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ORIGINAL RESEARCH

Renal calculus composition analysis using dual-energy CT: a prospective observational study

Jithin P. Johnson[1], Arushi Dhall[1], Arun Chawla[1] and K Prakashini[1*]

Abstract

Background To analyze preoperatively the composition of renal calculi using dual-energy computed tomography (DECT) and compare it with reference standard biochemical stone analysis.

Methods Eighty-one participants who were diagnosed with renal calculi underwent DECT at 80 kVp and 140 kVp. Spectral analysis was performed, and the energy map generated was used to classify the calculus based on available preset data. Average Hounsfield units (HU) were calculated for the two energy levels, and ratio of HU was derived (DE ratio) and calculus was categorized into different stone compositions. Hounsfield units of each calculus was measured at 120 kVp standard dose CT, and Hounsfield density (HU/largest transverse diameter) was derived. Comparison of results of spectral analysis and DE ratio was done and correlated with the biochemical laboratory analysis as reference standard wherever available.

Results Spectral analysis and CT prediction of stone were performed for all 81 patients. CT prediction of stone based on DE ratio into "uric acid," "struvite," "calcium oxalate" and "calcium carbonate apatite" was performed. Assessment of stone composition by biochemical analysis was done for 65 patients who eventually underwent PCNL for stone extraction.

Both DE ratio and spectral analysis were able to differentiate calculus into various types based on composition with statistically significant p values. However, spectral analysis proved to be marginally better in renal stone characterization particularly for mixed stones. The DE ratio for uric acid stones was derived as 0.9–1.1, 0.9–2.3 for mixed stones and 1.0–2.4 for calcium stones.

Conclusions Spectral analysis promises a practical approach to predicting calculus composition preoperatively, thereby avoiding unnecessary surgical intervention.

Keywords Dual-energy computed tomography (DECT), Renal calculi, Spectral analysis, DE ratio, PCNL

1 Background

Urolithiasis or urinary stone disease is a common clinical entity with an increasing prevalence of up to 14.8% and a 50% recurrence risk in the first five years [1–7]. "The most common types of calculi encountered are calcium oxalate (monohydrate or dihydrate) and calcium phosphate (brushite or apatite), uric acid, struvite and cystine with a prevalence of ~80%, 9%, 10% and 1%, respectively" [2–4]. Even though some might remain asymptomatic, most of the patients present with a wide range

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*Correspondence:
K Prakashini
docprakashinik@yahoo.co.in
[1] Department of Radiodiagnosis and Imaging, Kasturba Medical College, Manipal University, Manipal Academy of Higher Education (MAHE), Manipal, Karnataka 576104, India

of clinical scenario from colicky abdominal pain (loin to groin), strangury, vomiting, hematuria to complications like obstructive pyelonephritis, severe urinary tract infection, renal failure and septic shock [11–13]. The concept of metabolic activity, which promotes crystallization that would cause new stone formation or growth of present stones, should guide the treatment plan of the patient. As mechanism of stone formation and recurrent rates are different for different stones, the management strategy also changes with different stone composition [3, 35]. The knowledge of the type of stone is crucial before the commencement of treatment as treatment plan can change from an invasive surgical procedure to medical management significantly affecting factors like risk, cost and anxiety to the patient [13, 37]. DECT is an innovation in imaging technology which relies on scanning a particular anatomical region at two different energy levels to differentiate between materials based on their absorption of photons and differences in atomic number [9, 13, 16]. Because of its remarkable ability to evaluate urinary stone composition, DECT is being widely used for preoperative assessment of renal calculi composition in vivo and thereby facilitates better patient care by assisting clinicians to alter the treatment based on stone type.

2 Methods

This hospital-based prospective observational study was conducted over a period of 2 years in the Department of Radiodiagnosis and Imaging, Kasturba Medical College, Manipal, after obtaining approval from institutional ethical committee. Informed consent was taken from each patient. Patients confirmed to have calculi on CT KUB and posted for PCNL underwent dual-energy CT using PHILIPS NEW GENERATION 128 INCISIVE CT (a single-energy dual-source machine). After identifying the location of calculi, the area of interest was determined, and that area was scanned using dual-energy mode using 80 kVp and 140 kVp. Images with artifacts, postoperative cases and images with misregistration were all excluded from the study. Image post-processing was done using dual-energy application, Philips healthcare, which involved the following steps: (1) registration, (2) spectral analysis and (3) calculating DE ratio and Hounsfield density.

The patients underwent PCNL and stones were fragmented using a lithoclast and sent for biochemical analysis.

Biochemical analysis was done using simple microscopy manually.

There was no additional cost to the patient as this used a software application, and routine evaluation of all patients undergoing PCNL in our institution is subjected to stone analysis.

2.1 Registration

Registration involved aligning and combining of two images of different energies (i.e., 80 kV and 140 kV) to generate a single energy weighted image (110 kV) which could be used for analysis. Manual or automatic registration of the two set of images was performed.

2.2 Spectral analysis

Spectral analysis involves separating different tissue materials based on their energy values. Each tissue pixel in the scanned volume has two CT values: one for high energy and one for low energy. According to the composition of calculus, two different automated color-coding was applied on the combined energy weighted image. ROI which allowed maximum permissible area was drawn on the calculus which generated an attenuation graph showing change in attenuation from low to high energy levels. The attenuation graphs showed progressive increase or decrease in attenuation or a nonlinear change from low to high energy levels consistent with calcium, uric acid and mixed stones, respectively. An energy map was subsequently generated, which displayed pixels based on their CT values for high and low energies.

Graph separation into two or more materials was done on the energy map using graph lines. All pixels on the energy map below the threshold line were not included in the spectral analysis. All pixels on the energy map above the threshold line and above the blue line were classified as one substance and below the blue were classified as another substance. Preset for different stones was applied, and the graph was analyzed for different materials.

(See Figs. 1, 2, 3).

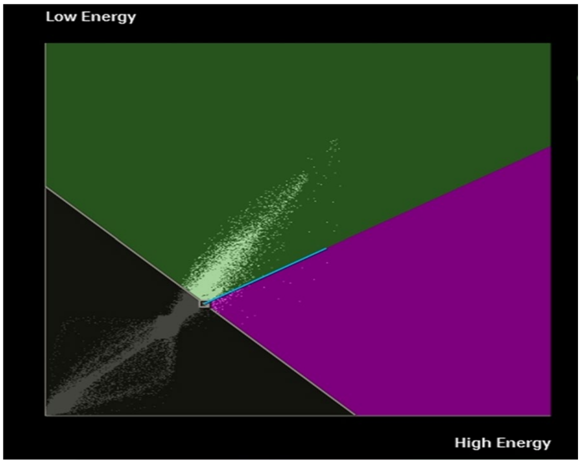


Fig. 1 Energy map displaying voxels based on their low-energy and high-energy attenuation values

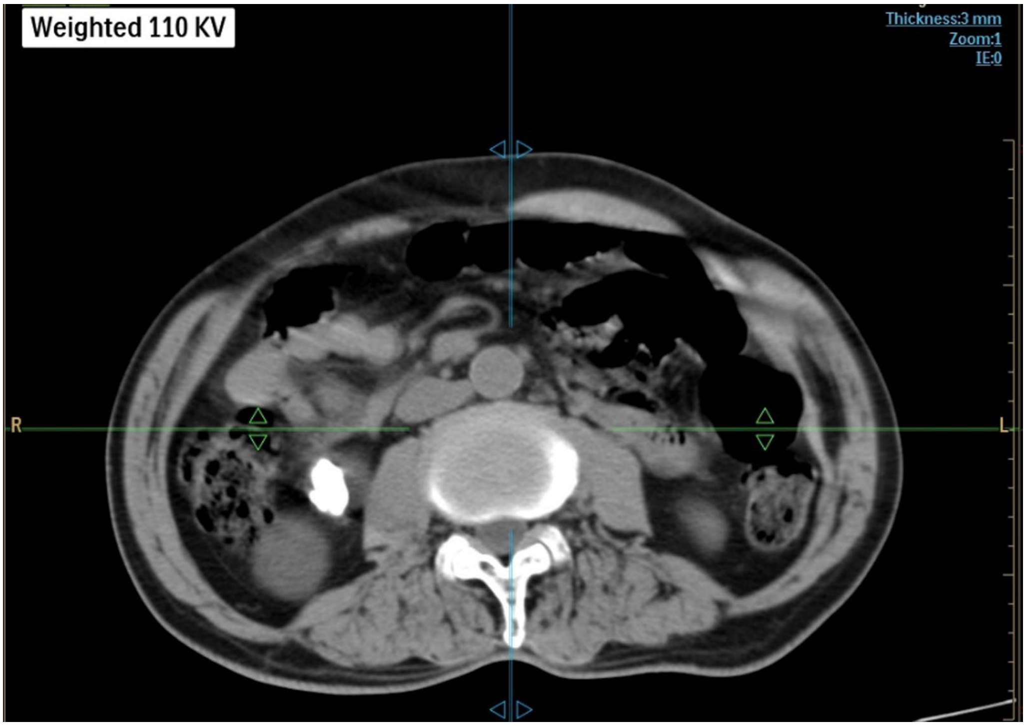


Fig. 2 Combined weighted image (110kVp) generated following registration demonstrating calculus at the right proximal ureter

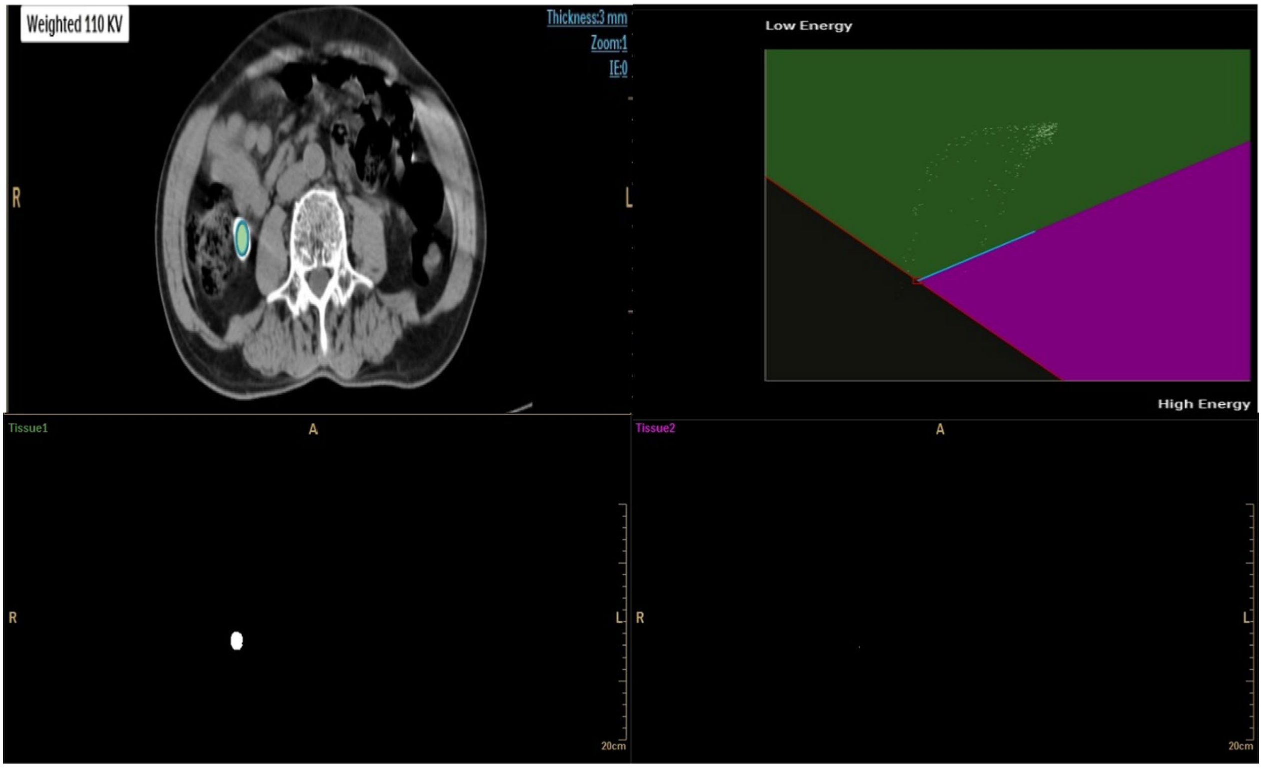


Fig. 3 Image with ROI drawn on the calculus shows the calculus coded in green representing calcium stone and the corresponding energy map which depicts the distribution of voxels based on their values at low and high energy levels

2.3 DE ratio

Dual-energy ratio (DE ratio), ratio between the average low-energy attenuation and the average high-energy attenuation, was calculated and stones were classified into different stone types based on their DE ratio values. Hounsfield units of each calculi were analyzed, and Hounsfield density (HU/largest transverse diameter) was calculated for studying stone density.

The stone composition analysis results obtained using spectral analysis and dual-energy CT were compared with reference standard biochemical analysis.

(See Figs. 4, 5, 6).

2.4 Statistical analysis

Data were analyzed using SPSS 25 version software. MS Excel and MS word were used to obtain various types of graphs such as bar diagram, pie diagram and scatter plots. The two methods of preoperative stone composition (DE ratio and spectral analysis) were compared with reference standard biochemical analysis using Cohen's kappa coefficient. Kappa values are interpreted as follows: 0.00–0.20—slight agreement; 0.21–0.40—fair agreement; 0.41–0.60—moderate agreement; 0.61–0.80—substantial agreement; and 0.81–1.00—almost perfect agreement. *P* value (probability that the result is true) of 0.05 was considered as statistically significant after assuming all the rules of statistical tests.

3 Results

Eighty-one participants who were diagnosed with calculus have been included in the study. Of the 81 participants, 60 were males and 21 were females. Mean stone diameters varied between 4.5 and 57 mm (mean diameter − 14.2 mm). Calculated range of HU and HD values was found to be between 285 − 1484 and 9–202, respectively. The DE ratio for uric acid stones was derived as 0.9–1.1, 0.9–2.3 for mixed and 1.0–2.4 for calcium stones. Spectral analysis and CT prediction of stone were performed for all 81 patients. CT prediction of stone based on DE ratio, into "uric acid," "struvite," "calcium oxalate" and "calcium carbonate apatite," was performed. Biochemical analysis was obtained for 65 patients who underwent PCNL for stone extraction. There were 40 calcium stones, 20 mixed stones and 5 uric acid stones.

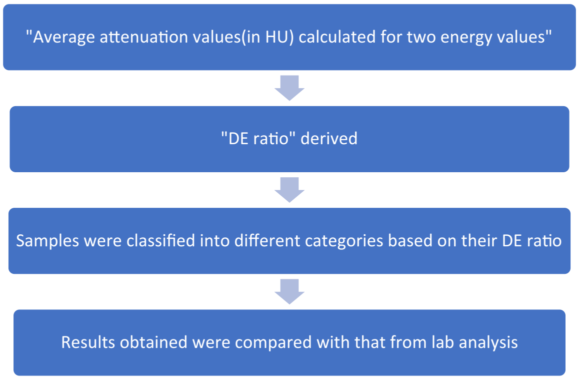


Fig. 4 Flowchart depicting classification of stones based on DE ratio

Two (3.1%) cases classified as calcium by spectral analysis were classified as uric acid by biochemical analysis. Eight (12.3%) cases classified as calcium by spectral analysis were classified as mixed by biochemical analysis. One (1.5%) case classified as uric acid by spectral analysis was classified as mixed by biochemical analysis. Eleven (16.9%) cases classified as mixed by spectral analysis were classified as calcium by biochemical analysis. One (1.5%) case classified as mixed by spectral analysis was classified as uric acid by biochemical analysis.

One (1.5%) case classified as calcium by DE ratio was classified as uric acid by biochemical analysis. Twelve (18.5%) cases classified as calcium by DE ratio were classified as mixed by biochemical analysis. One (1.5%) case classified as struvite by DE ratio was classified as mixed by biochemical analysis. Seven (10.8%) cases classified as uric acid by DE ratio were classified as calcium by biochemical analysis. Seven (10.8%) cases classified as uric acid by DE ratio were classified as mixed by biochemical analysis.

Spectral analysis showed fair agreement in classifying all three types of stones with kappa values 0.3, 0.3 and 0.5 for calcium, mixed and uric acid stones, respectively, at statistically significant p values. DE ratio, on the other hand, showed fair agreement in classifying calcium stones with kappa value of 0.2 at statistically significant p value.

4 Stone composition analysis

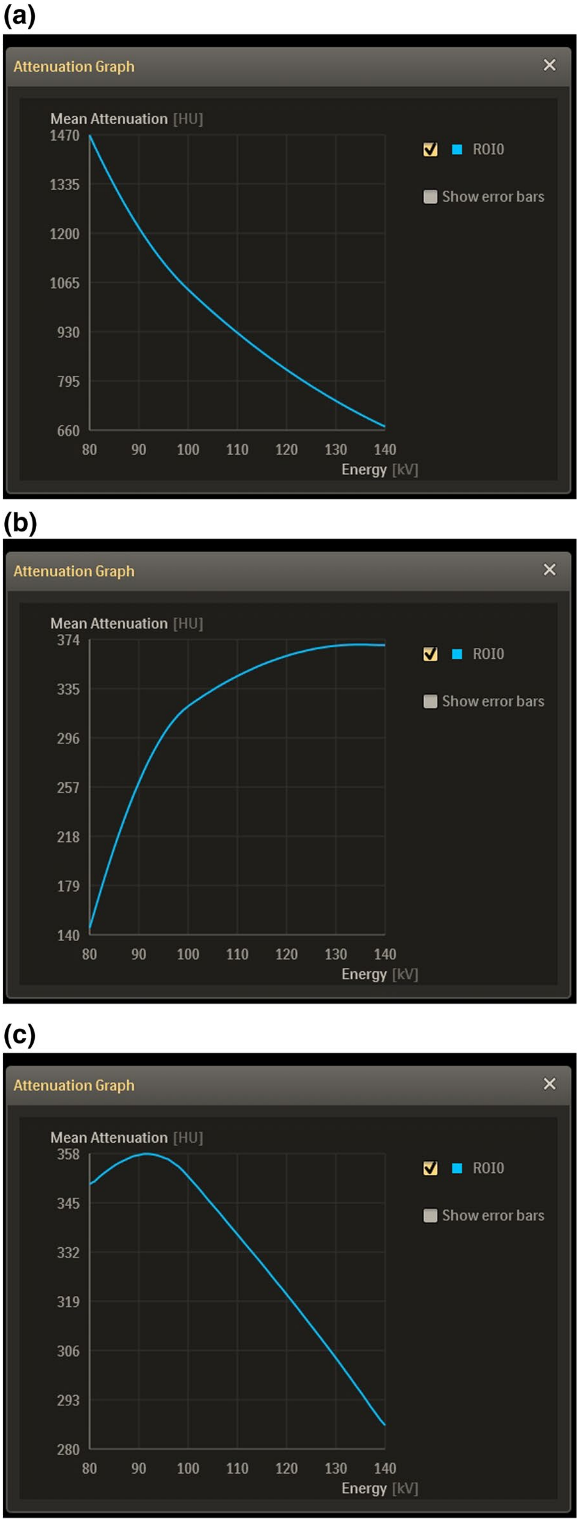
4.1 Comparison of stone composition analysis methods

4.1.1 Comparison between spectral analysis and biochemical analysis

The results of two methods of stone composition analysis, spectral analysis and biochemical analysis, were compared, and the two methods agreed in 64.6% of the cases and disagreed in 35.4% of the cases (Table 1).

There was fair agreement between the spectral analysis and biochemical analysis, and this agreement was statistically significant (Cohen's kappa = 0.317, $p = 0.003$).

(See Fig. 7).



◀ **Fig. 5** **a** Corresponding attenuation graph generated showing progressive decrease in attenuation from low to high energy levels consistent with calcium composition. **b** Corresponding attenuation graph generated showing progressive increase in attenuation from low to high energy levels consistent with uric acid composition. **C** Corresponding attenuation graph generated showing nonlinear change in attenuation suggestive of mixed composition

4.1.2 Comparison between DE ratio and biochemical analysis

The results of two methods of stone composition analysis, DE ratio and biochemical analysis, were compared, and the two methods agreed in 56.9% of the cases and disagreed in 43.1% of the cases. There was fair agreement between DE ratio and biochemical analysis, and this agreement was statistically significant (Cohen's kappa $=0.207$, $p=0.002$) (Table 2).

(See Fig. 8).

4.1.3 Comparison between DE ratio and spectral analysis

The results of two methods of stone composition analysis, DE ratio and spectral analysis, were compared, and the two methods agreed in 48.1% of the cases and disagreed in 58.9% of the cases. There was slight agreement between the two methods, and this agreement was statistically significant (Cohen's kappa $=0.110$, $p=0.036$) (Table 3).

(See Figs. 9, 10).

4.1.4 Comparison between sensitivity of DE ratio and spectral analysis in determining stone composition

See Table 4.

5 Discussion

Urolithiasis and its treatment continue to plaque the health system of the present-day society. Stone composition and its role in clinical management have gained paramount importance among other factors in the recent years.

Knowledge regarding the composition of a particular stone goes a long way in optimizing its treatment as well as prevention as there are different methods of effectively managing urolithiasis which are unique to the respective stone type. Uric acid stones do not usually require surgery and can be managed successfully with urinary alkalization [3, 6, 13, 16, 23, 36]. On the contrary, alkalization is avoided in calculi secondary to infective etiology as alkaline pH facilitates bacterial growth [1, 38]. Moreover,

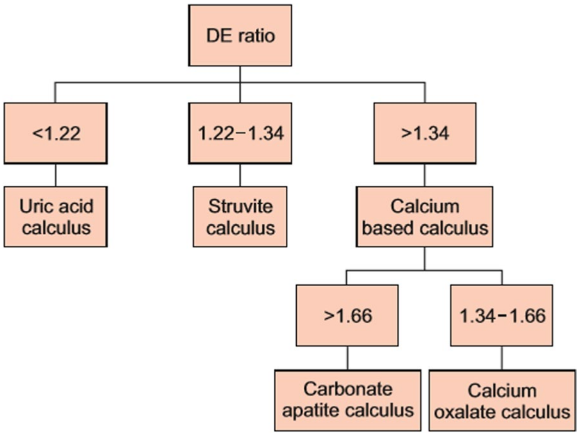


Fig. 6 Chart to classify stones using DE ratio values (image courtesy: Evaluation of low-dose dual-energy computed tomography for in vivo assessment of renal/ ureteric calculus composition by Mahalingam et al. KJU, 2015) 16

Table 1 Comparison of stone composition by spectral analysis with biochemical analysis

Stone composition		Spectral Analysis				Cohen's Kappa	
		Calcium	Uric Acid	Mixed	Total	k	P Value
Biochemical Analysis	Calcium	29 (44.6%)	0 (0.0%)	11 (16.9%)	40 (61.5%)	0.317	0.003
	Uric Acid	2 (3.1%)	2 (3.1%)	1 (1.5%)	5 (7.7%)		
	Mixed	8 (12.3%)	1 (1.5%)	11 (16.9%)	20 (30.8%)		
	Total	39 (60.0%)	3 (4.6%)	23 (35.4%)	65 (100.0%)		

The green cells on the diagonal represent cases where both the methods agreed. The red shaded cells represent cases where the two methods disagreed

certain stones like cystine, brushite or calcium oxalate monohydrate are resilient to SWL than others and may require invasive treatment modalities like RIRS or PCNL for successful removal [13]. Struvite and carbonate apatite stones are associated with urinary tract infection and carry an increased risk of post-treatment sepsis and recurrence [16].

Presently, non-enhanced CT is the reference standard test for diagnosis and assessment of urinary stones owing to its safety, higher sensitivity (~ 91–100%) and specificity (~ 95–100%) [1, 9, 14, 15]. Moreover, CT provides additional information such as location, size, number and composition of calculi and presence of other complications [1–3, 13]. The knowledge of the composition of renal calculi is integral as it can influence the course of management, which can vary from conservative to various surgical interventions. Current methods of characterizing stones are only available after the stones has been extracted and, thus, do not provide any benefit during the preoperative phase. CT using single energy is the first step in the attempt to understand the stone composition in vivo. Based on the attenuation values, CT scan can provide approximate inference regarding the stone type as uric acid stones have lower values. However, there is considerable overlap between stone types which prevents it from being used as a decision making tool for treating urolithiasis reliably [14, 16, 26, 40–43].

The utility of CT has grown beyond simply detecting and inferring the size of stone to stone characterization and assessment in terms of fragility and response to therapy with the advent of DECT [9]. DECT has greater accuracy in separating uric acid calculi (90–100%) and increased accuracy in subclassifying non-uric acid calculi

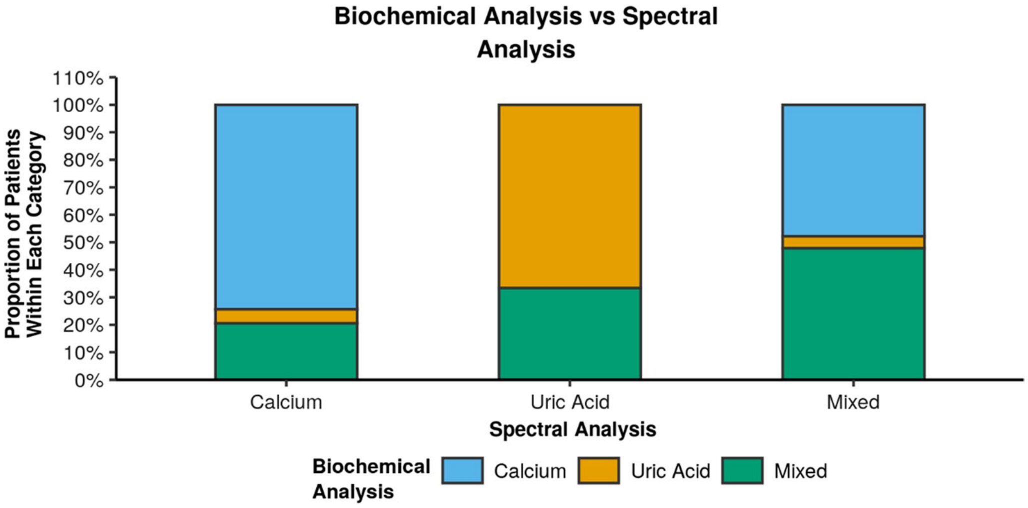


Fig. 7 Bar graph depicting the classification of stones by spectral analysis and biochemical analysis

Table 2 Comparison of stone composition by DE ratio with biochemical analysis

		DE Ratio					Cohen's Kappa	
		Calcium	Struvite	Uric Acid	Mixed	Total	k	P Value
Biochemical Analysis	Calcium	33 (50.8%)	0 (0.0%)	7 (10.8%)	0 (0.0%)	40 (61.5%)	0.207	0.002
	Struvite	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)		
	Uric Acid	1 (1.5%)	0 (0.0%)	4 (6.2%)	0 (0.0%)	5 (7.7%)		
	Mixed	12 (18.5%)	1 (1.5%)	7 (10.8%)	0 (0.0%)	20 (30.8%)		
	Total	46 (70.8%)	1 (1.5%)	18 (27.7%)	0 (0.0%)	65 (100.0%)		

The green cells on the diagonal represent cases where both the methods agreed. The red shaded cells represent cases where the two methods disagreed

Table 3 Comparison of stone composition by DE ratio and spectral analysis

Stone composition		Spectral Analysis					Cohen's Kappa	
		Calcium	Uric Acid	Mixed	Struvite	Total	k	P Value
DE Ratio	Calcium	36 (44.4%)	1 (1.2%)	18 (22.2%)	0 (0.0%)	55 (67.9%)	0.110	0.036
	Uric Acid	12 (14.8%)	3 (3.7%)	10 (12.3%)	0 (0.0%)	25 (30.9%)		
	Mixed	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)		
	Struvite	0 (0.0%)	0 (0.0%)	1 (1.2%)	0 (0.0%)	1 (1.2%)		
	Total	48 (59.3%)	4 (4.9%)	29 (35.8%)	0 (0.0%)	81 (100.0%)		

The green cells on the diagonal represent cases where both the methods agreed. The red shaded cells represent cases where the two methods disagreed

compared to single energy CT and without increasing patient radiation exposure. "Dual-energy CT" is a relatively new and emerging technological advancement which has proved its capability in in vivo stone differentiation. Advanced DECT scanners differentiate calculi based on its inherent spectral behavior at different energy levels and depict the results using post-processing software for the ease of clinical inference. One of the techniques based on dual-energy CT employed to demonstrate stone composition include color-coding, where different colors are assigned to stone components based on composition. Another technique is the calculation of effective atomic number, based on the dual-energy data obtained, to reliably predict the stone composition [13]. The conventional method of calculating DE ratio manually also provides information regarding the stone type without any other post-processing tool.

"Previous in vitro and in vivo studies have demonstrated the capability of DECT in differentiating uric acid from non-uric acid stones with reasonable sensitivity and specificity" [13]. However, to the best of our knowledge, studies on the efficacy and ability of dual-energy CT to identify and subclassify stones of mixed composition have been limited. Through our study, we attempted to further explore the role of spectral analysis and the potential of dual-energy CT to accurately depict the composition of urinary tract stones in a relevant clinical setting. Spectral analysis software in PHILIPS 128 INCISIVE CT scanner depicts the stone composition into uric acid stones, mixed stones and calcium stones by plotting

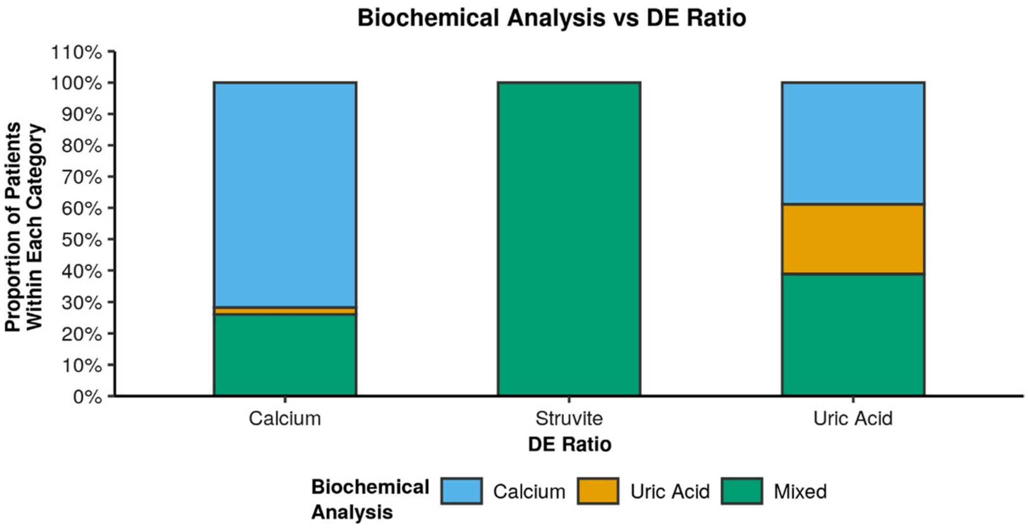


Fig. 8 Bar graph depicting the classification of stones by DE ratio and biochemical analysis

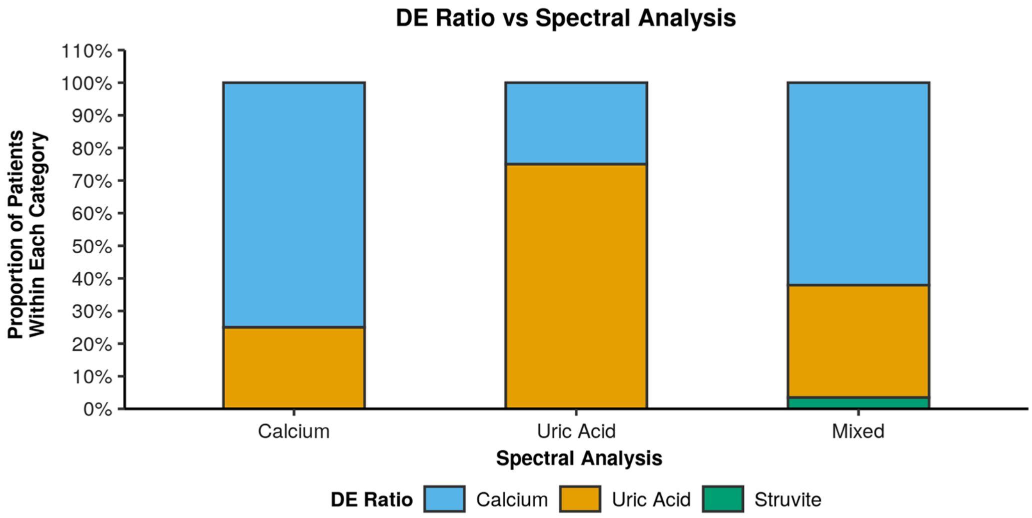


Fig. 9 Bar graph depicting the classification of stones by DE ratio and spectral analysis

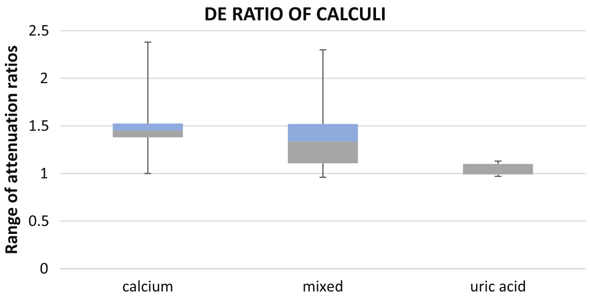


Fig. 10 Box-and-whisker plot showing the distribution of attenuation ratios of calculi based on composition

Table 4 Comparison of stone composition sensitivity by DE ratio and spectral analysis

Stone composition	DE ratio (%)	Spectral analysis (%)
Calcium	82.5	73
Uric acid	80	40

DE ratio has > 80% sensitivity for calcium and uric acid stones in our study

voxels based on their DE ratio in a color-coded graph and using stone presets.

We compared the efficacy of two methods of stone prediction based on dual-energy CT, viz. spectral analysis and DE ratio, in determining the composition of calculus, by comparing the results of both methods with biochemical analysis following PCNL as reference standard.

Methods available for in vitro analysis of urinary system stones include biochemical analysis, thermogravimeter, optic polarized microscopy, electron microscopy and spectroscopy. Of these methods, infrared spectroscopy is considered the most reliable, whereas biochemical analysis, which classifies stones qualitatively and semi-quantitatively, is the most widely used [3]. Even though we intended to use both the aforementioned techniques, spectroscopy could not performed for a substantial number of samples due to technical difficulties.

In our study, calcium was predominant stone type, with a relatively larger number of mixed stones and small number of uric acid stones compared to other studies. Our findings were consistent with previous studies demonstrating the superiority of DECT in differentiating calculi of single composition with a high degree of specificity. Our study showed that DE ratio could not reliably differentiate mixed stones from uric acid stones and calcium stones. This could be attributed to varying composition in mixed stones and mismatch between the true stone core and representative ROI. Moreover, the DE ratios used were previously derived using a different dual-energy CT technology and tube settings in a different population subset with different habitus and varying prevalence of stone types. Similar findings were noted in studies by *Hidas* et al. [25] which showed the capability of “dual-energy CT” in differentiating “calcium” from “uric acid” stones and inability to differentiate struvite stones. “Dual-energy attenuation ratios” derived by them were < 1.1 for “uric acid,” 1.1–1.24 for “cystine” and > 1.24 for “calcified stones.” They also noted that struvite stones had attenuation ratios that overlapped with calcified stone ratios which deterred reliable assessment.

Even though a subclassification of stones was not possible with spectral analysis, our study demonstrated the superiority of spectral analysis over conventional stone prediction using DE ratio in identifying mixed stones. This could be due to the significant overlap of attenuation ratios and a lack of proper cutoff for stones of mixed composition [44].

This was consistent with findings noted by *Erdogan* et al. [3] and *Manglaviti* et al. [1] who studied the efficacy of post-processing software using "dual-energy CT" to determine stone types. *Erdogan* et al. [3] reported that "DECT" could differentiate "uric acid" stones with a sensitivity of 100% and specificity of 100%, "cystine" stones with a sensitivity of 100% and specificity of 100%, calcium oxalate with a sensitivity of 83.3% and specificity of 100% and calcium hydroxy apatite with a sensitivity of 100% and specificity of 88.9%, respectively [3].

The study by *Manglaviti* et al. [1] showed "substantial agreement between dual-energy CT and crystallography for pure stones (Cohen $\kappa = 0.684$)" but "DECT" failed to identify stones of mixed composition. Their study also highlighted that stone composition had no correlation with either "stone diameter" or "stone CT density."

A similar study by *Ilyas* et al. [6] showed that DECT was 100% sensitive and specific for differentiating "UA stones" from "non-UA stones" and 97.8% sensitive and 92.3% specific in differentiating "calcium oxalate" from "non-calcium oxalate" calculus, respectively. The "DE ratio" for the "UA stones" was found to be 0.98–1.13.6.

Role of breathing motion artifact could also be responsible for the relatively less efficacy in differentiating various stones in our study as previously demonstrated in the study by *Grosjean* et al. [43].

Recent studies by *Kordbacheh* et al. [9] and *Khandelwal* et al. [22] have shown that patient body habitus and BMI could potentially affect the successful prediction of stone composition as factors like low penetration power of low-energy beam, image artifacts and excess noise due to large body habitus [9, 22].

The discrepancies in results could be attributed to the "overlap in chemical composition," "differential in absorption among patients of different sizes" and "technological limitations" [44]. Moreover, spectral analysis could differentiate calculi into calcium, mixed and uric acid stones only with no further subclassification. Our study samples contained a greater number of mixed stones and very few pure uric acid stones in our limited sample size. Finally, we would like to highlight and reiterate that the results of studies are specific to the respective DECT technology, scanning protocol and post-processing software used.

DECT is currently the most successful for achieving element decomposition. Since DECT acquisitions are at two different energy levels, the second attenuation measurement is made at a differing tube potential, in fact at a lower-energy spectrum, which enables quantification of composition of elements that have similar electron densities but varying photon absorption, thereby providing differentiation between materials. This is especially useful for materials with similar beam attenuation but different atomic numbers, such as iodinated contrast material and calcium. In renal stone evaluation, this ability of DECT is again extremely useful to identify chemical composition of stones and give preoperative analysis differentiating calcium containing stones, separate from cystine stones [45].

Identifying uric acid calculi with the help of DE ratios can change patient management as they can be medically managed with allopurinol and alkalinization of urine. Patients with familial metabolic diseases stand to benefit from this investigation. For example, for patients suffering from cystinuria—who develop cysteine renal calculi can be treated medically using captopril, and more invasive treatments such as ESWL or PCNL, which are both expensive and have potential complications including hemorrhage, sepsis can be avoided in these patients.

The characteristics of renal stone that are considered before advising appropriate treatment approach for renal calculary disease by a urologist are the stone size, number, location and composition, along with renal anatomy and the clinical factors. These parameters also help in predicting the success of the various procedures like ESWL, RIRS (flexible uretero-renoscopy) or PCNL. DECT enables better characterization of renal stones in terms of stone fragility, stone burden and stone composition.

Measurement of stone size at CT helps to accurately predict the rate of spontaneous passage of renal and ureteral stones. Medical management is indicated for renal calculi less than 7 mm in size. Symptomatic or asymptomatic small renal stones that are 6 to 8 mm in diameter can either be treated by ESWL or retrograde flexible ureteroscopy in case of failed medical management. 80–85% of simple renal calculi with a stone burden of less than 1.1 cm and normal renal anatomy can be treated successfully with ESWL.

ESWL is contraindicated in larger stones and in those located in dependent or obstructed parts of the collecting system. In stones with a composition of calcium oxalate monohydrate, brushite or cystine, or with body habitus issues like obesity, it is difficult to target the stone with shock wave delivery and subsequent fragmentation;

therefore, patients with larger stones should preferentially be treated with PCNL or ureteroscopy.

The location of stone in the pelvicalyceal system is important for appropriate and safe puncture positioning. One of the essential steps for successful percutaneous access while performing PCNL is localization of the posterior calyx. Stones located in posterior calyces are more amenable to removal by PCNL. Renal pelvic/ureteropelvic junction stones have a better clearance than calyceal stones on ESWL. Similarly, upper or middle calyceal stones are fragmented and cleared better than those in lower pole calyces.

Coronal reformatted images help in differentiating between calculi and other calcium containing structures such as calcified lymph nodes. DECT assists in analyzing the stone composition as knowledge of the composition of renal stone beforehand is crucial for planning management strategy for the patient. Uric acid stones can be dissolved medically with urinary alkalinization therapy using oral potassium citrate solution or allopurinol. Success of ESWL depends on stone composition that affects the type of fragments produced on decomposition of the calculus. Denser calculi made of calcium phosphate or cysteine are resistant to breakage by ESWL and require surgery.

Calcium oxalate monohydrate, struvite, calcium oxalate dihydrate and uric acid stones have a firm composition that may limit the success of ESWL. Cystine and calcium oxalate monohydrate calculi are resistant to fragmentation and are treated by ESWL only when the stone burden is smaller than 1.5 cm.

Stones composed of brushite and cystine are the most resistant to ESWL and warrant alternate treatment options.

A study by *Mahalingam* et al. [16] which included stones of mixed composition and were able to classify the stones into “uric acid,” “struvite,” “calcium oxalate” and “carbonate.” They reported that “DE ratio” could confidently differentiate “uric acid,” “struvite,” “calcium oxalate” and “carbonate apatite” calculi with cutoff values of 1.12, 1.34 and 1.66, respectively, giving > 80% sensitivity and specificity to differentiate them. They also observed that DE ratio could not differentiate COM from COM-COD calculi.

Therefore, the general applicability of a prederived DE ratio for classifying stones and a need for standardization of DE ratios in different geographical and population setting needs further study.

6 Conclusions

Spectral analysis using dual-energy CT has the capability to differentiate calculi based on composition and helps in the guiding the course of management. This can assist the urologist in determining the best modality for treatment and the effectiveness of energy sources used for lithotripsy while avoiding related cost and morbidity of additional procedures.

However, the scope of DECT in differentiating mixed stones, which are more representative of the clinical scenario, needs to be further explored and validated.

Abbreviations

KVP	Kilovoltage peak
DECT	Dual-energy computed tomography
HU	Hounsfield unit
HD	Hounsfield density
DE RATIO	Dual energy ratio
PCNL	Percutaneous nephrolithotomy
RIRS	Retrograde intrarenal surgery
SWL	Shockwave lithotripsy
CT	Computed tomography
COM	Calcium oxalate monohydrate
COD	Calcium oxalate dihydrate
UA	Uric acid
ESWL	Extracorporeal shock wave lithotripsy
BMI	Body mass index
ROI	Region of Interest

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Author contributions

JPJ is the primary author for study, AD is the reviewer, AC is the Professor and Head of Unit, Urology, and principal surgeon, and KP is the corresponding author and the Head of Radiology.

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Availability of data and materials

Not applicable.

Declarations

Ethics approval and consent to participate

The Institutional Ethics Committee of Kasturba Medical College has approved the study. Registration No. ECR/146/Inst/KA/2013/RR-16). A written informed consent was taken from all patients (or from their parent or legal guardian in case age less than 18 years) for taking part in this study after the ethics committee approval as per our institutional policy.

Consent for Publication

A written informed consent was taken from all patients (or from their parent or legal guardian in case age less than 18 years) for publication of their data as per our institutional policy.

Competing interests

No competing interests were noted.

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