Radiography Open

ISSN: 2387-3345 Volum 3, No 1 (2017) http://dx.doi.org/10.7577/radopen.2001

Characterization of Urinary Tract Stones with Dual Energy Computed Tomography

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Key words: attenuation, dual-energy, dual energy Computed Tomography, dual energy ratio, urinary calculi, X-ray absorptiometry

PEER REVIEWED ARTICLE

Abstract

Introduction. Dual Energy Computed Tomography (DECT) scan can provides simple and reliable differentiation between uric acid and non-uric acid stones. The characterization of various stones was based on the dual energy ratio and x-ray attenuation or HU.

Methodology. A prospective study was conducted among 101 adult patients in Tribhuvan University Teaching Hospital (TUTH), Nepal. Informed written consent was obtained from all the participants. The standard low doses CT KUB were performed in multi-slice CT scanner (Siemens Somatom Definition AS+ 128 slice) at 120 kVp and 250 mAs. When stones were detected, second dual energy scans using 80 kVp and 140 kVp were obtained focusing only on the region of stones for their characterization. After post processing and graphical analysis at Syngo Via work station, the components of the stones were identified. Statistical analysis was performed in SPSS v21.0 software.

Results. Out of 101 patients, 49 (48.5%) had calcium oxalate stones, 17 (16.87%) had uric acid stones, 16 (15.8%) had hydroxyapatite, 15 (14.9%) had cystine and 4 (4%) had mixed type of stones. Dual energy ratios were ranged from 0.55-1.11 for uric acid stone, 1.12-1.24 for cystine and more than 1.24 for calcium oxalate and hydroxyapatite stones. The mean HU noted in our study were; for uric acid stones (461.12 ± 119 HU at 80 kV, 449 ± 98.5 HU at 140 kV), for cystine (870.79 ± 386 at 80 kV, 743 ± 341 at 140 kV), for calcium oxalate (1246 ± 448 at 80 kV, 915 ± 316 at 140 kV) for hydroxyapatite (1301 ± 387 at 80 kV, 896 ± 315 at 140 kV) and mixed stone had (779.25 ± 269 HU at 80 kV, 665.5 ± 252 HU at 140 kV).

Conclusions. The highest number of stones found was calcium oxalate followed by uric acid, hydroxyapatitie, cystine and mixed type respectively. Distribution of stones was highest in left kidney and least at left ureter.

Introduction

Acute abdominal pain is a common chief complaint in patients examined in the emergency department (ED) and can be related to a myriad of diagnoses. Obtaining a careful medical history and performing a physical examination are the initial diagnostic steps for these patients. On the basis of the results of this clinical evaluation and laboratory investigations, the clinician will consider imaging examinations to help establish the correct diagnosis.[1] Abdominal pain continues to pose diagnostic challenges for emergency clinicians. In many cases, the differential diagnosis is wide, ranging from benign to life-threatening conditions. Causes include medical, surgical, intra-abdominal, and extra-abdominal ailments. Associated symptoms often lack specificity and atypical presentations of common diseases are frequent, further complicating matters.[2] Elderly and diabetic patients often have vague, nonspecific complaints and atypical presentations of potentially life-threatening conditions leading to time consuming workups.[2] The increasing prevalence of urolithiasis has gathered significant attention of the radiologist and imaging professionals for correct diagnosis.

Imaging in urolithiasis has evolved for more than decades due to technologic advancement and better understanding of disease processes.[3] Unenhanced Computed Tomography (CT) is considered as a gold standard for the evaluation of urinary stone disease and the introduction of Dual Energy CT (DECT) has further increased the scope of CT in the diagnosis of stone diseases.[3,4] DECT not only provides accurate submillimeter details of the size and location of the stone, its extension and invasion to adjacent structures, but distinguishes various types of stones on the basis of their mineral composition and characterizes the type of stone as well.[4,5] DECT utilizes the x-ray attenuation information from two different beam energies.[6,7]

The characterization of material on DECT largely depends on their CT number ratio (CTR) also called dual energy ratio.[5,7] It is defined as the CT number of a given material in the low energy image to the CT number of the same material in the high-energy image.[8,9] DECT and Spectral CT can be performed by rapid kVp switching, two consecutive scans with different energies Dual Spin, double layered detectors Detection Based and Dual source two tubes (80 or 140 kVp) dual energy computed tomography.[3,7,8] The major advantage of DECT is its ability to differentiate between uric acid and non-uric acid stones. The type and composition of stone is a fundamental part of pre-operative evaluation and this information influences the treatment strategy and preventive management of recurrence of stones.[10] Uric acid stones most often form as a result of high concentration of uric acid crystals. Non-uric acid stones are further divided into calcium, struvite and cysteine on the basis of elemental composition.[3,5] In this article, we discuss the application of DECT for determining the composition of urinary tract stones using attenuation values.

Methods

A prospective cross sectional hospital based study was conducted for to discern the composition of stones. The study was carried out in Department of Radiology and Imaging, Tribhuvan University Teaching Hospital (TUTH), Kathmandu, Nepal from October 2015 to February 2016. TUTH is the largest national hospital of Nepal. It runs academic programs (undergraduate, postgraduate as well as super-specialization) and medical research projects as well. There are altogether 22 departments. So, there are huge numbers of kidney patients of all age groups who are diagnosed and treated every day. The study population consisted of 101 patients who were referred for CT Kidney, Ureter and Bladder (KUB) scans for the evaluation of urinary stone and also were diagnosed having stones on CT KUB images. Purposive sampling method was used. All the patients >15 years willing to participate were included. Ethical approval was obtained from Institutional Review Board (IRB) of Institute of Medicine (IOM). There is no funding or allowances to disclose.

Patients

Initially, all the patients who were referred for CT KUB and met the inclusion criteria were included for the study. Patients were informed about the study and informed written consents were obtained. They were asked to remove any radiopaque metallic objects in abdominal region and were asked to lie on CT table in supine position.

All the scans were carried out on a Siemens Somatom Definition AS+128 slice CT scanner. (Siemens AG, Erlangen Germany). Initial topogram was obtained followed by KUB in helical mode from dome of diaphragm to symphysis pubis with slice thickness of 5x5 mm according to the standard scan protocol set by the department protocol (Table 1).

Table 1: Scanning Parameters

Parameters	Values
kV	100
mA	Variable
Beam Collimation	128 x 0.6mm
Acquisition Geometry	Helical
Pitch	0.8
Rotation Time	0.5 sec
Dose Modulation	CARE Dose 4D
Kernel	B30 f medium smooth
Slice Orientation	Axial
Window	Abdomen

The scanning area was customized to cover the region of interest. The images were analyzed while the patient remained on the scanner table and whether stone was detected; Dual-Energy scans using two different kilovoltages (80 kVp and 140 kVp) were performed focusing only at the region of stone for stone characterization. An 80 kVp CT exam is acquired, and then the patient is translated back to the origin, followed by the acquisition of 140 kVp CT exams. Both scans were taken at the same phase of respiration. After post processing and graphical analysis in Siemens Syngo.via (three dimensional (3D) imaging software solution, the compositions of urinary tract stones were analyzed. Dose modulation technique (CARE Dose4D) was employed.

Data Analysis
As per proforma, the data was sequentially collected and direct measurements were obtained from dual energy images. After completion of study, statistical analysis was done in SPSS version 21.0 and variables were presented as percentage and numerical data as minimum, maximum and mean.

Results
Among 101 patients, 59 (58.4%) were male and 42 (41.6%) were female. Age of the patients ranged from 16 to 86 years. The mean age of the patients was 38.51±1.6 years. Patient age were aggregated/ stratified in 10 years cohorts, for ages 27-76 years, the highest numbers of patients was in the age group of 27-36 years (n=32) and lowest number of patients in the age group of 67-76 years (n=3).

Among 101 patients, 29 (28.7%) patients had stones in right kidney, 32 (31.7%) had stone in left kidney, 15 (14.9%) had stone in right ureter, 5 (5%) had stone in left ureter and 20 (19.8) patients had stone in the urinary bladder as shown in the graph below (Fig. 1).

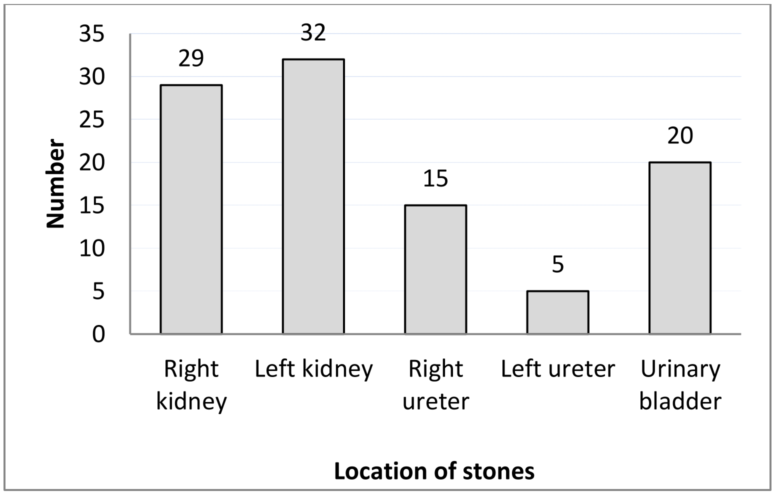

Figure 1 Urinary stone distribution.

The stones were predominantly of three type's namely uric acid, non-uric acid and mixed type. Uric acid stones were found in 17 (16.83%) cases, non -uric acid stones in 80 (79.20%) and mixed type in 4 (3.96%). Hounsfield unit (HU) values of stones are illustrated at 80kVp in figure 2, and at 140 kVp at figure 3.

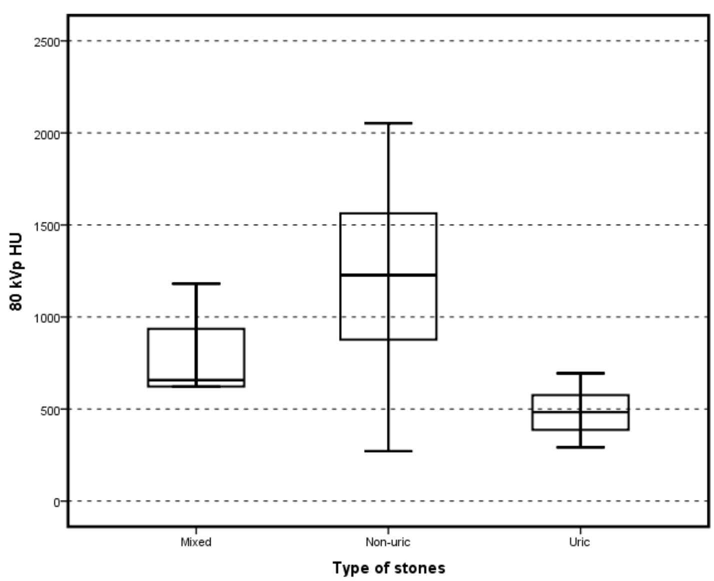

Figure 2 Box whisker plot of HU values of various stones at 80 kVp.

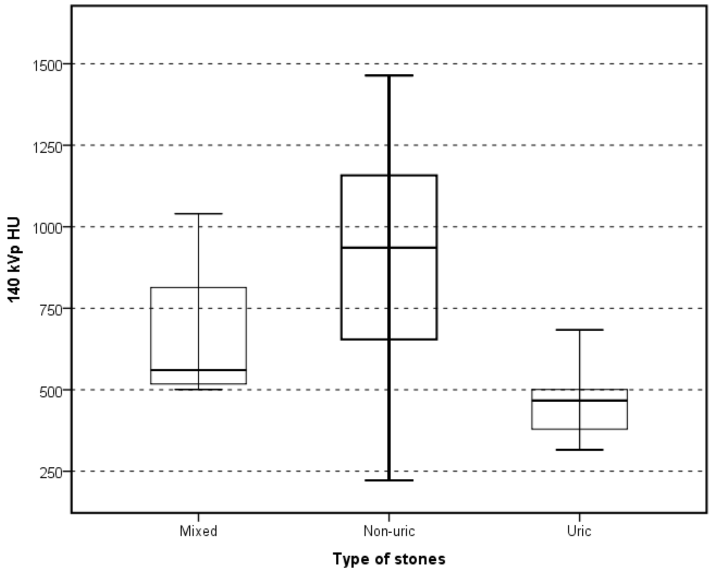

Figure 3 Box whisker plot of HU values of various stones at 140 kVp.

A total of 80 non uric acid stones were identified. The different types of non-uric acid stones were calcium oxalate, hydroxyapatite and cystine with the frequency of 49 (61%), 16 (20%) and 15 (19%) respectively. The mean HU value of calcium oxalate at 80 kVp was 1246.98 ± 448.13 HU and at 140 kVp was 915.80 ± 316.83 HU with significant difference of 331.18. Similarly, the mean HU value of hydroxyapatite at 80 kVp and 140 kVp were 1301.69 ± 387.92 HU and 896.06 ± 315.42 HU respectively. The mean HU value of cystine at 80 kVp and 140kVp were 870.79 ± 386.66 HU and 743.71 ± 341.91 respectively. The mean HU of Uric Acid stone at 80 kVp was 461.12 ± 119.93 HU and at 140 kVp was 449.00 ± 98.5 HU. There was no significant difference in the HU values of uric acid stone at low kVp and High kVp. The scatter plot in Figure 6 illustrates the HU values of all four types of stones at both 80 and 140 kVp.

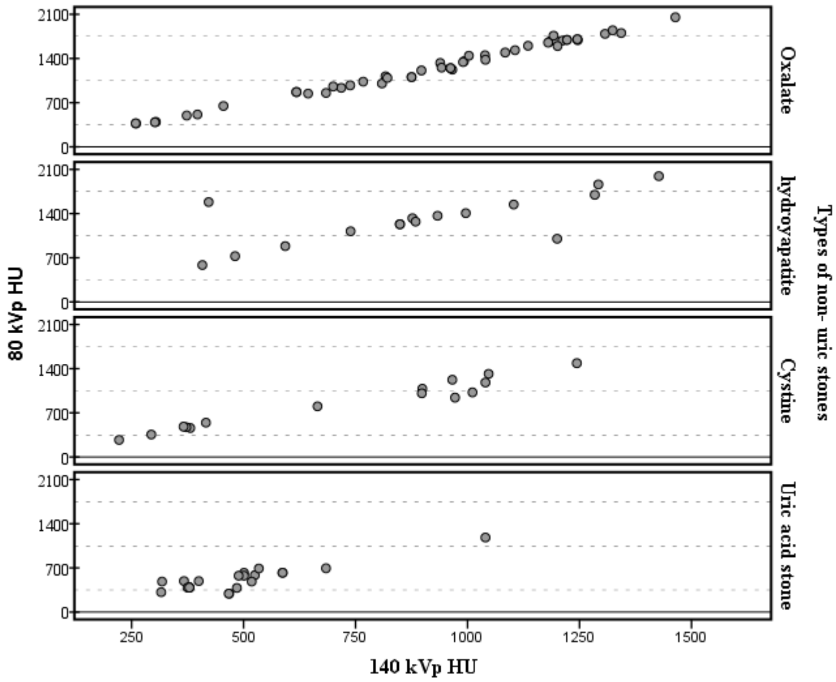

Figure 4 Scatter plot showing HU values of various stones at both 80 and 140 kVp.

The Mean HU of mixed stone at low kV was noted 779.25± 269.77 HU and at high kV 665.5 ± 252.16 HU. There was moderate difference in HU value of mixed stone at two energies level. The mean dual energy ratio of uric acid stone was 0.89 ± 0.17. Similarly, the mean dual energy ratio of mixed type stones was 1.09 ± 0.14 and the mean dual energy ratio of cysteine, calcium oxalate, and hydroxyapatite stones were 1.18±0.09, 1.36±0.05 and 1.47±0.05 respectively (Table 1). Box and whisker plot in Figure 7 explains the variation of DE ratios in different categories of stones.

Table 2: CT number ratios (Dual Energy ratios) of different stones:

Types of stones	**Dual Energy Ratio**			**SD**
	Minimum	Maximum	Mean	
Uric Acid	0.55	1.11	0.89	0.17
Mixed type	0.91	1.25	1.09	0.14
Cysteine	1.12	1.32	1.18	0.09
Calcium Oxalate	1.26	1.47	1.36	0.05
Hydroxyapatite	1.41	1.54	1.47	0.05

The minimum DE ratio was 0.55 for uric acid stones and maximum DE ratio was 1.54 for hydroxyapatite stones when scanned with 80 and 140 kVp.

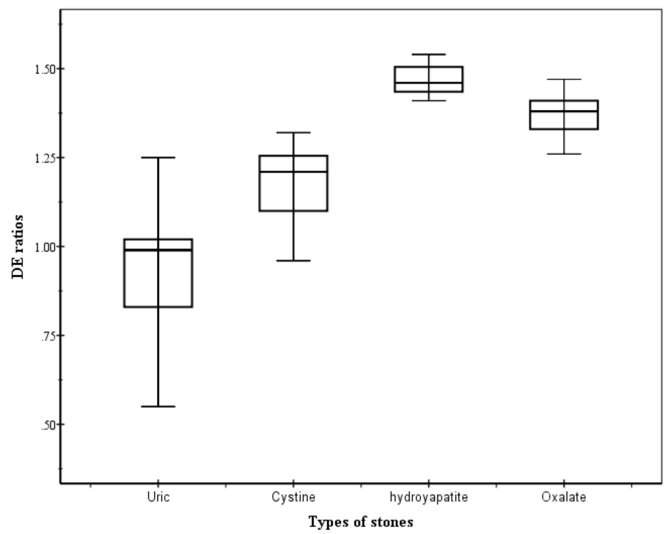

Figure 5. Box and whisker plot showing variation of DE ratios in various types of stones.

Discussion

This study has been conducted in an attempt to determine the chemical composition of urinary tract stones with dual energy multi detector Computed Tomography on the basis of x-ray attenuation of these stones. The primary reason for analysis of chemical composition of urinary tract stones is to facilitate more efficacious interventions, appropriate patient management and also limit stone recurrence. Determining the composition of calculi also has direct treatment implications.[6]

Qu et al. concluded that DECT can provide in vivo urinary stone characterization over a wide range of body sizes.[11] Qu et al. also demonstrated better separation of different types of stones ex vivo as well.[12] The characterization of various stone is based on the dual energy ratio and x ray attenuation or HU.

In our study, dual energy ratio was calculated and it ranged from 0.55 - 1.11 for uric acid stone, 1.12 - 1.24 was definitive for cystine and DE ratio more than 1.24 was observed for calcium stone. These values were categorized by the respective spectra displayed on the Syngo Via workstation. Struvite stone had attenuation ratio that largely overlapped with cysteine stone and thus could not be reliably assessed.

In addition to dual energy ratio, another parameter used for characterization of stone was HU of stones. The mean HU noted in our study were; uric acid stones (461.12 ± 119 HU for low energy, 449 ± 98.5 HU for high energy) cystine (870.79 ± 386 for low energy, 743 ± 341 for high energy) calcium oxalate (1246 ± 448 for low energy, 915 ± 316 for high energy)

hydroxyapatite (1301 ± 387 for low energy, 896 ± 315 for high energy and mixed stone (779.25 ± 269 HU for low energy, 665.5 ± 252 HU for high energy).
The values were similar to the study performed by Boll et al[13] which were uric acid (453-629 HU for low energy; 443-615 HU for high energy) cysteine (725-832 for low energy, 513-747 for high energy) calcium stones (1337-1530 HU for low energy, 1007-1100 HU for high energy).

A similar study on CT number by Stephanie Nykamp[14] found the HU values as; uric acid (337 ± 154 HU at 80kV, 378 ± 140 HU at 140 kV), cystine (706 ± 76 at 80kV, 548 ± 90 at 140 kV), calcium oxalate (1346 ± 378 at 80 kV, 856 ± 21 at 140 kV) and hydroxyapatite (1033 ± 209 HU at 80 kV, 670 ± 92 HU at 140 kV). The stones were displayed in specified colors *i.e*. uric acid stone in red color and non- uric acid stones in blue color.

Hidas et al[15] measured the dual-energy low-and high-energy attenuation ratios in the phantom were less than 1.1 for uric acid, 1.1-1.24 for cysteine and greater than 1.24 for calcified stones.

Thomas et al[16] identified uric acid, cysteine and calcium-containing calculi correctly by using dual-energy CT. Boll et al[13] detected clusters for uric acid (453-629 HU for low-energy CT, 443-615 HU for high-energy CT), cysteine (725-832 HU for low-energy CT, 513-747 HU for high-energy CT), and struvite (1337-1530 HU for low-energy CT, 1007-1100 HU for high-energy CT) stones; high-energy clusters showed attenuation value overlap. They concluded DE multidetector CT with advanced image post-processing techniques improved the characterization of renal stone composition beyond the capability of single-energy multidetector CT.[13]
Our study was performed under consecutive acquisition Dual energy CT approach, in which after standard CT-KUB, further dual energy scans at 80 kV and at 140 kV were taken for the region of stones (about 10-15 mm). This leads to an approximately 8-10% increase in radiation dose than a standard low dose stone protocol CT. It is substantially lower than most abdominal CT examination (40-60% lower dose) and within the limit specified in the guidelines by American college of Radiology for abdominal CT ($CTDI_{vol}$-25 mGy).[17]

Conclusions

Dual energy multi-detector CT with advanced post-processing techniques efficiently characterizes the composition of urinary tract stones. The ability of DECT to discriminate various stones depends on difference between the dual energy ratios (CT number ratio). The highest number of stones found was calcium oxalate followed by uric acid, hydroxyapatite, cystine and mixed type respectively. Distribution of stone was highest in left kidney and least at left ureter. Further studies are needed to evaluate the accuracy of our results.

Acknowledgement
Authors are thankful to Rajesh Rajan Yadav, Abhinash Jha, Niranjan Thapa, Dinesh Mishra and Dhana Prasad Panta for their kind co-operation and support.

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