7 years (20-70 years)	45.7±14.89 years (46-60 years)
Gender	Males (59%)	Males (71.7%)	Males (56.7%)	Males (60%)	Males (75%)	Males (65.7%)
Most predominant stone type	Hydroxyapatite (48%)	Calcium oxalate (78.4%)	Calcium oxalate (66.7%)	Calcium oxalate (58%)	Calcium oxalate (43.9%)	Calcium oxalate (66.7%)
Sensitivity of DECT in differentiation of oxalate from non oxalate calculus	80.00%	97.8%	-	-	83.3%	95.8%
Specificity of DECT in differentiation of oxalate from non oxalate calculus	98.90%	92.3%	-	-	89.8%	100.0%
Sensitivity of DECT in differentiation of UA from non UA calculi	82.60%	100.0%	100%	100%	90.0%	100.0%
Specificity of DECT in differentiation of UA from non UA calculi	97.50%	100.0%	96.9%	94%	98.8%	96.8 %

[Table/Fig-11]: Comparison of current study with other studies [2,6,8,12,13].

The present study results were also in conformity with the results published by Basha MAA et al., and Bonatti M et al., where the sensitivity and specificity of DECT in differentiating UA from non UA calculi was 100% and 96.9%; 100% and 94%, respectively [8,12].

Limitation(s)

Only stones with a diameter between 6.6 mm and 53 mm were assessed. The influence of stone size on DECT attenuation values was not studied. The effect of stone size on DECT attenuation could be the subject of future work. Due to the limited duration of the study period, patients were not followed-up to study their recurrence pattern.

CONCLUSION(S)

DECT is a highly sensitive tool in the non invasive, in vivo, preoperative assessment of urinary calculus composition which will be very helpful to the clinician in selecting the optimal treatment modality. In conclusion, with single-energy CT, the overlap between types of renal stones makes it difficult to reliably determine the chemical composition while DECT attenuation values can accurately predict the stone composition.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]
• Plagiarism X-checker: Jul 05, 2022
• Manual Googling: Oct 29, 2022
• iThenticate Software: Nov 02, 2022 (12%)

ETYMOLOGY: Author Origin

AUTHOR DECLARATION:
• Financial or Other Competing Interests: None
• Was Ethics Committee Approval obtained for this study? Yes
• Was informed consent obtained from the subjects involved in the study? Yes
• For any images presented appropriate consent has been obtained from the subjects. NA

Date of Submission: Jul 04, 2022
Date of Peer Review: Sep 09, 2022
Date of Acceptance: Nov 03, 2022
Date of Publishing: Mar 01, 2023