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Role of Dual Energy Computed Tomography in Evaluation of Renal Stones

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Abstract

Background: DECT is a new evolving technique used for in vivo prediction of renal stones chemical characterizations.

Aim of Study: This study aims to assess the role of Dual Energy computed Tomography (DECT) in evaluation of renal stone compositions.

Patients and Methods: This study is a prospective cohort study, it included 30 patients. Classic single energy examinations were done (100-120 kVp) followed by DECT performed by using a single-source dual energy with fast switching between two kilovoltages (80, 135 kVp). Results of DECT were then compared to crystallography.

Results: (20 males and 10 females) with known renal stones, no age or sex predilection. The patient aged from (16) to (79) years From all the examined 37 stones, DECT predicted chemical composition of stones as 24 Ca oxalate stones, 8 uric acid stones and 5 cystine stones. DECT accurately identified all uric acid stones. DECT recognized 2 stones as Ca oxalate and they were proven to be Ca phosphate by crystallography. DECT also failed to identify mixed compositions in 2 stones which were diagnosed as Ca oxalate and cystine stones. Statistical analysis revealed reliable agreement between DECT and crystallography with a (p-value) of >0.001 (highly significant).

Conclusion: DECT was found as an effective and reliable method in pre-analysis of renal stones prior to management.

Key Words: *Dual Energy Computerized Tomography (DECT) – Renal stones.*

Introduction

RENAL calculi affects about 10-14% of the population, with multiple different chemical compositions [1].

Unenhanced computed tomography has improved the ability to evaluate urinary calculi as it gives a good information about the presence, size and location of the stones. DECT is a new evolving technique that provides similar information in addition to chemical characterizations of renal stones [2,3].

From the physical aspect, three different concepts of DECT are available, the first concept is based on the technology of two X-ray tubes (known as dual source imaging) working simultaneously. The second method is based on the use of a dual-layer multi-detector where the top layer of detectors absorbs most of the low-energy spectrum and the bottom detector layer absorbs higher energy photons. The third concept is based on the use of a single X-ray source with fast switching between two kilovoltage settings (80 and 140 kVp) at intervals of 0.5 ms during a single gantry rotation to generate high- and low-energy X-ray spectra [4,5].

Previous studies reported that DECT had a very high sensitivity and specificity for characterizing the chemical composition of renal stones [6].

Dual energy CT was reported recently to differentiate uric acid from non-uric acid [7].

A reliable prediction of the stone's chemical type helps the clinician to choose between treatment options, such as those composed of uric acid, may be treated medically and may not require surgery [8].

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DECT : Dual Energy Computed Tomography.
kVp : Peak kilovoltage.
Ca : Calcium.
ESRD : End Stage Renal Disease.
HU : Hounsfield Unit.
ROI : Region of interest.
kV : Kilovoltage.
ESWL : Extracorporeal Shock Wave Lithotomy.
PCNL : Percutaneous Nephrolithotomy.
URS : Ureteroscopy.

The most reported limitation of DECT is related to its relatively high irradiation, however multiple techniques are used to reduce radiation doses [9].

It is expected that DECT is going to replace the classic single energy CT as the main imaging modality in evaluating patients with suspected urinary calculi [10,11].

This study aimed to evaluate the role of DECT in renal stones characterization.

Patients and Methods

Patients:

This study, a prospective cohort study, was performed at the Radiology department at International Medical Centre "IMC", Cairo, throughout the period from August 2018 to March 2020. The study included 30 patients (20 males and 10 females) with known renal stones. The patient aged from (16) to (79) years with a mean age (47.5) years.

Informed written consents were obtained from all participants in the study after full explanation of the benefits and risks of the procedure. Privacy & confidentiality of all patient data are guaranteed. All data provision are monitored and used for scientific purpose only.

Inclusion criteria included patients previously diagnosed with renal stones larger than 3mm. No age or sex predilection. Exclusion criteria included contraindications to radiation e.g., pregnancy.

Methods:

I- *Full history taking and clinical examination:*

a- Personal history included age, sex and special habits as smoking, alcoholism.

b- History of the present illness.

c- Past history with special concern on known urolisthiasis.

d- Clinical examination including general examination, local abdominal and pelvic examination.

II- *Radiological examination:*

a- *Ultrasonography:*

Grey scale Ultrasonography (using LOGIQTM P9 Ultrasound System, GE Healthcare, USA.), for assessment of:

- Presence of renal stones or backpressure changes of the kidney.

b- *Computed Tomography:*

- CT machine: all patients were scanned with multidetector CT scanner, Aquilion ONE TM 640/ GENESIS Edition, Toshiba, Japan.

- Patient preparation:

- The patients are allowed to eat, drink and take their prescribed medications prior to the exam.
- The patients are advised to drink water 1-2 hours before the scan and maintain a full bladder.

- Image acquisition:

- The patient lying in supine position with head fixation and arms above the head then asked for holding breath at various times during the procedure.
- Technical scan parameters include: Field of view, patient's body size; scanogram, covering the area from the xiphisternum to the symphysis pubis; tube voltage, 100-120 kVp; tube current, 150mA with automatic exposure control; slice thickness, 1mm; slice interval, 0; gantry rotation time, 0.5sec. Axial images are then reconstructed in coronal and sagittal planes. For each patient, we evaluate the number, location, maximal diameter and CT density. CT density is measured with a region of interest "ROI" occupying less than 50% of the stone surface area.
- DECT examinations performed by using a single-source dual energy with fast switching between two kilovoltages. Technical scan parameters for DECT scan include: Tube voltage, 80kVp and 135kVp; reference tube current, 115mA and 350mA with automatic exposure control; field of view, patient's body size; slice thickness, 0.5mm; gantry rotation time, 0.5sec.

- Post processing technique:

Images acquired with the dual energy modality were processed using the dedicated software of the CT machine for the evaluation of the stone chemical composition. After selection of both low-energy and high-energy image volumes, stones are numbered in both low-energy and high-energy images. The end result is presented when the software then calculates the attenuation ratio of the stone and displays it as a point on the graph and colorize it by a red or blue color according to color map Fig. (1).

- Result display:

- Stone number, site, size and density in single energy (in HU).
- Attenuation value in single energy CT and DE (in HU).
- Attenuation ratio (low energy HU/high energy HU) with colorization of the stone according to color map.

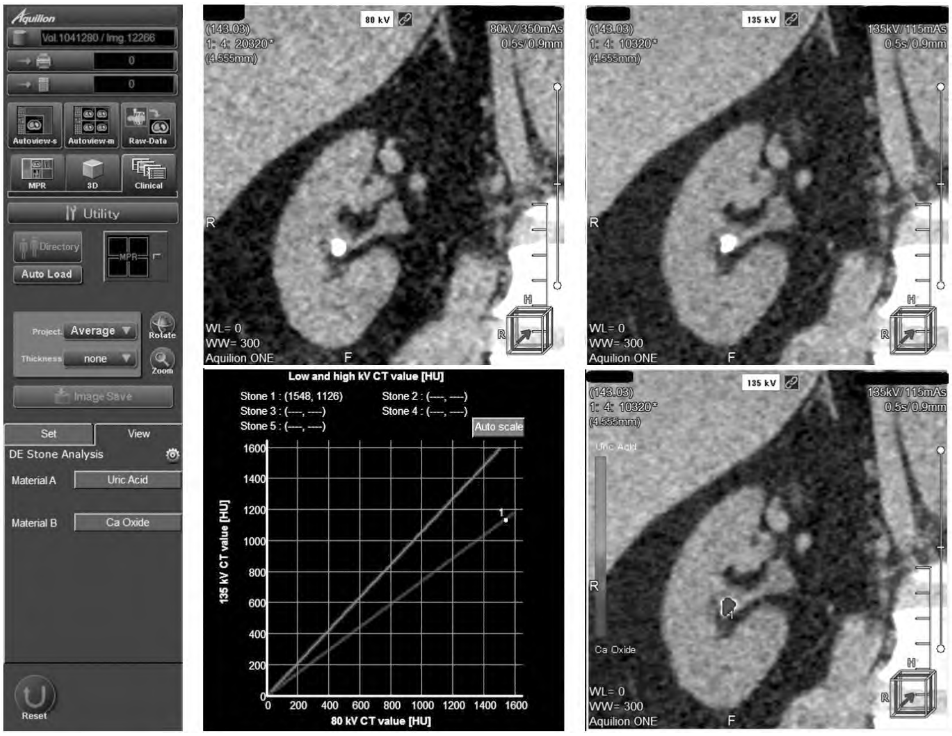

Fig. (1): The end result: The stone is represented by a point on the graph and colorized by red or blue color according to color map. This was a Ca oxalate stone.

III- Laboratory stone analysis:

All data were compared with result of laboratory stone analysis (crystallography) after passage or extraction of the stone.

IV- Statistical analysis:

Categorial and continuous variables were expressed and results were set in Tables and Figures using Microsoft Excel TM 2016. Agreement between DECT and laboratory stone analysis (crystallography) was estimated using Cohen's Kappa coefficient (k).

Results

This study included 30 patients, 20 males and 10 females. Their ages ranged from 16 to 79 years with a mean 48 years standard deviation (SD) of 14.2. Age and sex distribution is shown below (Table 1).

Clinical presentation of the patients was variable; classic loin pain was noted in 17 cases, hematuria in 5 cases, loin pain combined with hematuria in 3 patients, combined loin pain with nausea and vomiting in 3 patients, loin pain combined with fever in only 1 patient, one patient was asymptomatic. The percentage of each clinical presentation is shown in (Fig. 2).

Non-contrast computed tomography was performed for all patients. Twenty-five patients had a single stone and 5 patients had multiple stones, the total number of stones in the 30 examined patients was 37 stones. The sizes of stones ranged from 5 to 36mm with a mean of 15mm. Single energy CT density ranged from 405 HU to 1926 HU with a mean of 1124 HU. Eighteen stones were seen at the lower calyx, 4 stones seen at upper calyx, 3 stones seen at the middle calyx, 7 stones seen at the renal pelvis, 5 stones were staghorn stones. These findings are represented in (Fig. 3) and (Table 2).

DECT examinations performed by using a single-source dual energy with fast switching between two kilovoltage setting using 80kVp and 135kVp. DECT predicted chemical composition of stones as 24 Ca oxalate stones, 8 uric acid stones and 5 cystine stones. DECT accurately identified all uric acid stones Case example is shown in (Fig. 4). As DECT has only software criteria for Ca oxalate, Cystine and uric acid stones and the machine has no software criteria to detect other chemical compositions such as Ca phosphate, so in our study, DECT recognized 2 stones as Ca oxalate and they were proven to be Ca phosphate by crystallography. DECT also failed to identify mixed compositions in 2 stones which were diagnosed as Ca oxalate and cystine stones. These findings are represented in (Tables 3,4).

In our study, DECT recognized the chemical composition of uric acid stones ranging (405-530) HU for low-energy and (435-573) HU for high-energy with attenuation ratio of (0.88-0.93). Cystine stones ranging (762-1200) HU for low-energy and (696-1002) HU for high-energy with attenuation ratio (1.09-1.21). Calcium oxalate stones ranging (1249-2151) HU for low-energy and (710-1561) HU for high-energy with attenuation ratio of (1.27-2.21). These values are detailed in (Table 5).

Patients underwent various treatment options according to stone site, size and chemical composition. In our study, 6 stones responded to medical treatment, 15 stones responded to Extracorporeal Shock Wave Lithotomy (ESWL), 13 stones underwent Percutaneous Nephrolithotomy (PCNL) and 3 stones needed open surgery. (Table 6).

Only one patient had a stone of ≤5mm in size, which was uric acid stone, so it responded to medical treatment. Twenty-one stones (6-≤15mm); 4 of them were uric acid stones, 3 responded to medical treatment and one stone needed PCNL due to another larger stone in duplex calyceal system, 2 cystine stones responded to medical treatment and 15 stones were Ca oxalate of which 13 underwent ESWL and 2 needed PCNL after failure of ESWL. Six stones were (16-≤20mm); 2 of them were uric acid failed medical treatment and needed PCNL, 4 were Ca oxalate, of them 3 responded to ESWL and one needed PCNL. Nine stones >20mm; 6 of them underwent PCNL and 3 needed open surgery regardless the chemical composition (Table 7).

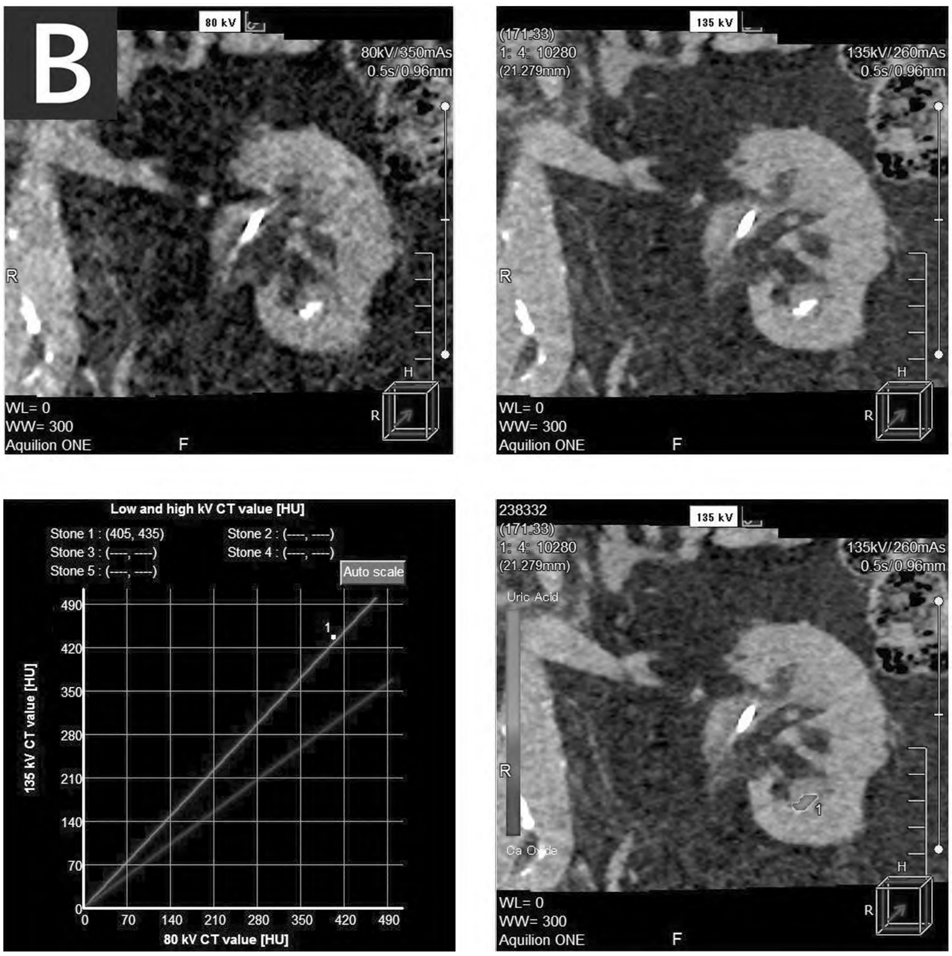

Fig. (2): Case (1): Dual energy chart showing attenuation of (405 and 435 HU) in low and high energy respectively, with attenuation ratio of (0.93), the stone is colorized by red color denoting uric acid composition according the color map.

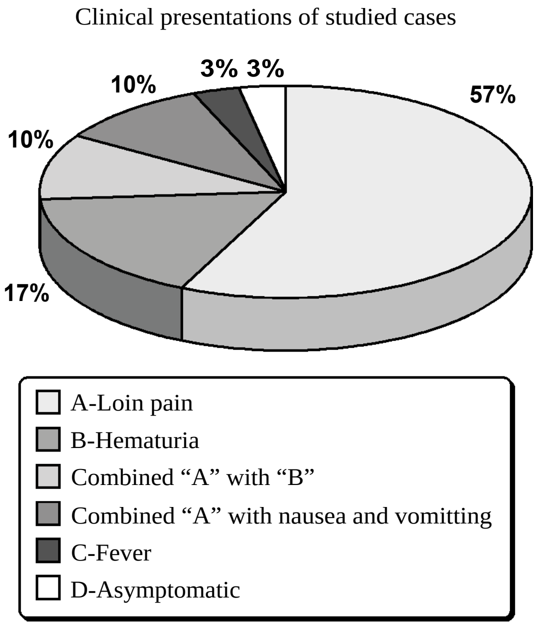

Fig. (3): Graph showing clinical presentations of the studied cases.

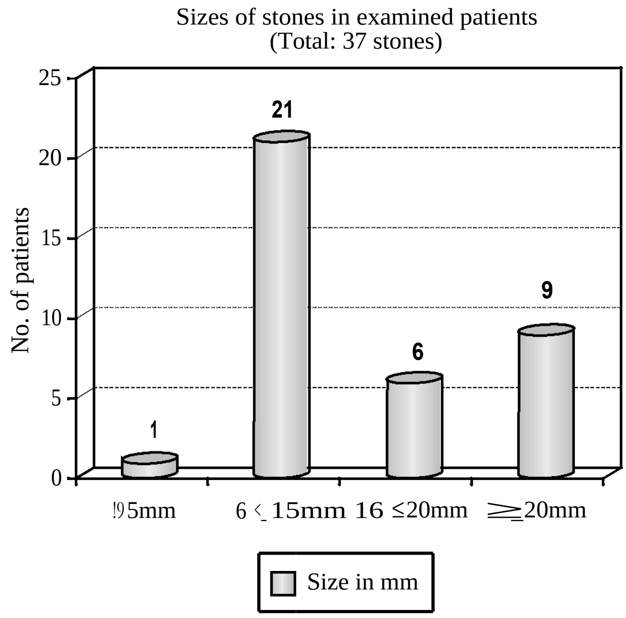

Fig. (4): Shows Sizes of stones in examined patients.

Table (1): Age and sex distribution of studied patients.

Age in years	Sex				Total	
	Male		Female			
	No.	%	No.	%	No.	%
<30	1	3.3	1	3.3	2	6.6
30 <40	6	20	1	3.3	7	23.3
40 <50	5	16.6	2	6.6	7	23.3
50 <60	4	13.3	3	10	7	23.3
60 <70	3	10	2	6.6	5	16.6
>70	1	3.3	1	3.3	2	6.6
Total	20	66.6	10	33.3	30	100

Table (2): Shows sites of stones in examined patients.

	Right	Left	Total	Percentage
Upper calyx	1	3	4	10.8
Middle calyx	2	1	3	8.2
Lower calyx	7	11	18	48.6
Pelvis	1	6	7	18.9
Staghorn	2	3	5	13.5
Total	13	24	37	100

Table (3): Different stone types predicted by DECT.

	Number of stones	Percentage
Ca Oxalate	24	64.8
Uric acid	8	21.6
Cystine	5	13.6
Total	37	100

Table (4): Agreement between DECT and crystallography.

DECT	Crystallography					X^2 (*p*-value)
	Calcium Oxalate	Calcium Phosphate	Cystine	Mixed	Uric Acid	
Calcium Oxalate (N=24)	21 (100%)	2 (100%)	0	1 (50%)	0 0	69.529 (>0.001**)
Cystine (N=5)	0	0	4 (100%)	1 (50%)	0	
Uric Acid (N=8)	0	0	0	0	8 (100%)	
Kappa agreement (*p*-value)	0.899 (>0.001 **)					

**: Highly significant.

Table (5): Detailed data of DECT stone characterization.

No.	Single energy HU	Low-energy HU	High-energy HU	Attenuation ratio	DECT stone type
1	505	475	535	0.88	Uric Acid
2	413	410	457	0.89	Uric Acid
3	405	467	520	0.89	Uric Acid
4	439	425	468	0.90	Uric Acid
5	461	439	475	0.92	Uric Acid
6	536	530	573	0.92	Uric Acid
7	489	458	492	0.93	Uric Acid
8	408	405	435	0.93	Uric Acid
9	704	762	696	1.09	Cystine
10	962	964	864	1.11	Cystine
11	853	927	780	1.18	Cystine
12	1057	1200	1002	1.19	Cystine
13	917	1035	849	1.21	Cystine
14	1100	1249	978	1.27	Calcium Oxalate
15	1286	1390	1081	1.28	Calcium Oxalate
16	1183	1314	1019	1.28	Calcium Oxalate
17	1456	1678	1298	1.29	Calcium Oxalate
18	1442	1777	1366	1.30	Calcium Oxalate
19	1577	1866	1432	1.30	Calcium Oxalate
20	1495	1682	1272	1.32	Calcium Oxalate
21	1799	1994	1500	1.32	Calcium Oxalate
22	1202	1560	1173	1.32	Calcium Oxalate
23	1169	1370	1027	1.33	Calcium Oxalate
24	1554	1643	1228	1.33	Calcium Oxalate
25	1178	1483	1104	1.34	Calcium Oxalate
26	1407	1695	1257	1.34	Calcium Oxalate
27	1620	1789	1312	1.36	Calcium Oxalate
28	1585	1835	1344	1.36	Calcium Oxalate
29	1634	1872	1361	1.37	Calcium Oxalate
30	1926	2151	1561	1.37	Calcium Oxalate
31	1306	1734	1256	1.38	Calcium Oxalate
32	1384	1777	1282	1.38	Calcium Oxalate
33	1249	1660	1180	1.40	Calcium Oxalate
34	1116	1603	1069	1.49	Calcium Oxalate
35	1466	1927	1231	1.56	Calcium Oxalate
36	1241	1591	913	1.74	Calcium Oxalate
37	1070	1571	710	2.21	Calcium Oxalate

Table (6): Number of stones underwent various management options.

Management options	Number of stones	Percentage
Medical treatment	6	16.2
Extracorporeal Shock Wave Lithotomy (ESWL)	15	40.6
Percutaneous Nephrolithotomy (PCNL)	13	35.1
Open surgery	3	8.1
Total	37	100

Table (7): Different management regarding size and chemical composition of stones.

Stone size	Number of stones	Composition	Management
≤5mm	1	Uric acid	Medical
	3	Uric acid	Medical
	1	Uric acid	PCNL
6 ≤ 15mm	2	Cystine	Medical
	13	Ca Oxalate	ESWL
	2	Ca Oxalate	PCNL
	2	Uric acid	PCNL
16 ≤20mm	3	Ca Oxalate	ESWL
	1	Ca Oxalate	PCNL
	6	Various	PCNL
>20mm	3	Various	Open Surgery
Total	37		

Discussion

Characterization of urinary calculi using non-invasive methods can affect clinical management. CT has been the gold standard for diagnosis of urinary calculi, but has not reliably differentiated varying stone compositions. DECT has emerged as a technology to improve CT characterization of anatomic structures. The use of DECT allows us to address the composition of urinary stones, a key determinant in identifying suitable treatment **[12,13]**.

In our study, male to female ratio was 2:1, this ratio agreed with Knoll et al. (2011) **[14]**, they found renal stones are more common in males with overall male to female ration of (2.4:1). This contrasts to other studies such as Dawoud et al. (2017) **[15]**, they found renal stones were common in females (55%) than males (45%).

Our study included 30 patients, the ages of the patients ranged from 16 to 79 with a mean of 50 years and the peak age group was 40-50 years (5 cases; 16.6%). This agreed with Pearle et al. (2008) **[16]**; they studied two groups undergoing SWL and URS and the mean ages were (52.5 $\pm$ 12.3) and (49.3$\pm$14.2) in the two groups respectively. These results differ from age groups determined by other studies such as Dawoud et al. (2017) **[15]**, as they found the age group 30-40 were the most affected and the peak of 33 years.

One of the defects in our study is the small population, this may be referred to difficulties that we faced in the laboratory stone analysis because of its high coast and unavailability in our institute.

In our study, 19 patients (64%) presented by loin pain, 7 patients (23%) presented by hematuria, 3 patients (10%) presented by nausea and vomiting, one patient (3%) presented by combined loin pain and fever. These clinical presentations agree with most of the previous studies, one of the latest studies from Egypt, Dawoud et al. (2017) **[15]**, found loin pain was the most common clinical presentation.

In our study, twenty-five patients had a single stone and 5 patients had multiple stones, the total number of stones in the 30 examined patients was 37 stones. The sizes of stones ranged from 5 to 36mm with a mean of 15mm. Single energy CT density ranged from 405 HU to 1926 HU with a mean of 1124 HU. These findings agreed with Chaytor et al. (2016) **[17]**, they found kidney stones are much more common (84.7%) than ureteric stones, single stones were found in 79% of cases, however they found sizes of stones ranging from 3-48mm with a mean of 8.8mm, this can be explain by the difference in number of examined patients; they examined 106 patients, compared to only 30 patients in our study.

In our study, DECT predicted chemical composition of stones as 24 Ca oxalate stones, 8 uric acid stones and 5 cystine stones. DECT accurately identified all uric acid stones. These findings agreed with Dawoud et al. (2017) **[15]**, Chaytor et al. (2016) **[17]** and Stolzmann et al. (2008) **[18]**, they concluded that DECT was able to differentiate uric acid stones from non-uric acid stones using attenuation ratio analysis of DECT scanners.

In our study, DECT failed to identify 2 Ca phosphate stones compared to crystallography, it also failed to identify mixed compositions in 2 stones which were diagnosed as Ca oxalate and cystine stones by crystallography. These findings agreed with Manglaviti et al. (2011) **[6]**, they found DECT was unable to identify chemical compositions of 4 stones that were found to be mixed uric acid and Ca oxalate by crystallography while DECT characterized them as cystine and Ca oxalate.

In our study, only one patient had a stone of <5mm in size, which was uric acid stone, so it responded to medical treatment. Twenty-one stones (6-$\leq$15mm); 4 of them were uric acid stones, 3 responded to medical treatment and one stone needed PCNL due to another larger stone in duplex calyceal system, 2 cystine stones responded to medical treatment and 15 stones were Ca oxalate of which 13 underwent ESWL and 2 needed PCNL after failure of ESWL. 6 stones were (16-$\leq$20mm); 2 of them were uric acid failed medical treatment and needed PCNL, 4 were Ca oxalate, of them 3 responded to ESWL and one needed PCNL. Nine stones >20mm; 6 of them underwent PCNL and 3 needed open surgery regardless the chemical composition. These findings regarding the management of renal stones according to site, size and medical compositions agreed with multiple studies such as Habashy et al. (2016) **[19]**, they concluded that distinguishing uric acid stones from calcium stones resulted in a change in patient management in the majority of their uric acid stone cases and avoided surgery in 12 patients (80%). Overall, 48 patients required a DECT scan for (identification and successful dissolution treatment of a uric acid stone. However, the impact of chemical composition pre-analysis is still controversial. In studies such as Thomas et al, (2009) **[18]**, calculus composition did not have an impact on the patient's clinical pathway, since in their institution, all calculi are extracted by the urology department by PNL or ureterorenoscopy whenever possible.

Conclusion:

DECT was found as an effective and reliable method in pre-analysis of renal stones prior to management. DECT is expected to replace the classic single energy CT as the main imaging modality to evaluate renal stones. DECT provides satisfactory information regarding the stone chemical composition, in addition to the basic information provided by single energy CT, such as, number of stones, their sites, sizes, surfaces and CT densities. Identification of renal stone chemical composition affects the choice of treatment options and can reduce the usage of unnecessary invasive or semi-invasive options and improve the outcome of medical treatment.

We recommend further studies should be done to calculate attenuation ratio of multiple other stones such as Calcium Phosphate, so DECT could be used to identify such stones in the future.

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دور الأشعة المقطعية ثنائية الطاقة
فى تقييم حصوات الكلى

التصوير المقطعى الحلزونى بدون صبغة قد أصبح طريقة جيدة فى تقييم المسالك البو لية من حيث وجود الحصوات وحجمها ومكانها ومضاعفاتها. يعتمد التصوير المقطعى ثنائى الطاقة على تحديد التكوين الكيميائى لحصوات الكلى بالإضافة إلى تقييم المعلومات التشريحية من حيث الموقع والحجم وخصائص السطح.

الأشعة المقطعية ثنائية الطاقة قد أثبتت كفاءة تقترب ١٠٠٪ من فى تحديد المكونات الكيميائية لحصوات الكلى التى يزيد حجمها عن ٣ملم.

تهدف هذه الدراسة إلى تقييم دور الأشعة المقطعية ثنائية الطاقة فى حصوات الكلى.

أجريت هذه الدراسة بقسم الأشعة بالمركز الطبى العالمى، فى الفترة بين أغسطس ٢٠١٨ ومارس ٢٠٢٠. ضمت هذه الدراسة ٣٠ مريضاً (٢٠ من الذكور و ١٠ من الإناث) ممن يعانون من حصوات الكلى. تراوحت أعمار المرضى بين ١٦ و ٧٩ عاماً بمتوسط إعمار ٤٨ عاماً.

تم فحص المرضى بالأشعة المقطعية الأساسية أحادية الطاقة، بتيار أنبوب مقداره ١٢٠ كيلو فولت، ثم تم إجراء فحص الأشعة المقطعية ثنائية الطاقة بعد تأكد وجود حصوات كلوية، باستخدام جهاز أحادى المصدر ثنائى الطاقة ذى تبديل سريع بين ٨٠ كيلو فولت و ١٣٥ كيلو فولت، وبالتركيز على مكان الحصوات.

تمت معالجة الصور الناتجة باستخدام ورشة عمل الجهاز لتقييم المحتوى الكيميائى للحصوات.

كانت الأشعة المقطعية ثنائية الطاقة طريقة فعالة وموثوقة لتوقع التركيب الكيميائى لحصوات الكلى ما قبل خطة العلاج. من المتوقع أن تحل الأشعة المقطعية ثنائية الطاقة مكان الأشعة المقطعية العادية كأداة تشخيص تصويرى رئيسية لتقييم حصوات الكلى، حيث توفر الأشعة المقطعية ثنائية الطاقة معلومات كافية عن التركيب الكيميائى للحصوات بالإضافة للمعلومات الأساسية للأشعة المقطعية العادية كالعدد والموقع والحجم وشكل السطح والكثافة.

التعرف على التركيب الكيميائى لحصوات الكلى يؤثر فى اختيار خطة العلاج، وقد يساعد فى تقليل استخدام الإجراءات الاجتياحية غيرالضرورية، ويحسن نتائج العلاج الدوائى.