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Determination of Renal Stone Composition with Dual Energy CT: In Vivo Analysis and Comparison with Renal Stone Biochemistry

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Abstract:
Background and Objectives: *The lifetime prevalence of urinary tract stone has been estimated to be 10-14%.The morbidity associated with urolithiasis includes colic pain and kidney obstruction, which can lead to renal failure and severe urinary tract infections such as pyonephrosis and septic shock in some patients . Dual –energy CT ,by facilitating low and high –energy scanning during a single acquisition, has inherent capability to help differentiate different materials that have similar electron densities but varying photon absorption .Our aim in this study was to preoperatively assess the composition of urinary tract stones with dual energy CT by*

using postoperative in vitro renal stone biochemistry analysis as the reference standard. Methods: This study was conducted in a group of 50 patients, Patients who are referred for DECT KUB and who are diagnosed to have Renal stone pathology were included in the study. DECT was performed by Somatom definition 128 slice dual energy CT.

Result And Conclusion: *After DECT finding total 18 patients were detected with calcium hydroxyapatite (CAH) stone. After the stone extraction process, biochemical analysis showed that among these 18 patients all have pure calcium hydroxyapatite as the stone components. This finding matches 100% with the DECT finding. 36% of the total patients have pure calcium hydroxyapatite stone as observed in this analysis. In the table % within DECT finding showed 100% meaning DECT was able to detect all the CAH stones successfully. Similarly, after DECT examination total 10 (20%) patients showed stone composed of pure calcium oxalate. on biochemical analysis, it was observed that among these patients 9(18%) patients have stones composed of pure calcium oxalate (CAO) and 1(10%) patient had calcium hydroxyapatite as the stone component. In this case, DECT was able to find out the stone composition accurately in 90% of cases. Total 3 (6%) patients were detected with uric acid stones after DECT examination. In*

the biochemical analysis, all of these patients showed the similar result as the DECT examination. Among the total 50 patients, 19 patients showed the presence of a mixed type of stones. In DECT scanning 15 (30%) patients were detected with stones composed of mixed type with calcium hydroxyapatite and calcium oxalate (CAH+CAO). On biochemical finding, a similar number of the patient were detected with calcium oxalate and calcium hydroxyapatite stones (CAH+CAO). Total 4 (8%) patients were detected with calcium oxalate and uric acid mixed stones. In the biochemical analysis, a similar number of patients showed the presence of calcium oxalate and uric acid stones. DECT has effectively identified the composition of calcium hydroxyapatite stones wherein calcium oxalate stones one patient was wrongly identified by DECT. Overall, DECT showed higher accuracy in determining the renal stone composition and very useful in patients with renal stone to decide precise choice of treatment.

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I. Introduction

Urinary calculus disease or urolithiasis is a common clinical issue having a lifelong persistence of 10-15% as well as a 50% chance of recurrence within a period of ten years (1,2). The incidence of the renal stone disease is high in the USA. It is reported that approximately 6% of women and 12% of men in the USA have this disease. The morbidity related to urolithiasis includes colic pain and obstruction of kidneys which may result in renal failure and severe infections like pyonephrosis and septic shock in the urinary tract in some patients (3). Besides the location and size of the renal stones and abnormalities of the urinary tract, composition of the renal stones are also considered as a significant parameter influencing management and in the follow-up process of this disease[4} The chemical composition of renal stones There is a total of 16 chemical compounds that can form the renal stone. Among them, the prevalence of calcium oxalate, calcium phosphate, uric acid, and cystine are most common stone components that are found, other compounds are rarely found in patients (7). A recent study has reported that crystallized and aggregated particles of extremely concentrated urinary constituents may be held responsible for the formation of renal stones (7). Renal stones may be broadly classified as calcium and non-calcium stones. The most widely occurring (40–60%) renal stones are formed of calcium oxalate. The next highest occurring renal stones (5–10%) are formed by uric acid. 2–4% and 1–3% of reported renal stones are reportedly formed of hydroxyapatite and cystine respectively (7). For instance, renal stones formed of cystine or calcium oxalate monohydrate possess a stable composition and are more successfully treated with percutaneous nephrolithotomy in comparison to application of extracorporeal shock wave lithotripsy (3). Renal stones formed of uric acid may be dissolved medically by urinary alkalinization therapy like an oral infusion of potassium citrate solution with/without allopurinol (9). The occurrence of renal stones having similar compositions may indicate an infestation of systemic and hereditary metabolic stone disease (9). Recent studies have also suggested that knowledge of the stone composition may help frame specific dietary and medical measures for reduction of the risk of recurrence (3). Diagnostic Modality: Clinical utility of quantitative imaging As evident from contemporary studies, x-ray diffraction, infrared spectroscopy, and polarization microscopy have so far been the most common techniques for in vitro analysis of renal stones. Besides incurring huge cost and time, these techniques possess another major limitation in the fact that chemical characterization of the concerned stones is possible only post extraction (3). However, these techniques provide no advantage in the planning of preoperative treatment strategies thereby necessitating the need for efficient quantitative imaging tools. The Quantitative Imaging Biomarkers Alliance defined quantitative imaging as an "extraction of quantifiable features from medical images for the assessment of normal or the severity, degree of change, or status of a disease, injury, or chronic condition relative to normal" (10).

Quantitative imaging also reportedly encompasses the development and standardization of protocols for imaging acquisition and analyses, methods of display and reporting of structures. In quantitative imaging, precise image-derived metrics are created and validation of these matrices with physiologically and anatomically relevant parameters such as treatment response can prove to be helpful for further application in research and patient care (11). Advanced technologies of quantitative imaging have facilitated better imaging with the attainment of improved loco-regional control and reduced toxicity as well as enhanced disease specificity. Of all other contemporary tools of quantitative imaging, computed tomography (CT) reportedly provides a brilliant portrayal of anatomical details with great precision (12). Standardization of pixel values of CT using Hounsfield Unit (HU) scale facilitates characterization of tissue density (13). HU estimations use region-of-interest (ROI) based calculations of average density or voxel-counting based on the basis of a threshold value for characterization of lesions (14). Moreover, the recent advent of dual-energy CT (DECT) scanners has strengthened the clinical application of quantitative imaging (15). DECT has enabled differential absorption of x-rays at different energies by tissues having different chemical composition thereby facilitating enhanced tissue characterization (10,15). For example, a recent study has reported that DECT had determined the composition of renal calculi with enhanced precision in comparison to commonly used single-energy CT (16).

Precise characterization of the composition of renal stones will help determine whether the concerned patient will undergo medical treatment or an invasive procedure like extracorporeal shockwave lithotripsy (10). Dual-Energy CT (DECT): A new diagnostic approach to urinary calculosis CT reportedly helps in framing treatment strategies according to the stone size, burden, and location as well as the extent of obstruction (18). However, in case of conventional CT, the extensive overlapping of different types of calculi hinders appropriate characterization of their composition (18). It has been suggested that a simple and reliable technique for differentiating between uric acid and non-uric acid stones can help a patient avoid invasive interventional procedures for stone removal (18). Recent studies have reported DECT to be the most precise CT technique for differentiating between renal and ureteral stones by virtue of their chemical composition (18). Moreover, both in vitro and in vivo investigations with a limited cohort of patients have established that CT is capable of efficiently distinguishing pure uric acid stones from mixed uric acid, and calcified ones (18). As reported a recent study, preliminary studies with CT operating with two different energies for identifying the ingredients of urinary calculi included consecutive scanning with different photon energies (19). Authors of the same study have also reported that this technology was limited by motion induced misregistration of two consecutive images and increased radiation exposure during the two acquisitions. This technique involved exposure of patients to comparatively higher dosages of radiation (19). This study also reported a tailored low-dosage dual-energy procedure involving a dosage of radiation as low as that required for conventional intravenous pyelography (19). Results obtained in this study indicated that non-enhanced low- dosage dual source DECT performed efficient differentiation between uric acid, cystine, and calcium-bearing urinary calculi in non-obese patients with a satisfactory image quality and dosage of radiation equivalent to that used for intravenous pyelography. Hence, this study established dual-source DECT as a potential technique for identifying the composition of renal stones and framing treatment strategies for patients diagnosed with urinary calculus disease. Techniques involving post-processing material decomposition enable classification of renal stones into broad categories like uric acid or cysteine stones (4). Various studies have established the capability of DECT for accurately differentiating between uric acid and non-uric acid (4). However, very few studies have reported in vivo analysis of mixed stones (4). Moreover, according to this study, only a single study performed for in vivo characterization of the urinary stone composition. Determination of renal stone composition with DECT and its comparison with other techniques The composition of renal stones is usually determined post extraction using conventional methods like Fourier transform infrared spectroscopy or polarization microscopy (4). However, these techniques provide no benefits for designing optimal therapeutic solutions or non-invasive in vivo prediction of stone composition (4).

DECT facilitates simultaneous low and high-energy scanning for a single acquisition (3). DECT also differentiates between different materials having similar electron densities but different photon absorption efficiency (3). Hence, DECT may be considered as an efficient technique for in vivo identification of renal stone composition. The aim of the present study includes preoperative assessment of the composition of urinary tract stones with dual-energy CT and compares the finding with the postoperative in vitro renal stone biochemistry analysis by infrared spectroscopy analysis as the reference standard.

II. Objectives of The Study

1. The objective of the study is to determine the accuracy of dual energy Computed Tomography in characterization of renal stone composition in comparison with postoperative renal stone biochemistry study.
2. To assess the role of dual energy CT in helping the treatment options
3. To correlate the CT findings with the biochemistry findings.
4. To analyze the limitations of the study, if any.

III. Review Of Literature

The prevalence of nephrolithiais has increased in the last decade in an alarming rate. In a study conducted by National Health and Nutrition Examination Survey (NHANES) among civilian US population has shown that the prevalence of kidney stone has increased in 3.2% to 5.2% in the past decade. It was also reported that men are affected more than the female. Recurrence of the kidney stone is one of the main reason behind the morbidity of the disease. Both appropriate treatment prophylactic workup for prevention of recurrences are highly essential for symptomatic occurrence of renal stones (20). Prevention of episodes of renal stone recurrences can be achieved by ensuring complete metabolic workup and appropriate analysis of stones (20). As reported by Basiri et al. (21), global incidences of nephrolithiasis have increased substantially over the last two decades. According to Basiri et al. (21), treatment of renal stone is often painful and may necessitate invasive procedures like surgery while renal failure is found to occur in almost 3% of patients diagnosed with the same. Authors have also stated that around 10 - 23% rates of recurrence is recorded every year and may increase up to 50% in 5 years in absence of proper analysis of stones, management and follow-up (21). Epidemiology and etiology of the renal stone disease The incidence and prevalence of the urinary stone disease are increasing at an alarming rate. According to a survey conducted in 2012, in the United States, the incidence of renal stone disease in men has increased from 6.3% in 1994 to 10.6% in

2012. Similarly, among women, it was 4.1% in 1994 and in 2012, 7.1% of women were diagnosed with the urinary stone disease (22). Alarming occurrence rate of nephrolithiasis has been reported in British island, North Australia, central Europe, Mediterranean and Scandinavian countries. Countries like Sudan, Egypt, Iran, UAE, Philippines, Saudi Arabia India, Pakistan, Thailand, Myanmar, and Indonesia are identified as the stone forming belt of the world. In all these countries cases of renal calculi have been reported in all age group patients including child below 1 year of age and adults over 70 years with a male to female ratio of 2:1 (23). In India, approximately 2 million people are diagnosed with this disease every year. The western part of the country and some states in the northeast has been denoted as stone belt due to the high occurrence of stone disease in this part. In the southern part of the country, the prevalence is also higher due to ingestion of tamarind in regular diet. Further, studies have shown that in India approximately 50% of the population is affected by renal calculi which have a chance to end up in loss of kidney function or renal failure (24). In a case study conducted in AIIMS, New Delhi, authors have reported that among upper urinary tract urolithiasis paints the main chemical composition of the stone is in the form of pure calcium oxalate crystals (24). Interestingly, in the past few years incidence of stone formation in women has increased by many folds. This increased incidence has outpaced the prevalence of renal stone disease among men. The incidence rate ratio of nephrolithiasis in man to women has narrowed from 3.4 to 1.3 (23).

Taylor et al in a follow up prospective study have shown the effect of weight gain, body mass index and waist circumference on the prevalence of nephrolithiasis among men and women. This study has evaluated 3 large cohorts: the Health Professionals Follow-up Study or HPFS (N = 45 988 men) in the age group of 40-75 years, the Nurses' Health Study I (N = 93 758 older women) in the age group of 34-59 years, and the Nurses' Health Study II (N = 101 877 younger women) in the age group of 27-44 years (26). In the 46 years of the follow-up study, they have observed that in obese men (weight >220 lbs) relative risk for development of nephrolithiasis was more among compared to those with a lesser body weight (<150 lbs). However, in women in younger women, the relative risk of increased body weight with the stone formation is less than in older women. Moreover, in younger women who gained weight since very young age, the risk of developing kidney stone disease becomes more. Based on the results thus obtained authors have concluded that obesity and weight gain imparts a greater risk of nephrolithiasis in women compared to men (26). In a study by Novak et al, the alarming trend of increase in pediatric urolithiasis has been reported. Using the Healthcare Cost and Utilization Project Kids' Inpatient Database, they have observed that in the pediatric population, the prevalence of stone formation varied significantly by age. In the first decade of age, boys were more affected which shifted to female dominance in the second decade. However, overall this study reported a higher rate of stone formation among girls than the boys (27). Dwyer et al. have conducted a 25-year population-based study in 2012 to study the incidence of symptomatic kidney stones among the pediatric population. In this study authors have examined 207 children under the age of 18 by using CT scan imaging technique to detect the formation of kidney stone. Among these children, 84 (41%) were detected to be stone formers. Moreover, they have also reported a 4% increase in the incidence of stone formation per year. A rise in the incidence of stone formation was reported in children in the age group of 12-17 year. From this study, the authors have concluded that this increase in the stone formation among the pediatric population is alarming (28). This increase in the incidence of renal stone disease among the pediatric population is thought to be contributed by rise in childhood obesity along with the rise in BMI. However, this view has been challenged by many. In a study by Kirean et al, it was reported that higher body weight was not associated with stone formation in children. In this study total, 62 boys and 50 girls with urolithiasis were classified depending on their BMI. They were stratified into children with lower percentile body weight, those with normal weight, and children with upper percentile body weight. In this study patient who was in the lower percentile body weight had an earlier presentation of the disease compared to the higher body weight patients. Interestingly, normal weight category patients have had a higher percentage of stone formation. Thus, from this study authors have concluded that obesity did not increase the risk of formation of stone disease in the pediatric population (29).

Pathogenesis of calculus formation The factors posing risk to patients suffering from renal stone disease are not properly elucidated (22). According to Miller et al. (22), super-saturation of urine results in precipitation of metabolite crystals. As reviewed by Cheng et al. (31), values of super- saturation have been found to be correlated with composition of urinary calculus. Cheng et al. (31) also suggested that the probability of urine super-saturation varies with formation of specific metabolites and phenotype of the concerned patient. Authors also reported that a greater risk of stone occurrence or recurrence was encountered by patients suffering from metabolic disorders like gout, renal tubular acidosis, and hypercalciuria (31). Comprehensive clinical assessment is expected to reveal metabolic disorders in more than 90% of patients diagnosed with urolithiasis (31). Park and Pearle (32) suggested repeated occurrence of urinary tract infection as another risk factor for renal stone disease.

Composition of renal stones The major chemical constituents of renal stones like uric acid and cystine were first reported in 1776 and 1810 respectively (21). The chemical characterization of urinary calculi was established only after systematic studies by Hellar and Ultzmann in 1847 and 1882 respectively (21). According to Basiri et al. (21), almost 75% of stones are composed of calcium. According to Pearle and Lotan (25), renal stones are primarily composed of pure or mixed calcium oxalate (60%), calcium oxalate mixed with hydroxyl apatite (20%), uric acid (10%), struvite (10%), brushite (2%) and cysteine (1%). Appropriate analysis of chemical constitution of renal stones enables qualitative differentiation and semi-quantitative determination of all stone constituents (21). The five primary types of renal stones reported so far are described as follows. Calcium-based stones These can grow upto1700 Hounsfield units (HU) when measured by CT with the densest growth being brushite (calcium hydrogen phosphate dihydrate) in nature (31). According to Cheng et al. (31), the primary cause for formation of this type of stone is hypercalciuria. Hypercalciuria may result from either inefficient calcium reabsorption within renal tubules or excessive calcium absorption by the intestine. Other reasons for formation of this type of stone may be disorders in metabolism of uric acid (in presence or absence of gout), hypocitraturia (resulting from prolonged diarrhea, distal renal tubular acidosis or usage of thiazide), and hyperoxaluria (31,32).

Struvite stones – According to Griffith (34), these stones are mostly formed as a result of urinary tract infections caused by urease-producing bacteria like Proteus sp., Pseudomonas sp., and Klebsiella sp. and other species of enterococci. Formation of the struvite stone in the renal pelvis and its extension in minimum two calyces is often referred to as staghorn stone due to its structural similarity with a stag's antler (31). Uric Acid Stones Formation of this type of stone is usually promoted by hyperuricosuria and urine acidity (caused by high body mass ratio or diabetes). Gout and chronic diarrhea are considered as causative factors for formation of such kind of stone. According to Cheng et al., stones composed of uric acid are radiolucent on radiography but easily revealed by CT (indicated by their low attenuation (< 500 HU) values (31). Cystine stones This type of stones are primarily formed due to cystinuria (a metabolic disorder caused from genetic defects of renal transport). This type of stones is often known as "ground-glass" stones and is radiolucent in nature. Some cystine stones have void regions that yield low-attenuation foci when scanned with CT (31). This feature is yet to be utilized for clinical detections. Medication-Induced stones As suggested by Cheng et al. (31), continuous and excessive consumption of medicines like Indinavir and similar protease inhibitors may result in the formation of renal stones. According to these authors, herbal supplements like ephedrine (consumed for weight reduction) as well as guaifenesin (an expectorant) also induce formation of renal stones (31). Few of this type of stones exhibit radiolucency on CT. Growth of this type of stones may be arrested and cured by altered dosage of medication, longer diuresis and administration of agents for reducing urine pH (31). Diagnostic modality for renal stone detection The conventional ex-situ methods Wet Chemical Analysis

According to Kasidas et al. (35), this is the most widely used technique for analysis of renal stone carried out in routine laboratories. However, this technique can only reveal individual ions and radicals present in the composition of the stone. Identification of a specific compound in mixtures of various types of stones is beyond the scope of this method (21).

According to previous reports both qualitative and semi-quantitative wet chemical analysis yielded poor results (21). As suggested by Kasidas et al. (35), the efficiency of this process may be enhanced by performing quantitative chemical tests (previously used for analysis of blood and urine) with appropriately prepared stone solutions.

Thermogravimetry Thermogravimetric analysis (TGA) of stones is a rapid, feasible and simple technique for continuous estimation of decline in temperature and weight of a material subjected to increasing temperature (upto 1000 ºC) in presence of oxygen. Every material exhibits specific pattern of transformation commencing and ending after attaining specific temperatures (27). The materials undergoing TGA also demonstrate specific weight loss and enthalpy. These distinct features are indicative of the nature of the material while the magnitude of change denotes the proportion of the material (35).

Optic Polarizing Microscopy In this technique, composition of the renal stone is determined by the interaction between polarized light and crystals constituting the stones (36). In this technique, materials are collected from different portions of a fractured stone. These materials are then analyzed with solutions having appropriate refractive index under a polarizing microscope. As suggested by Schubert (37), the parameters like color, refraction of light and double refraction of the material indicate the identity of the stone materials

Scanning Electron Microscopy (SEM) SEM is a non-destructive technique revealing the morphology of renal stones having dimensions as low as one nanometer without causing any changes in the specific morphology of stone components (38). SEM also produces high-resolution images of the material surface (38).

Spectroscopy As described by Solli et al. (39), this technique analyses how matter interacts with radiated energy. Different types of radiated energy used for spectroscopy are electromagnetic radiation (inclusive of microwave, terahertz, infrared, near infrared, visible, ultraviolet, x-ray and gamma spectroscopy), particles (electrons and neutrons) and acoustics (radiated pressure waves). Interactions between matter and energy may be determined in terms of absorption, emission, elastic scattering, reflection, impedance, inelastic scattering (like Raman scattering) and resonance (like nuclear magnetic resonance spectroscopy).

Infrared (IR) Spectroscopy According to Singh (20) and Basiri et al. (21), IR has been considered as a popular and reliable technique for quantitative analysis of renal stones in-vitro over the previous decade owing to its specific, rapid as well as versatile detectability. In this technique, IR radiation is applied for causing atomic vibrations that absorb energy and produce bands in the IR spectrum of stone samples. IR radiation may be transmitted directly through samples compressed to form pellets using potassium bromide. In this process, the stone material is not recovered for further supportive analysis like wet chemical tests. An enhanced non-destructive method of IR spectroscopy is the technique of attenuated total reflection (ATR). This technique does not require mixing of the sample with any IR inert compound for analysis rendering the same suitable for recovery and further supportive analysis (21).

X-Ray Powder Diffraction (XRD) As reported by Basiri et al. (21), in the XRD technique, monochromatic X-rays are applied for identification of stone constituents on the basis of the unique patterns of diffraction/reflection yielded by the respective constituents.

Elementary Distribution Analysis (EDAX) As described by Marickar et al. (40), EDX reveals the elemental composition (percentage) of stone samples in case of samples unidentified by ordinary light microscopy or SEM. EDAX analysis confirms results obtained in SEM analysis and provides an idea of the elemental composition of the analyzed stone samples (21,40).

Currently used diagnostic techniques Polarizing microscopy was introduced by Prien and Frondel in 1947 for identification of the crystalline components of renal stones by measurement of refractive indices (21). Rose and Woodfine reported the analysis of stone composition using TGA in 1976 (21). Though this method rapidly yielded quantitative results, it was limited by the facts that it the great amount of sample required for optimal resolution could not be recovered post analysis (21). Besides, similarity in ignition temperatures and rates of disintegration exhibited by closely related compounds like purines reportedly caused difficulty in identification of stone constituents (21). This process was also unable to differentiate silica calcium pyrophosphate from calcium phosphate as both compounds suffered from negligible weight change after heating (21). Later in 1993, Rebentisch performed a comparative analysis of six quantitative and different qualitative analytical methods used between 1983 and 1988 with data obtained from around forty laboratories from twenty three countries (21). He had considered both standard of quality and mean deviation as determining factors for ranking the analytical methods. According to Rebentisch, the methods yielding best results to worst were in the following order: XRD analysis, IR spectroscopy, ultra-micro-chemical analysis, polarization microscopy, differential thermo-analysis and quantitative chemical analysis (21). On the basis of the results obtained, Rebentisch had concluded that XRD analysis and IR spectroscopy could be considered at par for yielding highly satisfactory analytical results and should be considered as reference techniques for analysis of renal stones (21). With further progress in research, Jhaumeer-Laulloo and Subratty reported a combined approach of wet chemical tests and IR spectroscopy for analysis of renal stones in 1999 (21). Results obtained by Jhaumeer-Laulloo and Subratty revealed that solo application of chemical analysis method yielded results having significant clinical errors. They also established that IR was a comparatively more precise and reliable technique for identification of the chemical composition of renal stones even with highly reduced quantities of sample (21). However, Estepa et al. (41) portrayed the possibility of misidentification of constituents by IR resulting from library incompleteness and substantial difference between spectra yielded by natural and synthetic compounds. Singh (20) later analyzed the composition of renal stones using FTIR. He reported that a computerized IR spectrophotometer and its large reference library facilitated accurate quantitative determination of stone constituents. He also suggested the utilization of this technique at all urolithiasis centers. Later, Hesse et al. (42) performed a biannual quality control survey for examining the efficiency of most significant methods (chemical analysis, IR spectroscopy, and XRD analysis) used for analysis of renal stones on the basis of synthetic products from1980 to 2001. Results revealed in this study indicated that chemical methods of analysis performed for 80% of the participants recorded during 1980-2001 had been drastically reduced to 13% in 2001. On the other hand, incidences of application of IR spectroscopy was found to have progressively increased to 79% while application of XRD remained constant between 5-9% (21). Results obtained by Hesse et al. (42) had also suggested that errors obtained for IR spectroscopy and XRD analysis were restricted to individual constituents while analysis by chemical methods included 6.5- 9.4% error for both pure constituents and binary mixtures (21). Thereafter, majority of laboratories gave up chemical analysis thereby rendering it obsolete (42).

In addition to these methods of analysis, non-enhanced computed tomography (CT) was first reported by Smith et al. (43) for assessment of patients suffering from renal stone disease. CT has presently become the standard diagnostic tool for evaluation of patients having renal colic (36). With further research, Hidas et al. (3) reported DECT for characterization of renal stone composition having 82% accuracy. Authors of this study further reported that DECT was unable to identify struvite stones as their attenuation ratios overlapped with that of calcified stones (3).

According to the comparativ assessment of techniques for analysis of renal stone composition carried out herein it may be concluded that no method is by itself sufficient for providing all clinically beneficial information regarding the structure and chemical composition of renal stones. Marickar et al. (40) have previously reported a combined implementation of optical microscopy and IR spectroscopy for reliable identification of the stone structure and composition as well as quantification of stone components to be extremely cost- effective. In a separate study, Uldall (45) demonstrated a combined approach of XRD/ IR spectrometry and wet chemistry tests to be appropriately considered as reference methodology. Hence, application of a combination of one or more reported techniques is recommended in this regard.

Interventional radiology for detection of renal stones Radiography Radiography has been widely used as a diagnostic tool for evaluation of urolithiasis and its significant secondary complications for decades. The kidney-ureter-bladder radiograph was the primary diagnostic tool for assessment of acute flank pain.

According to Cheng et al. (31), almost 90% of all renal stones are radiopaque. Radiography may also reveal secondary indications of renal colic (like mild splinting, bowel ileus, and perinephric fluid blurring the renal outline) but these are nonspecific (31).

However, radiography has demonstrated only around 60% sensitivity for detection of urolithiasis due to obscuring of small renal stones by bowel contents, surrounding soft tissues, gas, and bony structures. Moreover, a visualized calculus might not be the causative agent of the pain suffered by the patient (31). Radiograph also serves to monitor the calculus burden as well as the expansion of an obstructing calculus in patients diagnosed with urolithiasis (31). The main reason behind the usage of radiation in such cases is to lower the radiation exposure to patients in comparison to that encountered during unenhanced CT. Ultrasound

According to Reddy (46), ultrasound is a more suitable diagnostic tool for patients who are children, pregnant or have recurrent sessions of urolithiasis as it does not involve exposure to ionizing radiation. Besides it is independent of stone composition.

All stones determined by ultrasound will reveal echogenicity and shadowing. Stones measuring as small as 0.5mm are also detected by ultrasound. These stones express themselves as echogenic foci with shadowing (31). For confirming the presence of a stone, color Doppler imaging may be used for stimulating a twinkle artifact in the anticipated region of shadowing captured in gray- scale imaging (31). In vitro studies carried out previously suggest that stone composition is correlated to occurrence of the twinkle artifact. Ultrasound also reportedly divulges secondary complications like obstruction, superimposed infection or abscess formation (31). Similar to CT, ultrasound depicts obstructions as collecting system and ureteral dilatation in the range of stone dimensions. However, ultrasound does not efficientlydistinguish between dilatation with and without obstruction. Ultrasound imaging of renal stones may be hindered due to superimposing bowel gas, relative depth of the ureter inside the pelvis and intervening fat (in case of obese patients) (31). Utility of ultrasound has received reduced importance since the advent of advanced techniques like CT. Better determination of renal stones have been performed by ultrasound on patients observing fasting or bladder filling (31). However recent studies by Edmonds et al. (47) and Moesbergen et al. (40) have applied a combination of radiography and ultrasound for reducing the radiation exposure in patients in comparison to CT. Moesbergen et al. (48) also suggested the utilization of ultrasound for follow-up of distal renal stones.

Computed tomography (CT) Since its initial application in the later 1990s, CT (both with and without enhanced contrast) has rapidly become a popular diagnostic tool for evaluation of suspected urolithiasis (23). Of all CT examinations conducted for diagnosis of acute abdominal pain, almost 20% is performed for assessment of urolithiasis using non-enhanced CT (31,33). A non-enhanced scan performed with CT places the risk of renal inadequacy or detrimental reactions after contrast material exposure (31). With advanced equipment, image acquisition is completed within seconds thereby facilitating efficient assessment of images. CT is capable of estimating stone attenuation, measuring secondary effects of obstruction, defining anatomy that necessitates surgery and identification of other significant causes of pain or pathologic abnormality (31). According to Cheng et al. (31), the major limitation of CT is its utilization of ionizing radiation. Dosage of radiation encountered may accumulate in a patient who undergoes the procedure repeatedly. However, in recent times, low-dose protocols have been reported which demonstrate slightly reduced efficiency for detection of urinary and non-urinary diseases (50-52).

According to Kambadakone et al. (53), tube current modulation (a new feature globally incorporated in modern equipment) has enabled reduction of radiation dosage. Newer features like iterative image reconstruction reduce the artifacts produced by noise and facilitate reduction of radiation dosage without compromising on image quality (53). Advanced equipment has therefore enabled anatomical tailoring of CT analysis for renal stones having identified locations (31).

Dual- and multi-energy CT According to McCollough et al. (54), DECT or multi energy CT decompose a substance to yield its constituent elements on the basis of x-ray attenuation dependent on energy and element constitution of that substance. They further added that photoelectric effect and Compton scattering processes are major factors responsible for this x-ray attenuation (46). Therefore, attenuation coefficient of any material may be represented as a linear amalgamation of the attenuation coefficients of composite materials (54). Using such a technique of material decomposition, one may gather material-specific knowledge like mass density, effective atomic number, etc. (54) Using the knowledge obtained thereby, this technique may be applied clinically for quantification of a specific component of a mixture having known elemental composition (like iodine, soft tissue, fat, etc.) and classification of materials into predefined groups (like uric acid and non–uric acid, etc.) (54). Classification of materials into subgroups is dependent upon estimation of the effective atomic number or density independent factors (like dual-energy ratio (DER) also referred to as CT number ratio (CTR)) (54). Tissue characterization using DECT Double X-ray spectrum used in DECT facilitates the distinction between different materials having similar elemental compositions (54). Recent advances in the DECT technology have been in the form of introduction of energy-resolving, photon- counting detectors for imaging. This feature enables acquisition of data in multiple energy bins which in turn enhance material-specific imaging by improving the signal- to noise ratio (54).

Material separation using DECT Material specific images captured by DECT reveal both qualitative and quantitative results regarding tissue composition and distribution of contrast media (55). According to Patino et al. (47), the capability of analyzing iodine distribution by creating an image exclusively depicting iodine is the most significant contribution of DECT till date. These images enhance tissue contrast and magnify fine differences in attenuation amidst normal and abnormal tissues and thereby improve detection and characterization of abdominal lesions (55). Besides, DECT facilitates software mediated elimination of iodine effect from an acquired CT image and provides virtual non-contrast images (55). DECT is also able to separate substrates like calcium, fat and uric acid and thereby facilitate analysis of metabolic imbalances, elemental deficiencies and abnormal material deposition in tissues using the acquired images (55). Obtaining material-specific images from a single, contrast-enhanced CT acquisition provides knowledge of the anatomy with functional information and may help decrease patient exposure to radiation by reducing the number of stages in a multiphasic CT investigation (55). DECT also produces energy specific and virtual monochromatic images (55). Detectability of urinary stones using DECT Intra-renal stones smaller than 3mm have spontaneous passage and are clinically insignificant may cause microscopic hematuria (56). According to Takahashi et al. (56), iodine-eliminated virtual non-enhanced images acquired by DECT in pyelographic phase demonstrated a sensitivity of approximately 63% (79% for stones larger than 3mm) for each stone analyzed in their study. Authors also reported that the images captured by conventional CT in pyelographic phase had exhibited a sensitivity of 9% for identification of stone constituents. Therefore the virtual non-enhanced images acquired by DECT had performed enhanced detection of renal stones (56). However, though virtual nonenhanced DECT images acquired with existing technology is unlikely to replace true non-enhanced CT images for diagnosis of hematuria or renal stone disease in suspected patients, the technique may be applied for detection of small renal stones in patients without prominent clinical effect (56). Virtual non-enhanced DECT carried out after the application of iodinated contrast material is also capable of characterizing enhancement of renal mass (57,58). However, this advanced DECT iodine subtraction technique necessitates further investigation prior to wide clinical application (56).

Characterization of urinary stone composition by DECT DECT acquires both high- and low-energy data of the same anatomical location simultaneously (9). Specific changes in attenuation (expressed as HU) between data acquired at two different energies distinguish materials having similar electron densities but dissimilar photon absorption from each other (9). As reported by Chaytor et al. (9), DECT software create separate attenuation profiles for different types of stone constituents like uric acid, calcium, etc. by assigning different colors to different materials. Previous studies conducted in vivo have reported precise pre-operative prediction of renal stone composition by DECT validated by crystallography analysis performed as standard reference (3,7,59).

Chaytor et al. (9) had invested the ability of DECT to characterize composition of renal stones using infrared spectroscopy as standard reference. They had also compared the result obtained with dosages of ionizing radiation used for DECT analysis and conventional non-contrast CT analysis (9). They had initially conducted a conventional non-contrast CT analysis of the abdomen and pelvis where the radiation dosage effect was monitored with regulation of automatic exposure and modulation of tube current (9). On detection of a renal stone by conventional CT, the radiographer performed DECT subsequently (9). The DECT software incorporated in a CT scanner performed post processing of acquired images automatically on the location of interest determined by the radiographer (9). Uric acid and calcium containing stones and stones having mixed compositions were differentiated by assignment of specific colors (9). Acquired images were evaluated in terms of stone number, location, maximum diameter and identification of the constituent materials (9). Stones were later extracted using invasive procedures and analyzed in vitro using FTIR spectroscopy for validation of results provided by DECT (9).

As concluded from the results obtained by Chaytor et al. (9), DECT had demonstrated reasonable precision in identifying stones having calcium as well as mixed compositions with a low-dose protocol (9). Inspite of enduring radiation exposure, the supplementary diagnostic evidence obtained in the techniqueproposed by Chaytor et al. (9) was considered beneficial for framing optimal definitive management. Quantification of urinary stone volume using DECT CT is used to reveal the size, number, and location of renal stones in patients suffering from recurrent episodes of renal stone disease (60). Use of CT monitors the metabolic activity in these patients in terms of formation and growth of stone over a year (60,61). Stone sizes are determined as their maximum axial diameter (60). However, stone size is not an appropriate indicator of stone volume as stones have complex 3D structures and usually occur in multiple quantities (60). Previous studies have investigated quantification of renal stone volume using CT (62-64). In a study by Yoshida et al. (65), authors investigated whether stone volume estimated using CT could determine stone fragility prior to extracorporeal shock wave lithotripsy. Bandi et al. (62) carried out studies to determine whether stone volume estimated using CT could efficiently predict a stone-free condition post extracorporeal shock wave lithotripsy.

However, Demehri et al. (60) claimed to be the first study to investigate the accuracy of an attenuation threshold–based CT method for precise quantification of renal stone volume. Results obtained in this study revealed a bias of 2% and a precision of 20%. According to Demehri et al. (60), besides being accurate and precise, results should also be reproducible for tracking changes occurring in stone value (if any) with time. Demehri et al. (60) also suggested that their proposed process could reduce incidences of inter-observer variability as volume estimations revealed changes in stone size with a broader range of inter-observer agreement provided by diameter measurements. Previous studies have also reported that volume determination may be considered as an appropriate substitute for diameter measurements in forecasting spontaneous transport of obstructing ureteral stones and selection of further treatment strategy from options like ureteroscopy, extracorporeal shock wave lithotripsy, percutaneous nephrolithotomy or conservative management (62-64). Demehri et al. (60) further suggested that this variable attenuation method could be investigated further for correlating CT-estimated stone volume with conventional indices of metabolic activities like biochemical composition of urine in patients diagnosed with renal stones and prediction of the success to be achieved by urologic interventions. Prospective prediction of urinary stone composition with DECT Conventional values of CT attenuation (expressed as HU) represent both density and attenuation coefficient of a material and may be the same for different materials at a specific x-ray tube potential (23). Utilization of attenuation values by single-energy CT for determination of small renal stones is often complicated by effects of partial- volume (31).

In such scenarios, DECT is considered more appropriate than single-energy CT as it differentiates between two materials by virtue of the their specific energy dependence of photoelectric absorption by simultaneous application of two separate tube potentials (kilovoltage) during one acquisition (57-59). According to Cheng et al. (31), post processing may be conducted for classification of renal stones into different types on the basis of their attenuation values at both energy levels irrespective of stone density. Previous studies have established the ability of DECT to differentiate between uric acid and non–uric acid stones (3, 16, 18, 68).

Manglaviti et al. (7) and Qu et al. (69) have also shown that DECT is able to distinguish between other types of stones. Takahashi et al. (56) have also suggested that virtual non-enhanced images acquired by DECT may facilitate detection of renal stones in pyelographic contrast-enhanced phase. Boll et al (2009) prospectively evaluated the capability of the non invasive DECT in the characterization of renal stone and compared this with result with renal stone spectroscopy result. Total fifty renal calculi were assessed in this process. On evaluation it was observed that among these stones, 30 stones were pure crystalline in nature composed of uric acid, cysteine, calcium oxalate, brushite, or calcium phosphate. DECT techniques were effective in analyzing the components of the renal stone efficiently. Statistical data showed that all components were identified using the DECRslope algorithm (16). Differentiation of non-uric acid renal stones using DECT As reported by McCollough et al. (54), in vitro and in vivo investigations performed previously have precisely distinguished uric acid stones from non uric acid ones. This accuracy was validated to be around 100% in phantom experimental designs (46). Stones made up of cystine, hydroxyapatite, calcium oxalate, etc. are considered as non–uric acid stones and are constituted of elements having higher atomic numbers (54). Therefore, these stones separate themselves from uric acid stones which are constituted of elements having lower atomic numbers (54). Enhanced spectral separation achieved by eliminating the high-energy beam of a dual-source scanner using a filter made of tin may facilitate accurate identification of several types of non– uric acid stones (16,18,53-55).

Sequential scanning techniques have also resulted in successful differentiation between uric acid and non–uric acid stones (54). In this technique, application of a flexible procedure of registration aligns differentiated stones in the data acquired by simultaneous low and high energy scans which otherwise remain misaligned by several millimeters (54). However, according to Leng et al. (72), this technique is vulnerable to disturbance caused by the slightest of motion specifically in case of small stones (measuring about 2 mm).Leng et al (2015) have conducted a study to evaluate the feasibility of conventional CT in discriminating between the uric acid with non uric acid stones. Total 33 patients were enrolled in this study. Dual-source dual-energy CT examination was performed in these patients. these data were then compared with the conventional CT scanning result. The result of this study showed that conventional CT can accurately differentiate between the uric acid stone from the non uric acid stones with 94.7% sensitivity and 96.9% specificity (72). Stolzmann et al (2010) investigated in vivo capability of dual-energy (DE) CT for the differentiation of non-uric acid stones from uric acid stones. Total 180 patients with suspected renal stones were included in this study. DECT examination was performed on these patients and according to the CT number measurements they were classified as uric acid or non-uric acid stones. Statistical analysis was done and sensitivity, specificity, positive and negative predictive value was calculated. The result showed that among 180 patients who were evaluated 110 patients were detected with urinary stones. Out of these patients 83% were non-uric acid stones and 17% were detected as uric acid stones. Moreover, they have also concluded that for the detection on non uric acid containing stones DECT had a 89% sensitivity, and 98% specificity (68). The large difference between effective atomic numbers of uric acid and non- uric acid stones facilitates highly accurate differentiation of the same using DECT (69). However, the difference between effective atomic numbers of common non- uric acid stones (like cystine, struvite, calcium oxalate, brushite, apatite, etc.) is reportedly much lower (69). Qu et al. (69) demonstrated in their study that in vivo recognition of different types of non- uric acid stones are possible using a DSDECT having enhanced spectral separation by filtration of the high- energy beam. However, as reported by Qu et al. (69), efficient discrimination of brushite and calcium oxalate stones is yet to be achieved by the process reported in their study. Quantification of urinary stone composition in mixed stones scenario using DECT Most of the studies reported this far have focused on identification of pure stones constituted of a single material. These studies have simplified data analysis and established the efficiency of DECT for differentiating different types of stones. However, in real scenarios, stones occur in mixed compositions (72). Hence, it is essential to both identify and quantify the different constituents present in the stone for designing proper therapeutic approach. According to Leng et al. (73), though a number of studies have investigated identification of constituents in mixed stones, none have reported quantification of the different components constituting a mixed stone.

Studies aiming to assess whether DECT is capable of both differentiation and quantification of components present in a mixed stone have considered techniques like XRD crystallography, FTIR spectroscopy, wet chemical analysis and micro CT as their reference standards (73). Of all other techniques reportedly considered as reference standards so far FTIR spectroscopy has been employed the most (73). However, in recent investigations, micro CT has been considered as a more efficient reference standard as it was found to provide precise identification and quantification of all components of a mixed stone without destroying the stone (74). Where IR analyzes only a fragment of the stone, micro CT offers a 3D image of the entire stone (73). In spite of its precise and accurate determination of renal stone, it is considered as a research technique unsuitable for clinical application as it requires extraction of the stone (73). Hence, despite its multiple benefits it is not considered as a substitute for clinical techniques like DECT (73). Nevertheless, the simultaneous of microscopic localization of minerals and generation of different x-ray attenuation for uric acid and calcium salts has rendered micro CT as an appropriate reference standard for quantification of mixed stone constituents using DECT (73,75).

Leng et al. in their study have reported efficient quantification of uric acid and non- uric acid components present in mixed stones using DECT with micro CT as reference. In this study total of 24 urinary stone were analyzed using microCT and this data was used as a reference standard for comparison purpose. CT number ratio was calculated for each pixel of the stone. It was observed that optimal CT number ratio varied depending on the stone composition. The authors have concluded that DECT can effectively determine the composition of uric acid and non uric acid stones and this result did not differ significantly from the micro CT result (73). However, according to the authors, it is more difficult to differentiate and quantify sub classes of non uric acid components owing to the smaller difference between their effective atomic numbers and therefore necessitates further investigations (73). Comparison of determination of renal stone composition by DECT and other contemporary techniques Conventional techniques of renal stone analysis have been used as standard in several studies for assessing the accuracy of DECT based characterization of renal stones. Comparison of DECT performance with these standards has been discussed as follows.

Comparison with X-Ray diffraction Hidas et al. (3) demonstrated the application of DECT for identification of the constituents of urinary tract stones in their study. In the phantom phase of their study, the authors reported ex vivo application of DECT for establishing a reference for low- and high-energy attenuation ratios recorded using pure stones having known compositions (3). At the clinical phase of the same study, the authors used the established attenuation ratios for in vivo prediction of stone constituents. Furthermore, the authors verified the results of in vivo stone analysis using ex vivo XRD analysis of extracted stones as reference standards (3). Results revealed that the DECT could successfully identify uric acid and calcium- containing stones in 100% and 79% of tested samples respectively (3). 100% of stones suggested as uric acid and 79% of stones suggested as calcium by DECT analysis was validated withXRD and chemical analysis respectively. Of these 79% calcium stones, 77% were calcium oxalate and 56% were carbapatite in nature (3).

Results had also suggested that 82% of all detected stones were pure in nature while15% had mixed compositions with carbapatite being their major component (3). XRD analysis also confirmed the presence of cysteine in samples (100%) pre detected by DECT. DECT however failed to identify struvite and sub-classes of calcium stones from in vivo analysis. This may have resulted from similar compositions, variation in absorption amidst patients having different sizes and technologic limitations of contemporary DECT equipment (3).

Besides, a major limitation of the study was its small sample size. The reason for the small sample size was the necessity of extracting the stones for ex vivo analysis by percutaneous nephrolithotomy (3). The incapability of precise identification of struvite stones had also hindered the application of results obtained in this study for larger populations (3).

Comparison with conventional CT According to Wisenbaugh et al. (76), overlapping HU ranges of struvite and cystine may have led to misdiagnosis of the same using conventional CT. Wisenbaugh et al. (76) also reported that, though conventional CT was able to identify uric acid from other constituents, it was unable to perform further classification of the same. Wisenbaugh et al. (68) also determined that single energy CT scanning misdiagnosed 60% of non-uric acid stones to be uric acid in nature. Authors reported DECT to be an enhanced technology capable of more accurate identification of renal stonecomposition (68).In a recent study, Li et al (77) had compared the performance of conventional CT with DECT for differentiation of phenotypes between seven types of pure stones. Though authors reported some overlap between monohydrate and dihydrate salts of calcium oxalate, struvite and cysteine as well as calcium phosphate and brushite, the overall values of all seven tested stone types determined by DECT were found to be statistically different when determined at 50 keV (77). However, convential CT was incapable of distinguishing between the tested phenotypes (77). Nevertheless, in a sepatare study, Hidas et al. (3) had pointed out the incapability of DECT to identify struvite stones. Another risk posed by DECT technology is the high radiation exposure received by the patient during analysis. However, the dosage of radiation differs with different techniques (68). Recent protocols of diagnosis have ensured the application of reduced radiation dosage with a negligible compromise in sensitivity of the technology (76). Wisenbaugh et al. (76) claimed to be the first investigators to compare the performance efficiency of conventional CT with DECT. They compared the performance efficiency and accuracy of both techniques in a clinical situation instead of merely assessing their mean attenuation values in a retrospective fashion (76). Results obtained by Wisenbaugh et al. (76) indicated that DECT exhibited superior accuracy and efficiency for classification of calcium oxalate, cystine, struvite and uric acid stones and differentiation between non-uric acid and uric acid stones in comparison to conventional CT.

Comparison with semi-quantitative biochemical analysis Analysis of renal stone composition post extraction is widely conducted with FTIR spectroscopy or polarization microscopy (4). According to Zhang et al. (4), these techniques were limited by the fact that they do not facilitate selection of optimal therapeutic strategies (4). Hence, it had become imperative to design a simple and non-invasive technique which could perform in vivo analysis of renal stone composition at early phases of patient evaluation (4). Zhang et al. (4) thereby conducted a study for prospective evaluation of the accuracy of dual-source (DS) DECT for determining the composition and primary constituent of renal stones using postoperative FTIR spectroscopy for in vitro analysis of stones as reference.

According to the results obtained by Zhang et al. (4), DSDECT had precisely predicted the primary constituent of 92.8% pure stones analyzed in this study. However in two cases, stones misdiagnosed by DSDECT to be pure calcium oxalate and pure uric acid in composition were found to have mixed composition (containing hydroxyapatite and calcium oxalate as minor constituents respectively) (4). DSDECT had also correctly identified the primary constituent in 89.5% of the mixed stones analyzed in the study conducted by Zhang et al. (4). Nevertheless, DSDECT had misdiagnosed one calcium oxalate, two uric acid and one hydroxyapatite stone in this study. In comparison to results obtained from in vitro FTIR spectroscopy of renal stones, DSDECT was found to demonstrate an overall accuracy of 97.5% for diagnosis of renal stone composition. DSDECT used in this study had also exhibited specific accuracy of 93.8%, 80.2%, 93.8% and 97.5% for detection of calcium oxalate, hydroxyapatite, cystine, and uric acid respectively (4). Hence, results obtained in this study established that DSDECT had demonstrated excellent precision for determining the major constituents of renal stone using FTIR spectroscopy as reference standard (4). Nevertheless, two stones having mean diameter of 3 mm obtained from the renal calyx of the same patient were misdiagnosed by DSDECT to be calcium oxalate in composition. FTIR analysis had precisely identified the correct primary constituent of these stones to be ammonium acid urate (AAU) (4). AAU stones are sporadic stones caused by uric acid (4). The formation and biochemical processes of these stones are markedly different from the more commonly available anhydrous uric and uric acid monohydrate containing stones (78, 79). According to Zhang et al. (4), the difference between the X-ray absorption spectra of AAU stones and the other common stone types had been responsible for its misdiagnosis by DSDECT. Besides, the small size and multiple constituents present in these AAU stones may also have had reduced the efficiency of the DSDECT technique for precise determination of a uniform surface for identification of its constituents resulting in misdiagnosis of the same (4). In comparison to other contemporary investigations, Zhang et al. (4) analyzed the accuracy of DSDECT for identification of major constituents of renal stones in mixed stone scenarios. Almost half the stones considered in this study were of mixed composition. Besides stones considered in this study were of different sizes as observed in regular clinical practice.

According to Zhang et al. (4), they had focused more on identification of the principal stone constituent over determination of the composition of each stone. The reason for doing so was that in real scenarios, occurrence of mixed stones is significantly higher than pure stones and therapeutic strategies of mixed stones are decided on the basis of their principle constituent (4). Moreover, though FTIR is considered as standard reference for analysis of stone composition it often fails to distinguish between compounds having overlapping absorption bands (like cystineand uric acid) present in minute quantities in stones having mixed composition (4,21). According to Zhang et al. (4), misdiagnosis by reference standard FTIR analysis may be considered responsible for lower rates of identification of cystine by DSDECT recorded in their study. Hence, authors concluded that identification of the major stone constituents were of clinical importance and could overcome the limitation of FTIR in determining the precision of DSDECT for identifying the minor stone constituents (4). Pawan Kumar and Sanjita das (2013) have conducted a study in Delhi, India to evaluate the renal stone composition by FTIR method. The study result showed that calcium oxalate and carbonate phosphate stones were the most prevalent type and patients in the age group of 20 to 43 years have a higher risk of kidney stone formation compared to others. This study have also pointed out that people who drink more water are less likely to develop kidney stones. Approximately 4.2% of the patients were diagnosed with uric acid stones. From this study authors have concluded that the most likely component for renal stone is calcium and men are more prone to develop renal stone disease than women (80). Moslemi et al (2011) have conducted a study in Iran to evaluate the urinary stone composition by biochemical analysis. In a prospective study conducted in 255 patients, they have observed that most dominant composition of urinary stone was calcium oxalate. Approximately 73% of stones analysed in this study was calcium oxalate followed by uric acid (24%). 2% of the stones were ammonium urate and 1% were composed of cysteine. The overall male to female ratio found in this study was 4.93:1 (81). Conclusion DECT is an emerging technique for in vivo identification and quantification of components of renal stone. Their ability to differentiate and characterize stoneconstituents on the basis of effective atomic numbers has ensured application of this technique for a variety of clinical purposes. Active research in this field is ongoing for improvising the performance efficiency of this technique. DECT with its current advancements is being widely considered for mainstream CT imaging. Though micro CT is recently reported as an accurate reference standard for validating the data obtained from DECT analysis, FTIR is still widely performed in most studies as a reference standard for DECT analysis of renal stones. Form the literature review conducted in this study, it can be concluded that DECT with its enhanced features is capable of accurate in vivo identification and quantification of most commonly occurring renal stone constituents (uric acid, calcium oxalate, and cystine) and thereby plays a major role in deciding further therapeutic approach for patients diagnosed with renal stone disease.

Further studies are required for ensuring proper identification and quantification of uncommon stone constituents like struvite, UA, hydroxyapatite, etc. using DECT. Further studies should also be conducted with larger patient groups for efficient evaluation of the clinical impact of DECT technique.

IV. Research Methodology

METHOD: This was a prospective study performed at A.J. Institute of Medical Sciences, Mangalore. The study was conducted for a period of two years (January 2015 to July 2017)in patients presenting in the Radiology Department, A.J. Institute of Medical Science, Mangalore with renal stone pathology .

SAMPLE SIZE A total of 50 patients were studied. Patients who were diagnosed to have renal stone pathology and were referred for DECT KUB were included in the study.

MATERIAL AND METHODS: The study was conducted on a Somatom definition 128 slice dual energy CT scanner.

DATA COLLECTION METHODS: The data collection method is essential for collecting data from primary sources for analyzing the results so that research objectives can be met. Data was entered in the spreadsheet and will be analyzed using SPSS statistical software. Data was expressed in the form of tables and charts. Appropriate statistical tests like Chi square test and other non parametric tests were used.

INCLUSION CRITERIA:

- Patients who were diagnosed to have renal stone pathology were referred for DECT KUB
- Both the genders were included in the study.

EXCLUSION CRITERIA

- Patients who are not willing to participate in the study.
- Pregnant females were excluded from the study.

- Patients who did not have renal stone on DECT

Ethical Consideration:

There are arrays of ethical considerations which must be followed while conducting a medical research. Keep into consideration that this research has human respondents involved in it; the researcher has made sure that the ethical considerations has been strictly complied and adhered. Most common ethical considerations include voluntary participation, informed consent, confidentiality and protection of information. Voluntary participation: The researcher has ensured that all the respondents had taken part in the research in a voluntary manner. No respondents were forced at any point in time and they had the full liberty to walk out from the research if they felt uncomfortable at any point in time. Each responded had been briefed about the nature of the research and only the ones willing were questioned further. Informed consent: Prior to the start of the research, complete consent was obtained from the respondents regarding their participation in the research. The nature of the research and the extent of advantages and disadvantages were explained to the respondents. A consent form was also signed from them. {Annexure II}

Confidentiality: This is one of the most important clauses of ethical consideration and the researcher ensured that identity of the respondents was protected during the research. The name and location of the patients are sensitive information and the researcher ensures full anonymity of the respondents. The researcher also promises not to use this information for any personal use or for any other work without the knowledge of the respondents. In addition, the researcher ensured that no deception was used in the research and no information was hidden from the respondents. Data Protection: Every participant was provided with a data protection sheet, which comprised information about the nature and duration of research, the ways in which data will be stored and protected from hackers and the ways in which the data is meant to be used.

V. Result And Interpretation

his prospective study was done in A.J. Institute of medical sciences, Mangalore. Patients who were referred for DECT KUB and who are diagnosed to have renal stone pathology were included in this study. The following section describes the result and interpretation of this study.

Table 1: Details of the study participants

		Age	Sex
Number of patients	Valid	50	50
	Missing	0	0

Table 1 depicts the details of the study participants. Total 50 patients were included in this study. Age and gender of all the patients were recorded. In the two year study period consecutive data were reported for all the study participants. Hence, no missing cases were reported.

Table: 2 Sensitivity &Specificity of the Three Types of Stones

PARAMETER	BOTH NEGATIVE	BOTH POSITIVE	TEST NEGATIVE GOLD STANDARD POSITIVE	TEST POSITIVE GOLD STANDARD NEGATIVE	SENSITIVITY	SPECIFICITY	POSITIVE PREDICTIVE VALUE	NEGATIVE PREDICTIVE VALUE	DIAGNOSTIC ACCURACY	GOLD STANDARD	KAPPA STATISTICS	P VALUE
DECT CALCIUM OXALATE	21	24	0	5	100.00%	80.80%	82.80%	100.00%	90.00%	BIOCHEMISTRY FINDINGS CALCIUM OXALATE	0.8010	**<0.001**
DECT CALCIUM HYROXYAPATITE	12	33	5	0	86.80%	100.00%	100.00%	70.60%	90.00%	BIOCHEMISTRY FINDINGS CALCIUM HYROXYAPATITE	0.7600	**<0.001**
DECT URIC ACID	43	7	0	0	100.00%	100.00%	100.00%	100.00%	100.00%	BIOCHEMISTRY FINDINGS URIC ACID	1.0000	**<0.001**

- On comparison of the test group DECT CALCIUM OXALATE with the Gold standard of BIOCHEMISTRY FINDINGS CALCIUM OXALATE the test group has a sensitivity of 100 % and specificity of 80.8%. The test has a positive predictive value of 82.8% and Negative predictive value of 100%. The test and the gold standard agree on 45 out of 50 having a diagnostic accuracy of 90%. The Kappa value of 0.801 indicates Excellent agreement with a p value of <0.001.
- On comparison of the test group DECT CALCIUM HYROXYAPATITE with the Gold standard of BIOCHEMISTRY FINDINGS CALCIUM HYROXYAPATITE the test group has a sensitivity of 86.8 % and specificity of 100%. The test has a positive predictive value of 100% and Negative predictive value of 70.6%. The test and the gold standard agree on 45 out of 50 having a diagnostic accuracy of 90%. The Kappa value of 0.76 indicates Very Good agreement with a p value of <0.001.
- On comparison of the test group DECT URIC ACID with the Gold standard of BIOCHEMISTRY FINDINGS URIC ACID the test group has a sensitivity of 100 % and specificity of 100%. The test has a positive predictive value of 100% and Negative predictive value of 100%. The test and the gold standard agree on 50 out of 50 having a diagnostic accuracy of 100%. The Kappa value of 1 indicates FALSE agreement with a p value of <0.001.

Table: 3 the Above Table Has Been Made From The Below Cross Tabulations

DECT CALCIUM OXALATE * BIOCHEMISTRY FINDINGS CALCIUM OXALATE Crosstabulation

			BIOCHEMISTRY FINDINGS CALCIUM OXALATE		Total
			ABSENT	PRESENT	
DECT CALCIUM OXALATE	ABSENT	Count	21	0	21
		% within DECT CALCIUM OXALATE	100.0%	0.0%	100.0%
		% within BIOCHEMISTRY FINDINGS CALCIUM OXALATE	80.8%	0.0%	42.0%
	PRESENT	Count	5	24	29
		% within DECT CALCIUM OXALATE	17.2%	82.8%	100.0%
		% within BIOCHEMISTRY FINDINGS CALCIUM OXALATE	19.2%	100.0%	58.0%

Total	Count	26	24	50
	% within DECT CALCIUM OXALATE	52.0%	48.0%	100.0%
	% within BIOCHEMISTRY FINDINGS CALCIUM OXALATE	100.0%	100.0%	100.0%

Table: 4 Symmetric Measures (A)

		Value	Asymp. Std. Error^a	Approx. T^b	Approx. Sig.	Exact Sig.
Measure of Agreement	Kappa	.801	.083	5.781	.000	.000
N of Valid Cases		50				

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Chart: 1 Symmetric Measure(a)

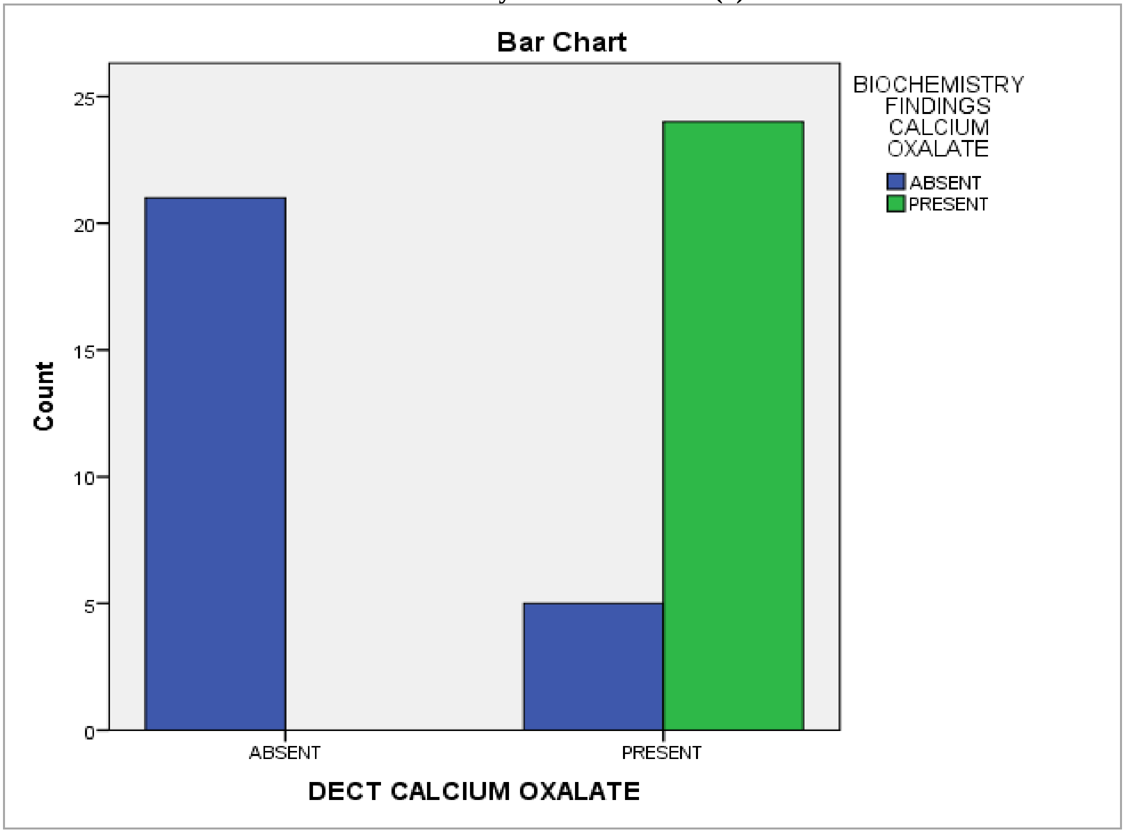


Table: 5: Dect Calcium Hyroxyapatite * Biochemistry Findings Calcium HyroxyapatiteCrosstabulation

			BIOCHEMISTRY FINDINGS CALCIUM HYROXYAPATITE		**Total**
			ABSENT	PRESENT	
DECT CALCIUM HYROXYAPATITE	ABSENT	Count	12	5	17
		% within DECT CALCIUM HYROXYAPATITE	70.6%	29.4%	100.0%
		% within BIOCHEMISTRY FINDINGS CALCIUM HYROXYAPATITE	100.0%	13.2%	34.0%
	PRESENT	Count	0	33	33

	% within DECT CALCIUM HYROXYAPATITE	0.0%	100.0%	100.0%
	% within BIOCHEMISTRY FINDINGS CALCIUM HYROXYAPATITE	0.0%	86.8%	66.0%
Total	Count	12	38	50
	% within DECT CALCIUM HYROXYAPATITE	24.0%	76.0%	100.0%
	% within BIOCHEMISTRY FINDINGS CALCIUM HYROXYAPATITE	100.0%	100.0%	100.0%

Table: 6: Symmetric Measures(B)

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.	Exact Sig.
Measure of Agreement	Kappa	.760	.099	5.536	.000	.000
N of Valid Cases		50				

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Chart: 2 Symmetric Measure(b)

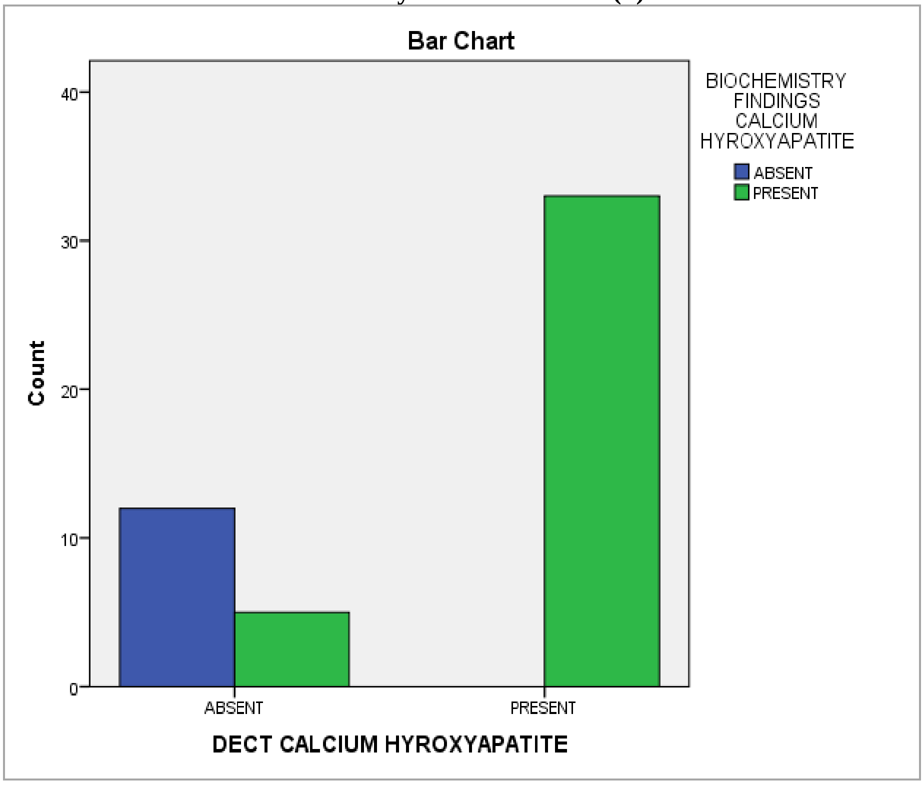


Table: 7: DECT Uric Acid * Biochemistry Findings Uric Acid Crosstabulation

			BIOCHEMISTRY FINDINGS URIC ACID		Total
			ABSENT	PRESENT	
DECT URIC ACID	ABSENT	Count	43	0	43
		% within DECT URIC ACID	100.0%	0.0%	100.0%
		% within BIOCHEMISTRY FINDINGS URIC ACID	100.0%	0.0%	86.0%
	PRESENT	Count	0	7	7
		% within DECT URIC ACID	0.0%	100.0%	100.0%
		% within BIOCHEMISTRY FINDINGS URIC ACID	0.0%	100.0%	14.0%

Total	Count	43	7	50
	% within DECT URIC ACID	86.0%	14.0%	100.0%
	% within BIOCHEMISTRY FINDINGS URIC ACID	100.0%	100.0%	100.0%

Table: 8: Symmetric Measures(C)

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.	Exact Sig.
Measure of Agreement	Kappa	1.000	.000	7.071	.000	.000
N of Valid Cases		50				

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Chart: 3 Symmetric Measure(c)

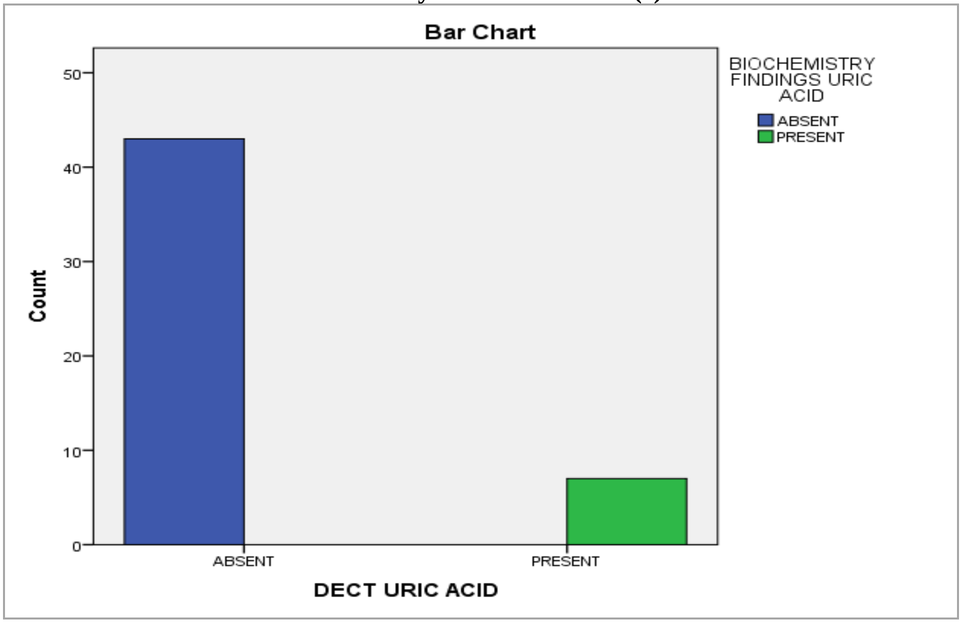


Table: 9: DECT Cystine Biochemistry Findings Cystine Crosstabulation

			BIOCHEMISTRY FINDINGS CYSTINE	Total
			ABSENT	
DECT CYSTINE	ABSENT	Count	50	50
		% within DECT CYSTINE	100.0%	100.0%
		% within BIOCHEMISTRY FINDINGS CYSTINE	100.0%	100.0%
Total		Count	50	50
		% within DECT CYSTINE	100.0%	100.0%
		% within BIOCHEMISTRY FINDINGS CYSTINE	100.0%	100.0%

Table: 10: Symmetric Measures(D)

Symmetric Measures

		Value
Measure of Agreement	Kappa	.[a]
N of Valid Cases		50

a. No statistics are computed because DECT CYSTINE and BIOCHEMISTRY FINDINGS CYSTINE are constants.

Chart: 4 Symmetric Measure(d)

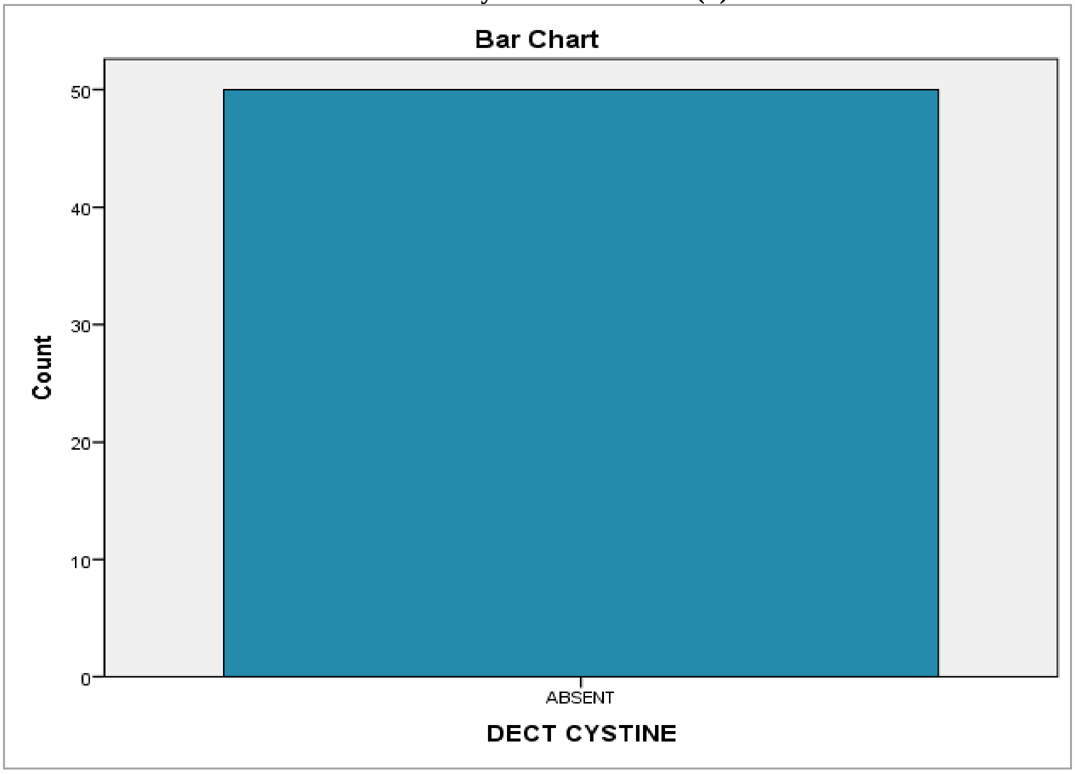


Table: 11:Age

	AGE	Valid Percent
<30	4	8
31-40	13	26
41-50	14	28
51-60	9	18
61-70	7	14
71-80	3	6
Total	50	100

Table: 12: Sex

	SEX	Valid Percent
F	8	16
M	42	84
Total	50	100

Table: 13: Clinical Findings

	CLINICAL FINDINGS	Valid Percent
DIFFICULTY IN PASSING URINE	6	12
LEFT LOIN PAIN	9	18
PAIN ABDOMEN	27	54
RIGHT COLIC PAIN	8	16
Total	50	100

Table: 14: USG Findings

		Valid Percent

BILATERAL RENAL CALCULI	22	44
LEFT RENAL CALCULI	12	24
LEFT STAGHORN CALCULUS	2	4
RIGHT RENAL CALCULI	12	24
VESICAL CALCULUS	2	4
Total	50	100

Table: 15

	DECT CALCIUM OXALATE	**Valid Percent**
ABSENT	21	42
PRESENT	29	58
Total	50	100

Table: 16

	DECT CALCIUM HYDROXYAPATITE	**Valid Percent**
ABSENT	17	34
PRESENT	33	66
Total	50	100

Table: 17

	DECT URIC ACID	**Valid Percent**
ABSENT	43	86
PRESENT	7	14
Total	50	100

Table: 18

	DECT CYSTINE	**Valid Percent**
ABSENT	50	100

	BIOCHEMISTRY FINDINGS CALCIUM OXALATE	Valid Percent
ABSENT	26	52
PRESENT	24	48
Total	50	100

Table: 19

	BIOCHEMISTRY FINDINGS CALCIUM OXALATE	**Valid Percent**
ABSENT	26	52
PRESENT	24	48
Total	50	100

Table: 20

	BIOCHEMISTRY FINDINGS CALCIUM HYROXYAPATITE	**Valid Percent**
ABSENT	12	24
PRESENT	38	76
Total	50	100

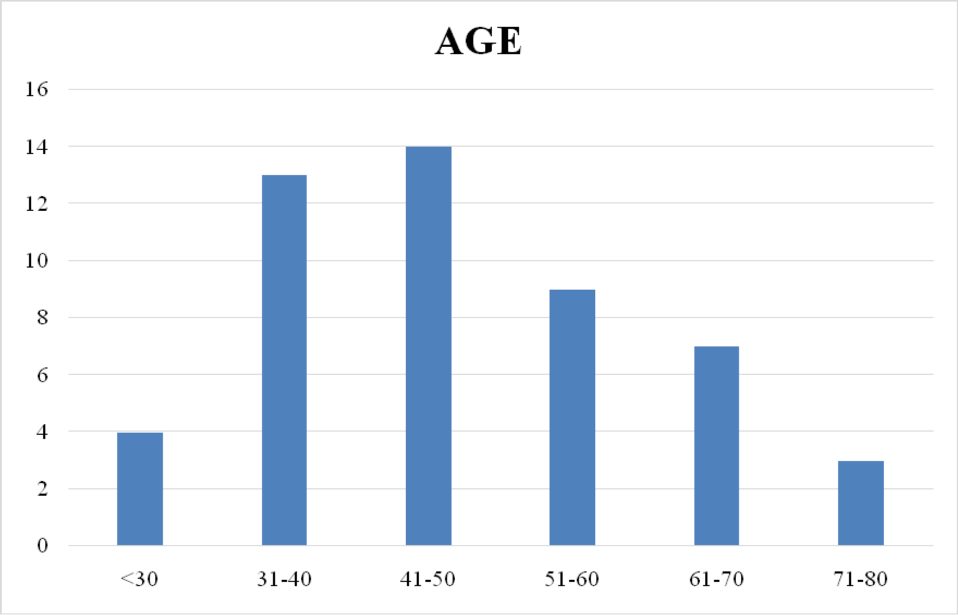
Table: 21

	BIOCHEMISTRY FINDINGS URIC ACID	Valid Percent
ABSENT	43	86
PRESENT	7	14
Total	50	100

Table: 22

	BIOCHEMISTRY FINDINGS CYSTINE	Valid Percent
ABSENT	50	100

Chart: 5



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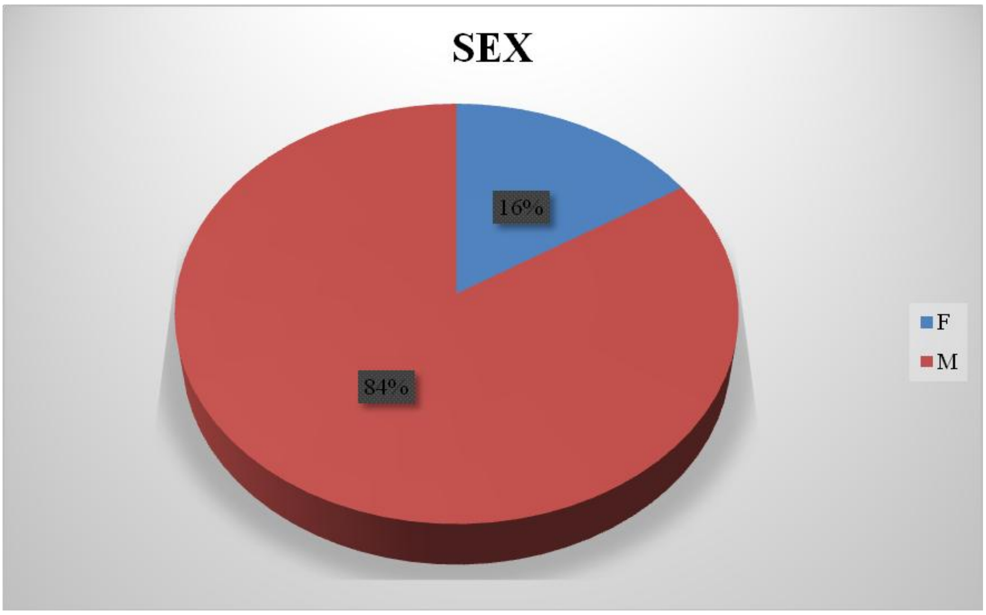


Chart: 7

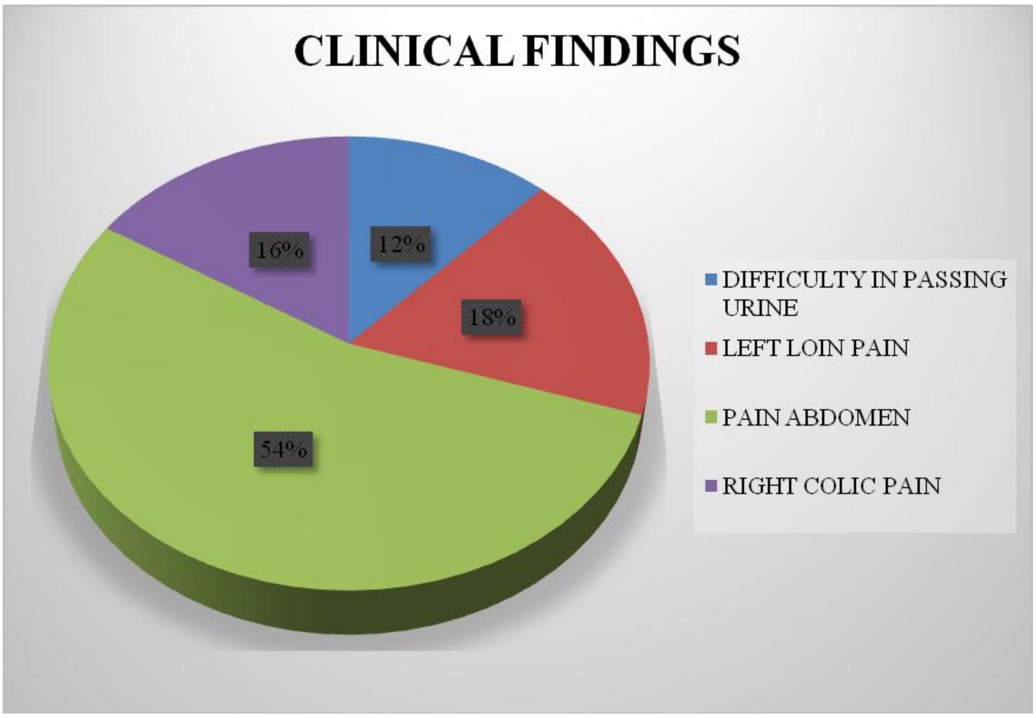
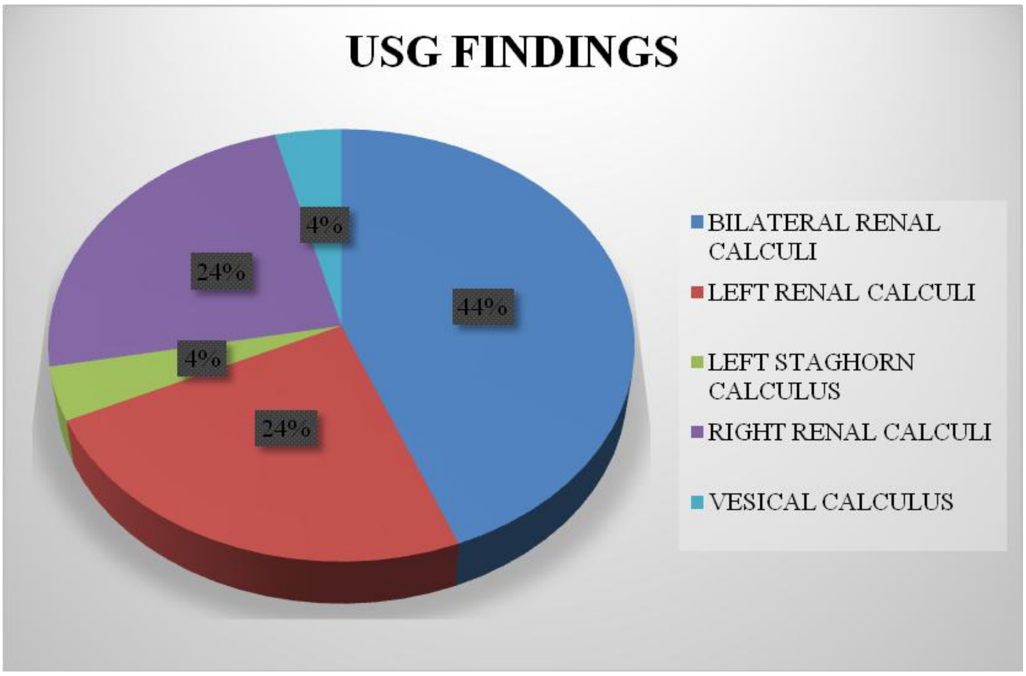


Chart: 8



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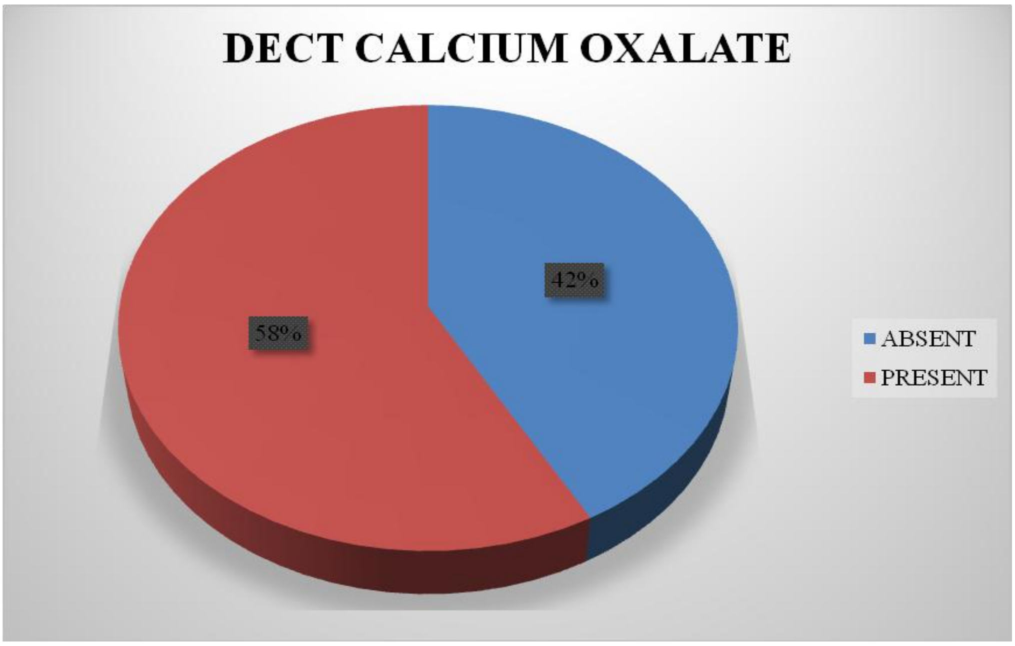

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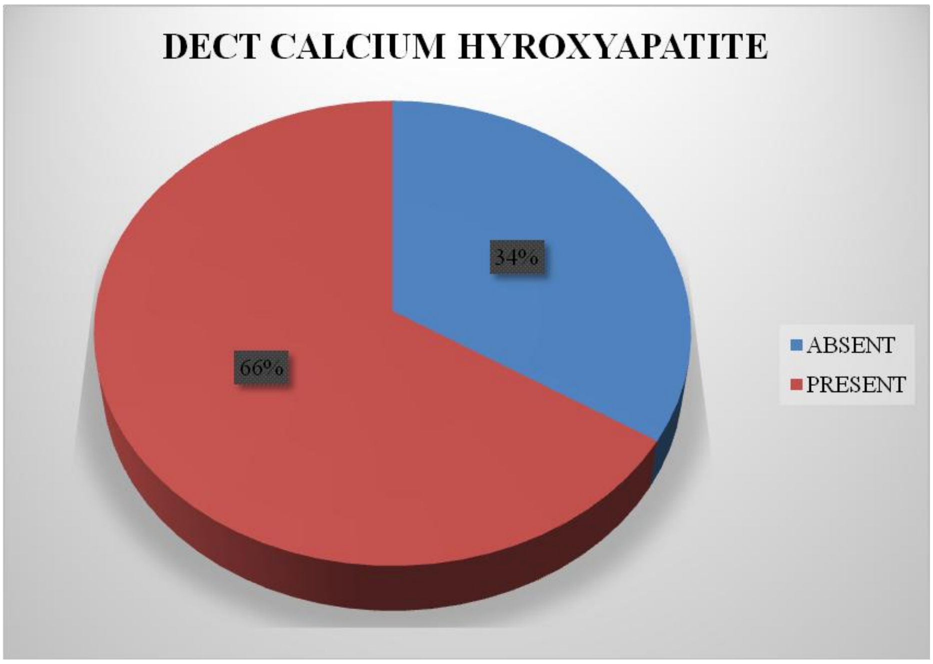
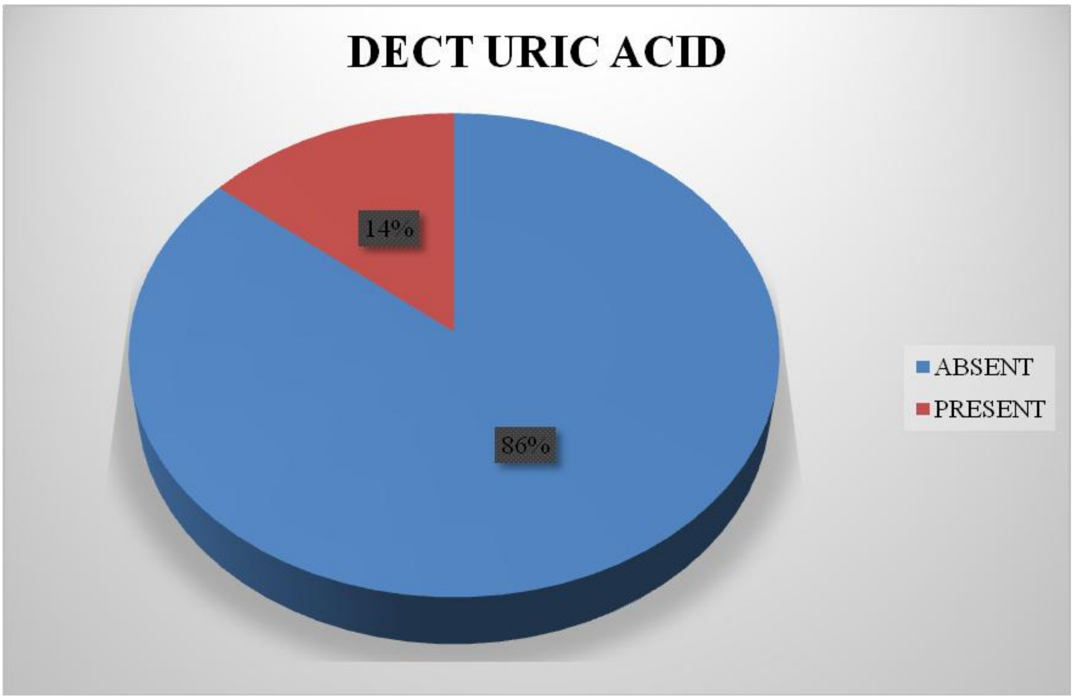


Chart: 11



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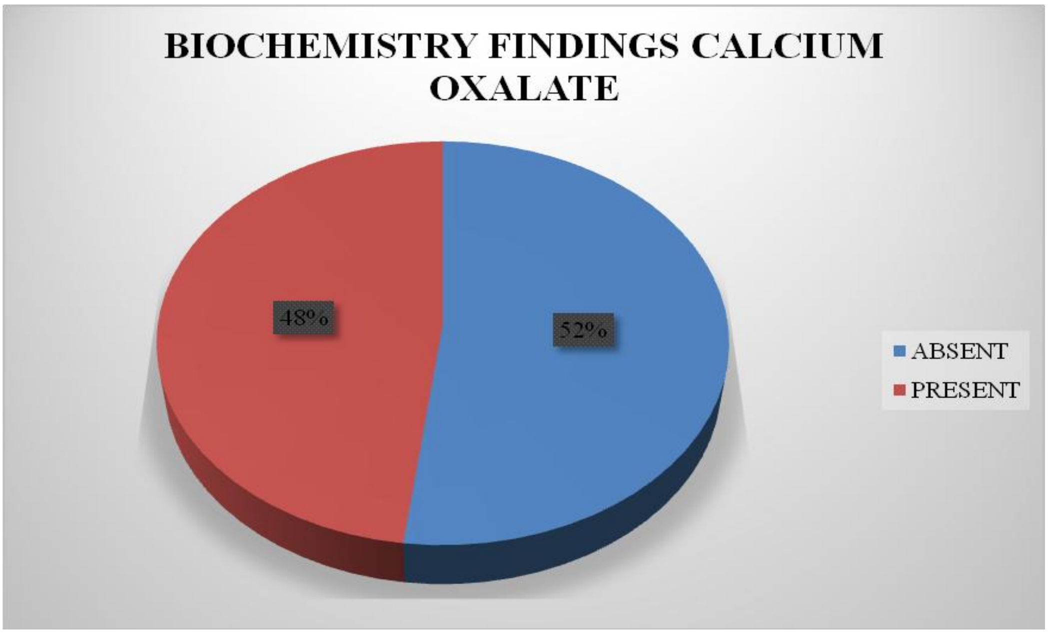

Chart: 13

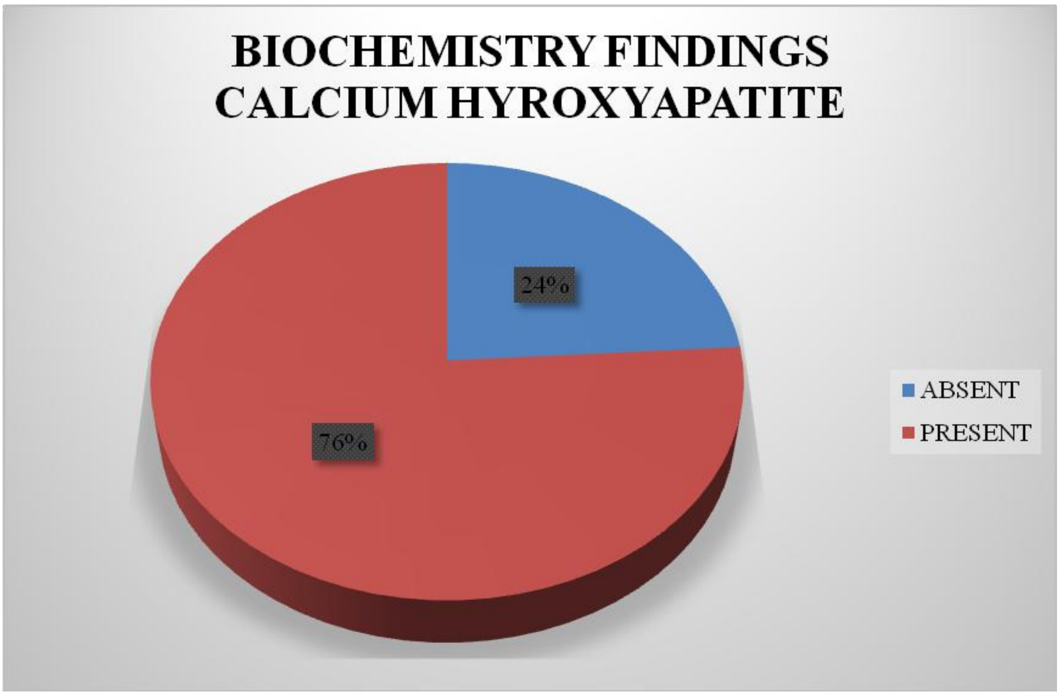

Chart: 14

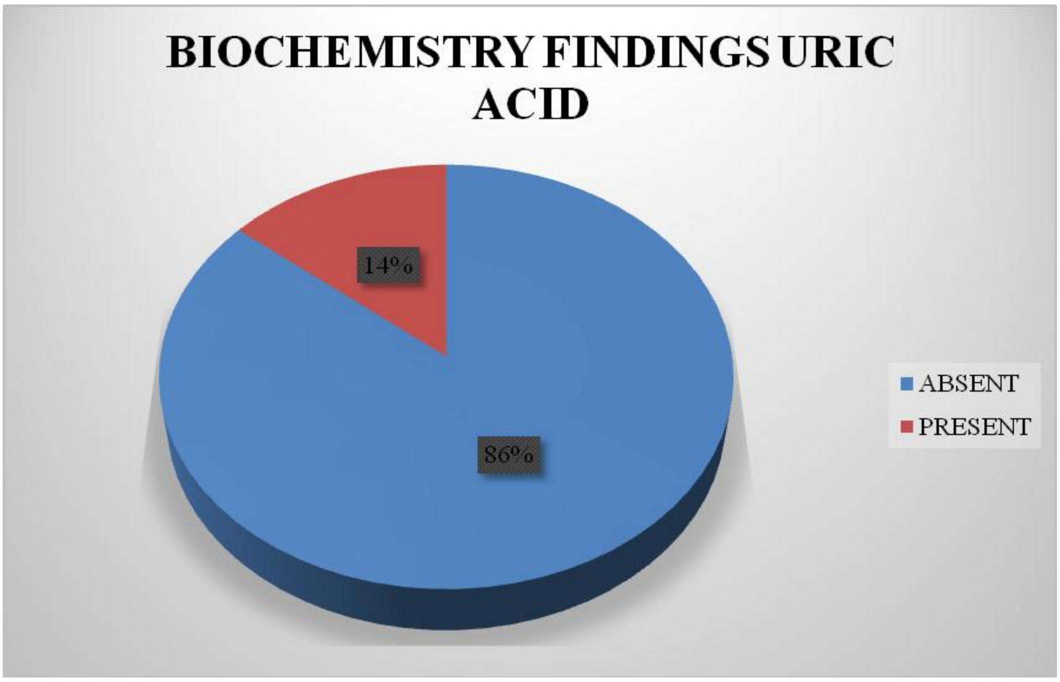

Table: 23TYPES OF RENAL STONE COMPOSITION

TYPES	NO	PERCENT
PURE CAOH	**18**	36%
PURE CAO	**10**	20%
PURE URIC ACID	**3**	6%
MIXED CAH & CAO	**15**	30%
MIXED CAO &UA	**4**	8%

The above table depicts various types of renal stones encountered in this study. After DECT finding total 18 patients were detected with calcium hydroxyapatite (CAH) stone. After the stone extraction process, biochemical analysis showed that among these 18 patients all have pure calcium hydroxyapatite as the stone components. This finding matches 100% with the DECT finding. 36% of the total patients have pure calcium hydroxyapatite stone as observed in this analysis. In the table % within DECT finding showed 100% meaning DECT was able to detect all the CAH stones successfully.

Similarly, after DECT examination total 10 (20%) patients showed stone composed of pure calcium oxalate. on biochemical analysis, it was observed that among these patients 9(18%) patients have stones composed of pure calcium oxalate (CAO) and 1(10%) patient had calcium hydroxyapatite as the stone component. In this case, DECT was able to find out the stone composition accurately in 90% of cases.

Total 3 (6%) patients were detected with uric acid stones after DECT examination. In the biochemical analysis, all of these patients showed the similar result as the DECT examination.

Among the total 50 patients, 19 patients showed the presence of a mixed type of stones. In DECT scanning 15 (30%) patients were detected with stones composed of mixed type with calcium hydroxylapatite and calcium oxalate (CAH+CAO). On biochemical finding, a similar number of the patient were detected with calcium oxalate and calcium hydroxyapatite stones (CAH+CAO).

Total 4 (8%) patients were detected with calcium oxalate and uric acid mixed stones. In the biochemical analysis, a similar number of patients showed the presence of calcium oxalate and uric acid stones.

Table 24: Pearson Chi-square test

Chi-Square Tests			
	Value	df	P-VALUE
Pearson Chi-Square	192.632^a	16	0.000
			HIGHLY SIGNIFICANT

e analyzed 50 participants and evaluated for DECT scan and biochemical analysis was done on all the stones obtained from these patients. The comparison data were analyzed using a Pearson chi-square goodness of fit test. From the above results, P-value=0.00, which is less than 0.5, hence the result is highly significant.

VI. Discussion

Urolithiasis is the most common and widespread disease that affects a wide gamut of the patients. Presence of various risk factors including age, gender, eating habits, race manipulates the prevalence of this disease. The incidence of urinary stone disease in both developing and developed countries has been increased in the past few decades. Rising prevalence of obesity is one of the prime contributing factors responsible for this increase (33).

Knowledge of the composition of kidney stone is a fundamental part of the preoperative patient evaluation. This primary knowledge helps in devising a proper treatment plan and the prevention protocol as well. For example, stones composed of calcium oxalate, monohydrate or cysteine have a firm texture that complicates extraction procedure by extracorporeal shock wave lithotripsy. Percutaneous nephrolithotomy (PCNL) is the preferred technique for this type of stones (3).

Several methods are available for stone analysis that includes, infrared spectroscopy, in vitro x-ray diffraction, and polarisation microscopy. In addition to these tests, few other techniques such as dry and wet chemical spot tests, X-ray powder diffraction, and Raman spectroscopy can also be performed to know the composition of the stone. However, these techniques can only be performed after the stone gets extracted. Hence, these techniques do not provide any help during the preoperative treatment planning (21).

In contrast to all these techniques, Dual-energy CT facilitates low and high-energy scanning during a single acquisition. This techniques also has an inherent capacity to differentiate between different materials that have similar electron densities but varying photon absorption and thus, making it a suitable method for renal stone composition analysis (3).

In the present study, this aspect of the DECT techniques was used in vivo to differentiate the composition of different renal stone in patients and also this composition was analyzed with the infrared spectroscopy data.

Comparison with the existing literature

Several studies were conducted to understand the renal stone composition as knowledge of the composition decides the therapy for the patients. Stone composed of brushite, calcium oxalate or cysteine are less fragile and shock wave lithotripsy is preferred for exacting these stones. In contrast, uric acid stones can be treated medically and do not need any other mode of treatment (3).

In this study, it was found that most of the patients (46%) with renal stone were found to be in the

41-60 years of age group. This result agrees with that of the S ***Ahmed et al (2016),*** where they have reported a higher prevalence of stone disease among patients in the 30-50 year of the age group. In this retrospective study total of 1176 samples were evaluated from both male and female patients. The result of the study showed that in males the higher prevalence of stone disease was observed in the 40-49 year age group, whereas, in females, it is prevalent in the 30-39 years time (82).

Tasadaque et al (2003) have also reported that kidney stone is more prevalent in the age group 13-50 years. In a study conducted in Multan, Pakistan among the reported operated cases of kidney stone they have shown a higher prevalence of kidney stone in the wide age range group (83). The similar opinion was also proved by ***Ahmed I et al (2011).*** According to this paper maximum incidence of renal calculi is reported in the 30-50 years age group (84).

In contrast to this finding, ***Moudi et al (2017)*** have shown that occurrence of renal stone is very common among the elderly population also. In a study conducted among patients with the mean age of 69.37 ± 7.42 years, authors have shown that among these study population 14.53% cases had renal stones. However, as the age increases this prevalence starts decreasing (85).

In the present study, it was observed that the number of male patients has this disease compared to the females. 84% of the male population had this disease compared to the 16% of females with a male to female ratio of 5.25:1. Many studies have reported a higher incidence of renal stone formation among the male population. The similar type of finding was reported by ***Moslemi et al (2011).*** In this studyconducted in Iran in 255 patients, the authors have reported an overall male to female ratio of 4.93:1 (81).

S Ahmed et al (2016) have also reported a higher preponderance of renal stone disease among males compared to females. They have reported a male to female ratio of 2.8:1 (82).

Higher prevalence of nephrolithiasis in males has also been reported by ***Moudi et al (2017).*** Studies have shown that among middle-aged patients this male predominance is more prominent (85). In middle-aged men prevalence of renal stone formation is 2.8 times more common than in females. However, as the age progresses this incidence declines and becomes 1.6 times more in the 90 years of age. However, studies have also indicated that this gender disparity of developing nephrolithiasis is narrowing recently (86).

As observed from this study the high prevalence of renal calculi in males can be explained by the effect of sex hormones on lithogenic risk factors. The male sex hormone or androgen increases the deposition of calcium oxalate crystals in the kidney. In the other hand estrogen or the female sex, hormone decreases the urinary oxalate excretion. Hence, males are more prone to have kidney stone formation compared to females (87).

In this study, we have used DECT to determine the renal stone composition and then compared this finding with the FTIR analysis. The study has shown that a maximum number of patients (62%) has pure crystal stones comprises of either calcium or uric acid, whereas, 38% patients had a stone that is of mixed composition.

Calcium hydroxylapatite crystals were the predominant stone in the study undertaken. Among the 50 patients, 18 (54%) patients had CAH stones as observed from the DECT scanning and also FTIR analysis. Next higher number of patients was diagnosed with mixed stones composed of calcium oxalate and calcium hydroxyapatite. 30% of the totals study participants had this type of stone. Uric acid stones were found to less prevalent in this study both in the pure and the mixed type stone category.

Several studies have reported that calcium-containing stones are the most prevalent stone type among renal stone patients. ***Lieske et al. (2014)*** have reported that calcium oxalate stones are the most common stone type as found in this study. 67% of patients had calcium oxalate stones followed by hydroxyapatite (16%) and uric acid (8%) (90).

In a study by ***Amir et al. (2018)*** conducted among adult patients in Saudi Arabia has shown that majority of stone that was detected is calcium oxalate followed by uric acid stones (88). ***Knoll et. al. (2011)*** have pointed out the presence of calcium-containing stones among most of the patients. In a study conducted among a study population where 224,085 urinary stone were analyzed from 22 German centers, authors have reported the increased prevalence of uric acid stone (89).

In the past, an array of studies has reported the accuracy of DECT in differentiating the renal stone composition. ***Stolzmann et al*** demonstrated that using a dual energy CT approach uric acid– and uric acid–containing stones can be accurately differentiated. In an ex vivo setting using a dual-energy CT with a dual-source CT scanner, they were able to compare and differentiate stones on the basis of differences in attenuation at 80 and 140 kV. Further, they have found significantly higher attenuation among the stones that contained no uric acid (68).

Chaytor et al. (9) had invested the ability of DECT to characterize the composition of renal stones using infrared spectroscopy as the standard reference. They had also compared the result obtained with dosages of ionizing radiation used for DECT analysis and conventional non-contrast CT analysis (9). Uric acid and calcium-containing stones and stones having mixed compositions were differentiated by assigning different colors to them.

As concluded from the results obtained by ***Chaytor et al.***, DECT had demonstrated reasonable precision in identifying stones having calcium as well as mixed compositions with a low-dose protocol (9).

Boll et al (2009) prospectively evaluated the capability of the non-invasive DECT in the characterization of renal stone and compared this with the result of renal stone spectroscopy result. Total fifty renal calculi were assessed in this process. On evaluation, it was observed that among these stones, 30 stones were pure crystalline in nature composed of uric acid, cysteine, calcium oxalate, brushite, or calcium phosphate. DECT techniques were effective in analyzing the components of the renal stone efficiently. Statistical data showed that all components were identified using the $\text{DECR}_{\text{slope}}$ algorithm (16).

Hidas et al. (3) demonstrated the application of DECT for identification of the constituents of urinary tract stones in their study. In the phantom phase of their study, the authors reported ex vivo application of DECT for establishing a reference for low- and high-energy attenuation ratios recorded using pure stones having known compositions (3). At the clinical phase of the same study, the authors used the established attenuation ratios for in vivo prediction of stone constituents. Furthermore, the authors verified the results of in vivo stone analysis using ex vivo XRD analysis of extracted stones as reference standards (3).

Finally, in this study, we were able to differentiate between uric acid, and calcium stones and also can identify the mixed stone types. Moreover, we have shown that DECT can effectively identify the composition of calcium hydroxyapatite, uric acid, calcium oxalate and mixed stones, only in one patient having calcium oxalate stones were wrongly identified by DECT. Overall, the ability of DECT to differentiate between calcium oxalate and calcium hydroxyapatite may have been due to real chemical overlap between stone compositions.

VII. Summary

In this prospective study total of 50 patients were evaluated who visited the A.J. Institute of medical sciences, Mangalore. The age of the patients varies from 25 years to 75 years. Among these patients 42 patients were male whereas, 8 patients were female. This study result demonstrates that DECT can effectively differentiate between the compositions of different renal stones. The study has shown that the maximum number of patients (62%) have pure crystals comprises of either calcium or uric acid, whereas, 38% of patients had the stone that is of mixed composition. In our study , DECT could identify uric acid and calcium stones with 100% and 90% accuracy when compared with our gold standard biochemical analysis .Further DECT could accurately differentiate between calcium and uric acid stones with 100% accuracy .The differentiation between various calcium containing stones such as calcium oxalate and calcium hydroxyapatite was 90% .One patient with calcium oxalate was wrongly identified by DECT. Determination of stone composition may have important therapeutic implications , since uric acid stones are likely to be treated medically, calcium containing stones are more amenable to shock wave lithotripsy.

SUMMARY

In this prospective study total of 50 patients were evaluated who visited the A.J. Institute of medical sciences, Mangalore. The age of the patients varies from 25 years to 75 years. Among these patients 42 patients were male whereas, 8 patients were female. This study result demonstrates that DECT can effectively differentiate between the compositions of different renal stones.

The study has shown that the maximum number of patients (62%) have pure crystals comprises of either calcium or uric acid, whereas, 38% of patients had the stone that is of mixed composition.

In our study ,DECT could identify uric acid and calcium stones with 100% and 90% accuracy when compared with our gold standard biochemical analysis .Further DECT could accurately differentiate between calcium and uric acid stones with 100% accuracy .The differentiation between various calcium containing stones such as calcium oxalate and calcium hydroxyapatite was 90% .One patient with calcium oxalate was wrongly identified by DECT.

Determination of stone composition may have important therapeutic implications , since uric acid stones are likely to be treated medically, calcium containing stones are more amenable toshock wave lithotripsy.

In conclusion, DECT is very useful in the clinical workup of patients with renal stones to determine the stone composition and to decide the precise choice of treatment.

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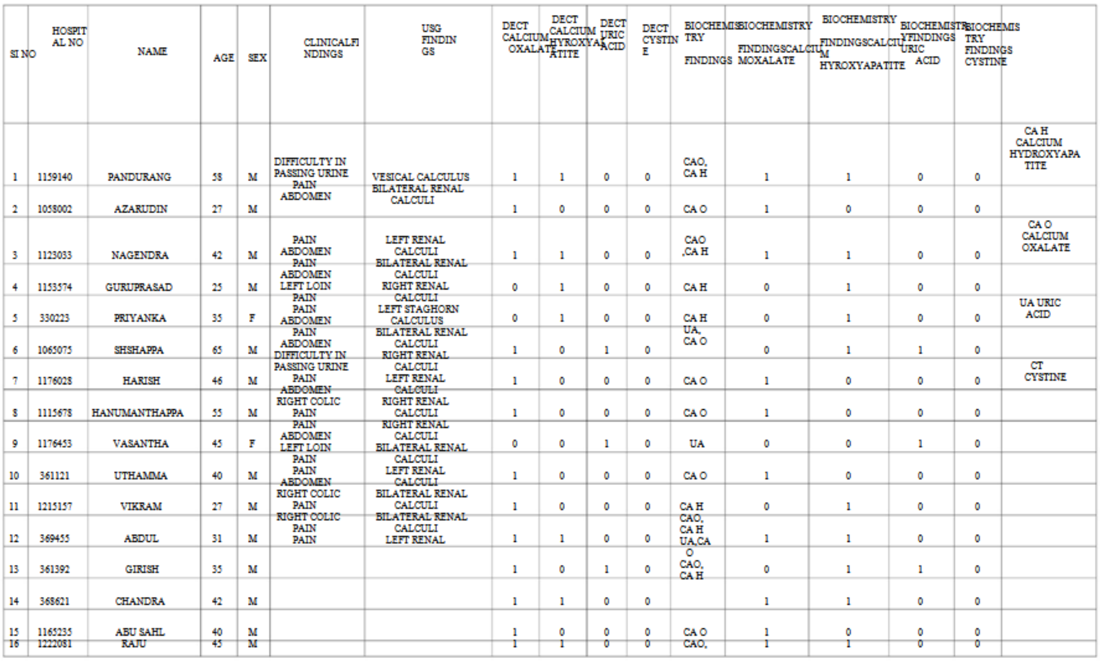
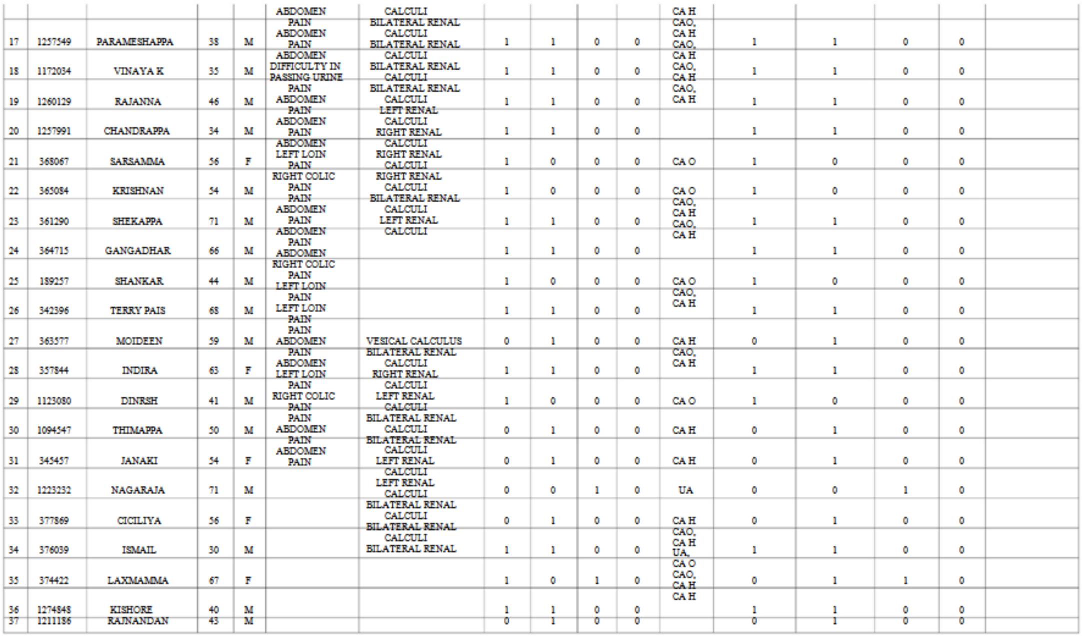
MASTER CHART



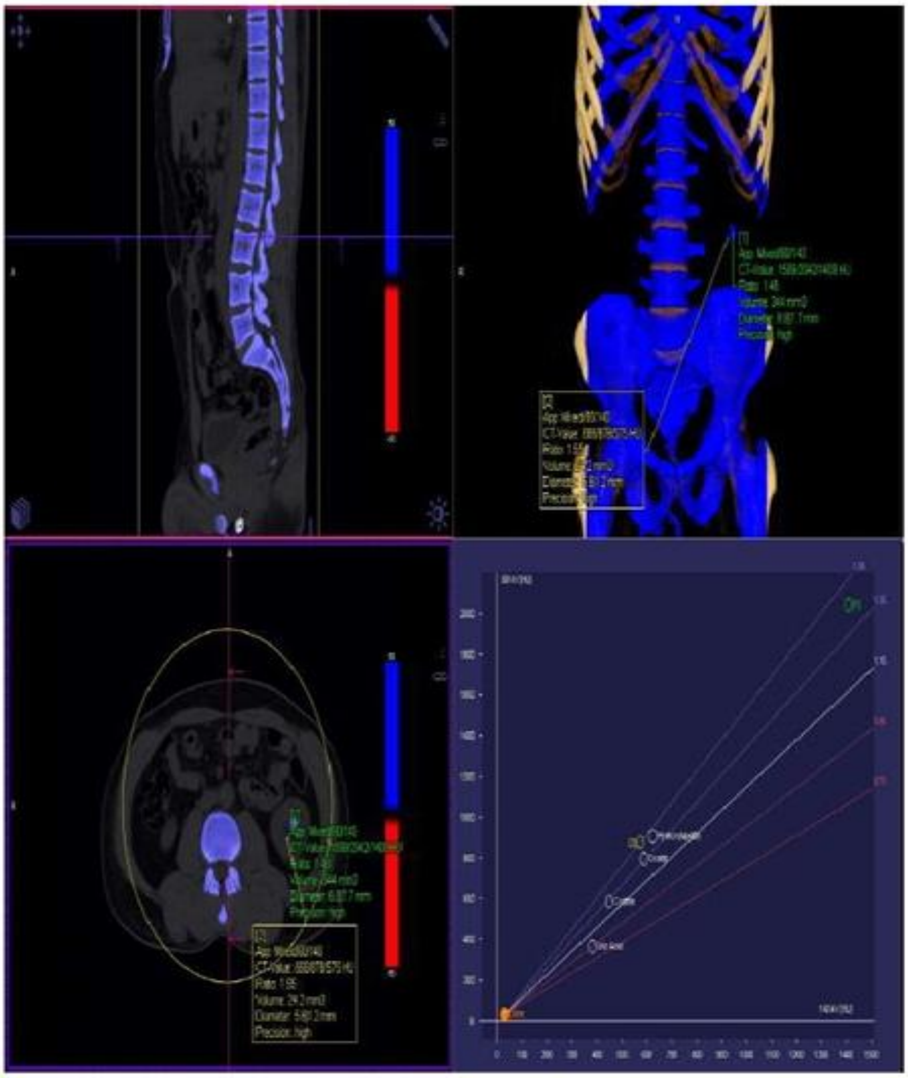


SI NO	HOSPITAL NO	NAME	AGE	SEX	CLINICALFINDINGS	USG FINDINGS	DECT CALCIUM OXALATE	DECT CALCIUM HYROXYAPATITE	DECT URIC ACID	DECT CYSTINE	BIOCHEMISTRY FINDINGS	BIOCHEMISTRY FINDINGSCALCIUM OXALATE	BIOCHEMISTRY FINDINGSCALCIUM HYROXYAPATITE	BIOCHEMISTRY FINDINGS URIC ACID	BIOCHEMISTRY FINDINGS CYSTINE	
1	1159140	PANDURANG	58	M	DIFFICULTY IN PASSING URINE	VESICAL CALCULUS	1	1	0	0	CAO, CA H	1	1	0	0	CA H CALCIUM HYDROXYAPATITE
2	1058002	AZARUDIN	27	M	PAIN ABDOMEN	BILATERAL RENAL CALCULI	1	0	0	0	CA O	1	0	0	0	
3	1123033	NAGENDRA	42	M	PAIN ABDOMEN	LEFT RENAL CALCULI	1	1	0	0	CAO ,CA H	1	1	0	0	CA O CALCIUM OXALATE
4	1153574	GURUPRASAD	25	M	PAIN ABDOMEN LEFT LOIN PAIN	BILATERAL RENAL CALCULI RIGHT RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
5	330223	PRIYANKA	35	F	PAIN ABDOMEN	LEFT STAGHORN CALCULUS	0	1	0	0	CA H	0	1	0	0	UA URIC ACID
6	1065075	SHSHAPPA	65	M	PAIN ABDOMEN	BILATERAL RENAL CALCULI	1	0	1	0	UA, CA O	0	1	1	0	
7	1176028	HARISH	46	M	DIFFICULTY IN PASSING URINE PAIN ABDOMEN	RIGHT RENAL CALCULI LEFT RENAL CALCULI	1	0	0	0	CA O	1	0	0	0	CT CYSTINE
8	1115678	HANUMANTHAPPA	55	M	RIGHT COLIC PAIN	RIGHT RENAL CALCULI	1	0	0	0	CA O	1	0	0	0	
9	1176453	VASANTHA	45	F	PAIN ABDOMEN	RIGHT RENAL CALCULI	0	0	1	0	UA	0	0	1	0	
10	361121	UTHAMMA	40	M	LEFT LOIN PAIN PAIN ABDOMEN	BILATERAL RENAL CALCULI LEFT RENAL CALCULI	1	0	0	0	CA O	1	0	0	0	
11	1215157	VIKRAM	27	M	RIGHT COLIC PAIN	BILATERAL RENAL CALCULI	1	0	0	0	CA H	0	1	0	0	
12	369455	ABDUL	31	M	RIGHT COLIC PAIN PAIN	BILATERAL RENAL CALCULI LEFT RENAL	1	1	0	0	CAO, CA H	1	1	0	0	
13	361392	GIRISH	35	M			1	0	1	0	UA,CA O CAO, CA H	0	1	1	0	
14	368621	CHANDRA	42	M			1	1	0	0		1	1	0	0	
15	1165235	ABU SAHL	40	M			1	0	0	0	CA O	1	0	0	0	
16	1222081	RAJU	45	M			1	1	0	0	CAO,	1	1	0	0	
					ABDOMEN	CALCULI					CA H					
17	1257549	PARAMESHAPPA	38	M	PAIN ABDOMEN	BILATERAL RENAL CALCULI	1	1	0	0	CAO, CA H	1	1	0	0	
18	1172034	VINAYA K	35	M	PAIN ABDOMEN DIFFICULTY IN PASSING URINE	BILATERAL RENAL CALCULI BILATERAL RENAL CALCULI	1	1	0	0	CAO, CA H CAO, CA H	1	1	0	0	
19	1260129	RAJANNA	46	M	PAIN ABDOMEN	BILATERAL RENAL CALCULI	1	1	0	0	CAO, CA H	1	1	0	0	
20	1257991	CHANDRAPPA	34	M	PAIN ABDOMEN PAIN ABDOMEN	LEFT RENAL CALCULI RIGHT RENAL CALCULI	1	1	0	0		1	1	0	0	
21	368067	SARSAMMA	56	F	LEFT LOIN PAIN	RIGHT RENAL CALCULI	1	0	0	0	CA O	1	0	0	0	
22	365084	KRISHNAN	54	M	RIGHT COLIC PAIN	RIGHT RENAL CALCULI	1	0	0	0	CA O	1	0	0	0	
23	361290	SHEKAPPA	71	M	PAIN ABDOMEN PAIN ABDOMEN	BILATERAL RENAL CALCULI LEFT RENAL CALCULI	1	1	0	0	CAO, CA H	1	1	0	0	
24	364715	GANGADHAR	66	M	PAIN ABDOMEN		1	1	0	0	CAO, CA H	1	1	0	0	
25	189257	SHANKAR	44	M	RIGHT COLIC PAIN		1	0	0	0	CA O	1	0	0	0	
26	342396	TERRY PAIS	68	M	LEFT LOIN PAIN LEFT LOIN PAIN		1	1	0	0	CAO, CA H	1	1	0	0	
27	363577	MOIDEEN	59	M	PAIN ABDOMEN	VESICAL CALCULUS	0	1	0	0	CA H	0	1	0	0	
28	357844	INDIRA	63	F	PAIN ABDOMEN	BILATERAL RENAL CALCULI	1	1	0	0	CAO, CA H	1	1	0	0	
29	1123080	DINRSH	41	M	LEFT LOIN PAIN RIGHT COLIC PAIN	RIGHT RENAL CALCULI LEFT RENAL CALCULI	1	0	0	0	CA O	1	0	0	0	
30	1094547	THIMAPPA	50	M	PAIN ABDOMEN	BILATERAL RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
31	345457	JANAKI	54	F	PAIN ABDOMEN PAIN	BILATERAL RENAL CALCULI LEFT RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
32	1223232	NAGARAJA	71	M		LEFT RENAL CALCULI	0	0	1	0	UA	0	0	1	0	
33	377869	CICILIYA	56	F		BILATERAL RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
34	376039	ISMAIL	30	M		BILATERAL RENAL CALCULI BILATERAL RENAL	1	1	0	0	CAO, CA H	1	1	0	0	
35	374422	LAXMAMMA	67	F			1	0	1	0	UA, CA O CAO, CA H	0	1	1	0	
36	1274848	KISHORE	40	M			1	1	0	0	CA H	1	1	0	0	
37	1211186	RAJNANDAN	43	M			0	1	0	0		0	1	0	0	

					ABDOMEN	CALCULI										
38	755565	VISHWANATH	65	M	LEFT LOIN PAIN	RIGHT RENAL CALCULI	0	0	1	0	UA	0	0	1	0	
39	296986	SUCHITAKSH	45	M	PAIN ABDOMEN	RIGHT RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
40	1279592	PARAMESHAPPA	56	M	PAIN ABDOMEN	RIGHT RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
41	1263867	PRAKASH	36	M	RIGHT COLIC PAIN	BILATERAL RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
42	361121	UTTAMA	41	M	DIFFICULTY IN PASSING URINE	LEFT RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
43	233018	PRATAP	51	M	RIGHT COLIC PAIN	LEFT RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
44	258828	KANTHIRAJ	38	M	LEFT LOIN PAIN	LEFT STAGHORN CALCULUS	0	1	0	0	CA H	0	1	0	0	
45	1162143	KUSHALAPPA	32	M	PAIN ABDOMEN	LEFT RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
46	1251177	MAHESHAPPA	32	M	PAIN ABDOMEN	BILATERAL RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
47	361290	SHEKAPPA	72	M	LEFT LOIN PAIN	BILATERAL RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
48	269889	RAJIV	41	M	DIFFICULTY IN PASSING URINE	BILATERAL RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	
49	359832	SUNITHA	46	F	DIFFICULTY IN PASSING URINE	RIGHT RENAL CALCULI	1	0	1	0	UA, CA O	0	1	1	0	
50	385520	JALEEL	62	M	PAIN ABDOMEN	BILATERAL RENAL CALCULI	0	1	0	0	CA H	0	1	0	0	

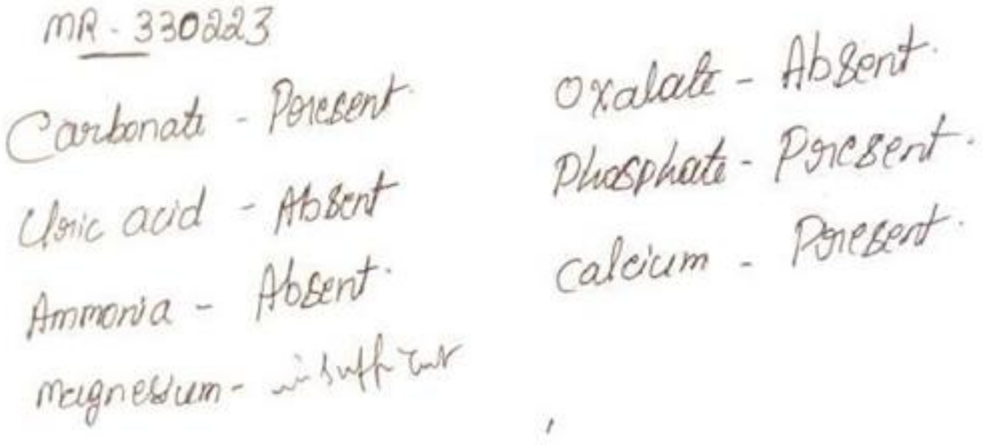
IMAGE GALLERY

1) DECT IMAGES



In above images DE ratio of renal stone is 1.55 which corresponds to calcium hydroxyapatite.

BIOCHEMISTRY FINDINGS



MR - 330223

Carbonate - Present

Uric acid - Absent

Ammonia - Absent.

Magnesium - insufficient

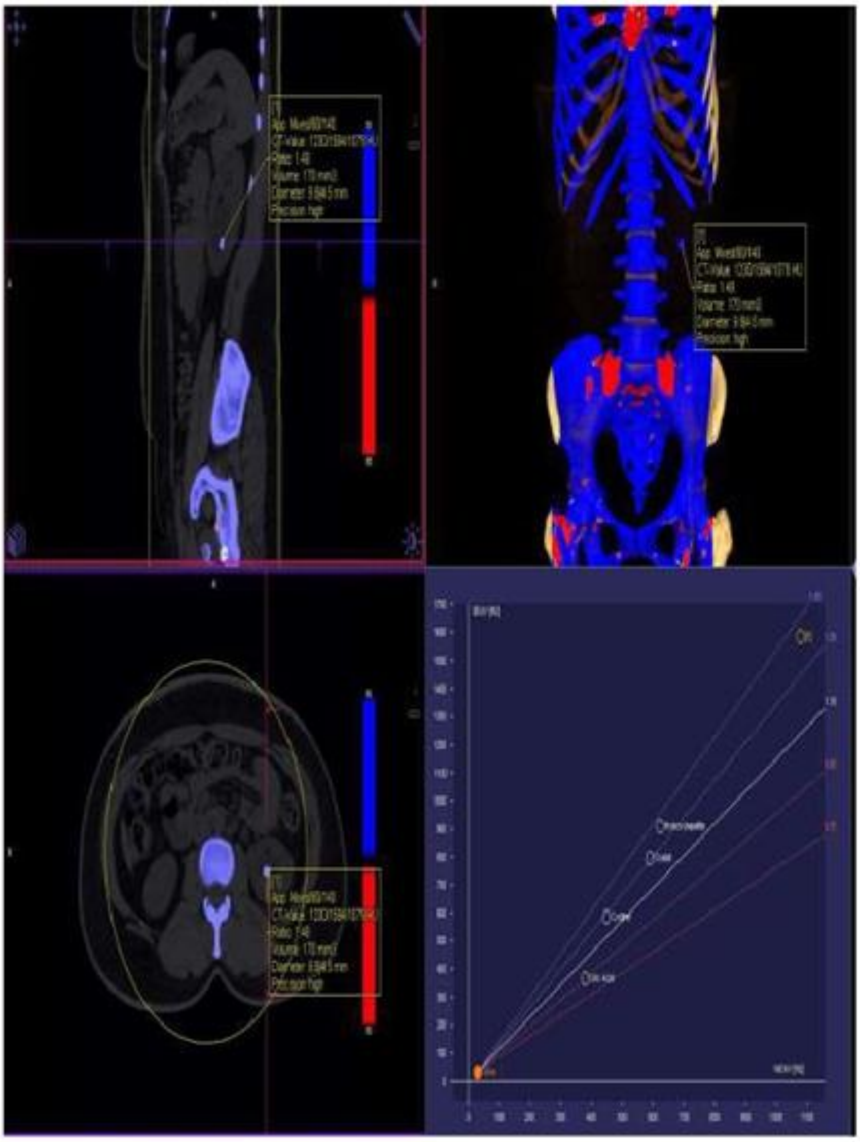
Oxalate - Absent.

Phosphate - Present.

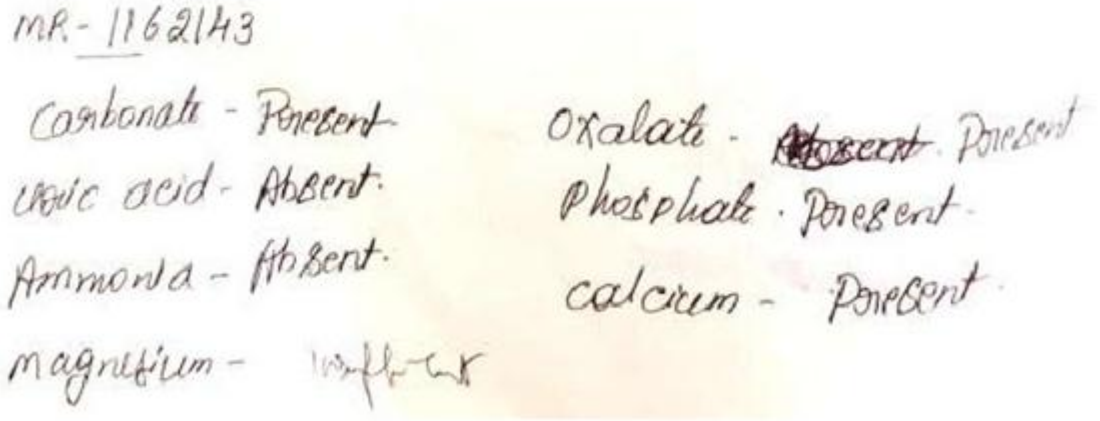
Calcium - Present.

Above results represent biochemistry study of renal stone(1).

2) DECT IMAGES



In above images DE ratio of renal stone is 1.48 which corresponds to calcium oxalate



MR - 1162143

Carbonate - Present

Uric acid - Absent.

Ammonia - Absent.

magnesium - insufficient

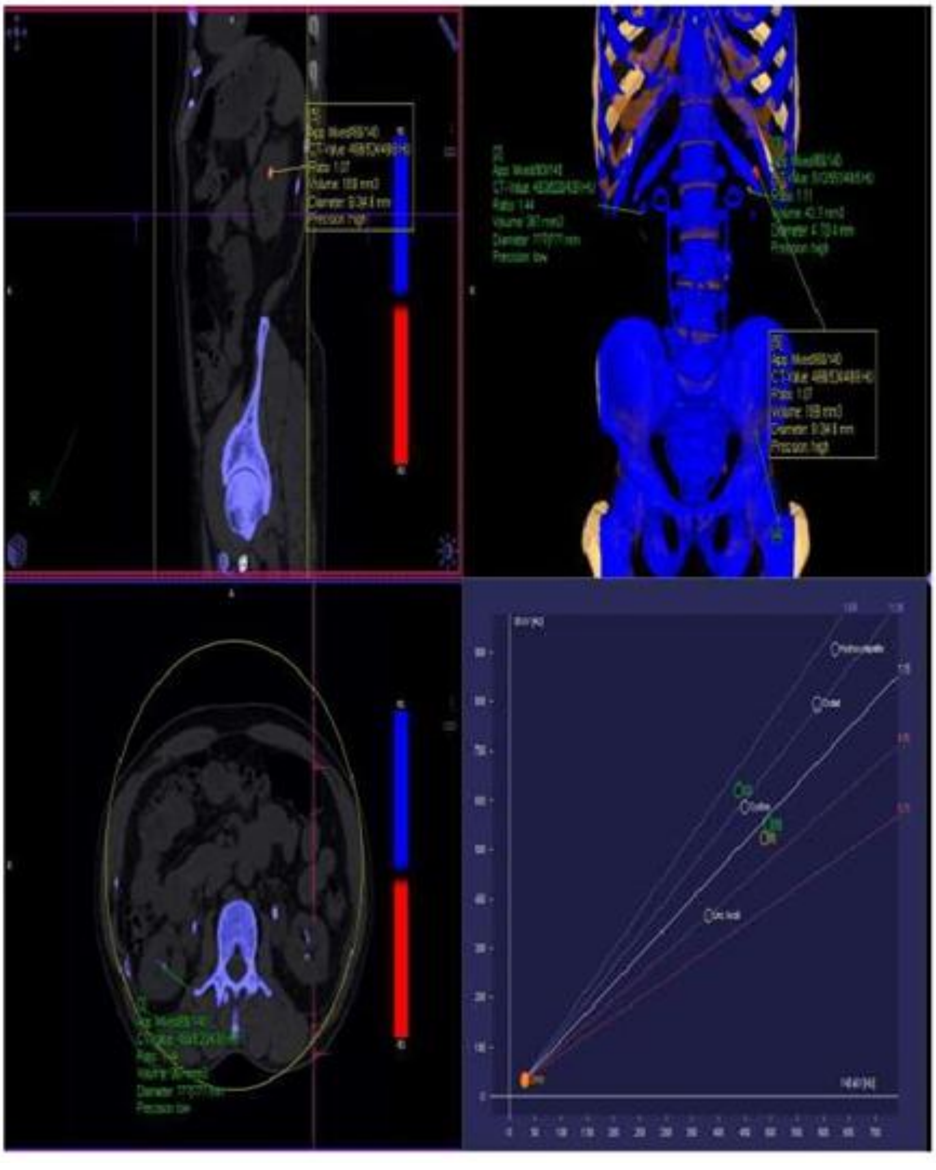
Oxalate - ~~Absent~~ Present

Phosphate · Present

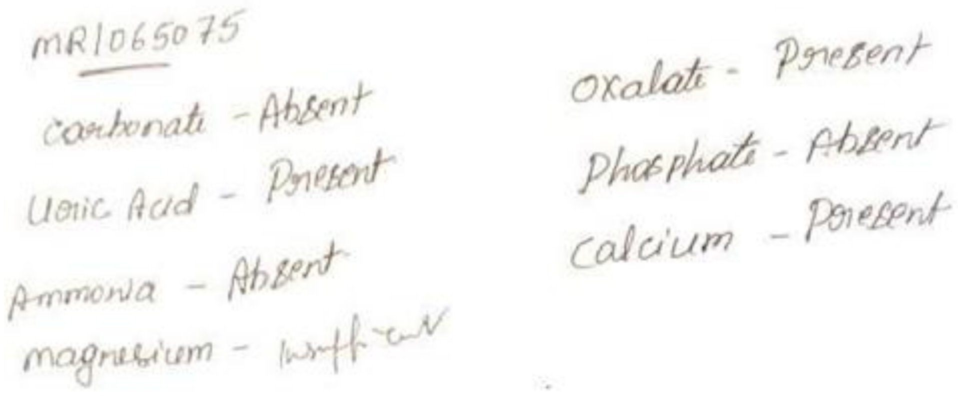
calcium - Present

Above results represent biochemistry study of renal stone(2).

3) DECT IMAGES



In above images DE ratio of renal stone is 1.07(LEFT ABOVE) which corresponds to uric acid.



MR1065075

Carbonate - Absent

Uric Acid - Present

Ammonia - Absent

Magnesium - Insufficient

Oxalate - Present

Phosphate - Absent

Calcium - Present

Above results represent biochemistry study of renal stone(3).

Dr Abdul Wahab Abdulla Mohammed. "Determination of Renal Stone Composition with Dual Energy CT: In Vivo Analysis and Comparison with Renal Stone Biochemistry." IOSR Journal of Dental and Medical Sciences (IOSR-JDMS), vol. 18, no. 04, 2019, pp 01-35.