ejpmr, 2023, 10(4), 103-110

SJIF Impact Factor 6.222

EUROPEAN JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH
www.ejpmr.com

Review Article
ISSN 2394-3211
EJPMR

APPLICATION OF CT SCAN IN UROLITHIASIS

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Article Received on 06/02/2023 **Article Revised on 27/02/2023** **Article Accepted on 19/03/2023**

ABSTRACT

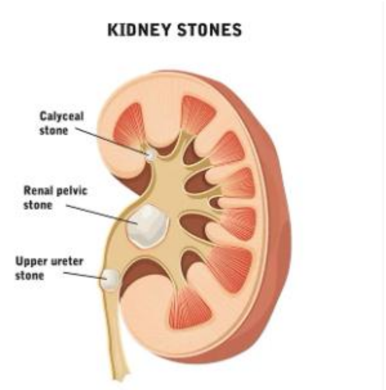
Imaging has an essential part in the diagnosis, management and follow- up of cases with renal stone complaint. A variety of imaging modalities are available these days including conventional X-ray, intravenous urography, ultrasound, magnetic resonance imaging and computed tomography (CT) scans, each with its advantages and limitations. IVU was once regarded as the gold standard for diagnosing renal stones, but unenhanced spiral CT scan has largely taken its place at most centers these days. For suspected renal stones in children and pregnant women, renal US is advised as the initial imaging technique. For the follow-up of radiopaque calculus, plain radiography is advised.. Plain radiography is suggested for the follow- up of radiopaque calculus, with ultrasound and limited IVU reserved for the follow- up of radiolucent calculi to minimize radiation exposure from repeated CT scan. Cases with asymptomatic calyceal stones can have a monthly KUB to see progression of stone size and position.[1] Spiral CT is superior to US and IVU in the demonstration of renal calculi but because of its high cost, higher radiation dose and high workload, it can be reserved for cases where US and IVU do not show the cause of symptoms.

KEYWORDS: renal stones, ct scan, mri, dual energy ct scan.

INTRODUCTION

• Crystal-based solid masses known as renal calculi or stones are found in the kidneys. The kidneys are where stones usually start to form. The urinary tract is made up of the following parts, but they can appear anywhere along it.

• kidneys
• ureters
• bladder
• urethra



Medical conditions like kidney stones can be excruciatingly painful. According to the type of stone, different factors can cause kidney stones.

No matter a patient's race, culture, or location, urolithiasis is a prevalent condition that affects a wide range of people globally.[2] Due to changes in lifestyle, notably the rising prevalence of obesity, urinary stone disease has increased in frequency over the past few decades in both developed and developing countries. Recent research has also shown that urolithiasis is evolving, and that the incidence of stone illness in females and younger patients has significantly increased during the past ten years. Because urolithiasis is associated with consequences like infection, chronic renal disease, and a high likelihood of recurrence, proper care of the condition has significant therapeutic implications.[3]

Imaging is essential for the initial diagnosis, therapy planning, and follow-up care of urolithiasis patients. Since its introduction for stone imaging in the 1990s, unenhanced computed tomography (CT) has replaced intravenous urography and radiography as the de facto gold standard for the first and follow-up evaluation of patients with suspected kidney stones. In comparison to other imaging modalities like plain radiography and ultrasound, non-contrast CT has a number of advantages, such as high sensitivity and specificity (>95% and >96%, respectively) for the detection of stones, easy accessibility, faster acquisition speeds, and no requirement for intravenous contrast administration. The use of CT in the management of urolithiasis has increased with the development of multi-detector CT (MDCT) and cutting-edge technologies like dual-energy CT (DECT).[4] Due to its capacity to describe stone composition and fragility, MDCT not only helps in correct diagnosis but also in treatment planning, follow-up, and assessment of treatment success. In this review article, we'll talk about the evolving function of CT in treating patients with kidney stones, as well as how it affects the development of treatment plans and patient monitoring.

SIGNS AND SYMPTOMS

• Kidney stones can cause severe pain. This severe pain is called renal colic. You may have pain on one side of your back or abdomen.
•The groin region can experience pain in males. Renal colic may cause excruciating pain.
• Other symptoms
-red, pink, or brown urine with blood in it.
-nausea, vomiting
-foul-smelling urine
-chills, fever
-frequent urination
-urinating small amounts of urine
If you have a small kidney stone, you might not experience any pain or other symptoms until the stone has passed through your urinary tract.

IMAGING TECHNIQUES

Xray

This X-ray using contrast reveals a kidney stone at the junction of the kidney and the tube that connects the kidney to the bladder (ureter).

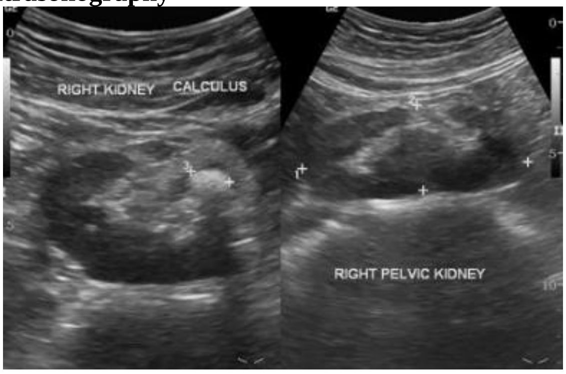
□ Calcium-containing stones are radiopaque.
✓ Strivite (triple phosphate),
✓ calcium oxalate,
✓ cystine stones
✓ calcium phosphate in its purest form.

□ Lucent stones include
• uric acid
• medication (indinavir is best known) stones
• pure matrix stones

Fluoroscopy

An intravenous urography (IVU) is a conventional radiographic method of examining the urogenital tract. In this procedure, intravenous contrast is administered. but CT has largely replaced this examination.

Ultrasonography



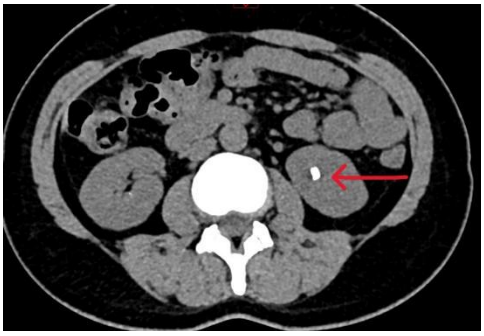
Ultrasound is well-suited to evaluating renal pathology. Ultrasound is very effective in the detection of Renal stones. Ultrasound can reliably detect larger renal stones showing posterior acoustic shadowing. Although ultrasound is frequently used as the initial examination of the urinary tract, it is less sensitive than CT.[5] But smaller stones, less than 5 mm in size, may be difficult to detect on ultrasound. Nearly 75% of calculi that are not visualized are < 3 mm. Sometime small stones may be missed on combination of ultrasound and plain radiograph of the abdomen.

Echogenic foci, acoustic shadowing, twinkle artifact on color Doppler, and color comet-tail artifact are examples of US features.

MRI

• Kidney stones are not typically evaluated with MRI scans, which use magnetic waves to create computerized images.
• It can sometimes help pregnant women diagnose kidney stones safely with this procedure, which doesn't use radiation.

CT Scan



99% calculi on renal tract can be seen on a non-contrast CT. The vesicoureteric junction is one of the most frequent locations where stones get stuck. Most stones appear opaque on CT scans, though their densities vary.

struvite (triple phosphate): typically opaque but variable; pure calcium phosphate: 400–600 HU; uric acid: 100–200 HU; cystine: opaque.

Dual-energy CT

Dual-energy CT (DECT) is the most significant technological advance in renal stone imaging in recent years. By comparing the attenuation of two different kVp levels, a stone's composition can be identified. Each CT vendor has its own set of dual-energy CT algorithms for analyzing the composition of stones. In order to find stones that have been hidden by the collecting system's opacification, dual-energy CT may be helpful. It has also been demonstrated that dual-energy CT can forecast how well extracorporeal shock wave lithotripsy will work.

MDCT Multiditector CT

Simple helical For the initial assessment of patients with suspected urinary stones, CT is the imaging modality of choice since it is extremely sensitive (up to 98%) and specific (96-100%) in identifying urolithiasis.[6] Due to its accessibility, speed, simplicity in image acquisition, lack of need for oral or intravenous contrast media administration, and capacity to identify pathologies other than urological ones like diverticulitis or appendicitis as well as gynecological ones like hemorrhagic cysts or ovarian torsion that may mimic renal colic, CT is highly preferred.This is crucial when treating patients who present to emergency rooms (EDs) with acute abdominal pain that mimics renal colic because, frequently, urologists do not evaluate these patients and, as a result, the ordering doctors also want to rule out other possible abdominal pathologies. A different diagnosis can be made using CT in roughly 10–14% of patients who present to the emergency room with renal colic symptoms. Congenital urinary tract disorders, renal/urothelial neoplasms, and other urogenital anomalies can also be diagnosed using CT, and their identification has important clinical implications for patient care and prognosis.[7,8]

Due to its capability to perform multi-planar reformations and three-dimensional (3D) reconstructions, MDCT, introduced in 1998, has opened up new possibilities in the management of urolithiasis and improved the identification and quantification of urinary stone burden. The volumetric assessment of stone burden by MDCT has shown to be a good predictor for treatment planning and outcome, along with routine evaluations of the quantity, location, size, and presence or absence of hydronephrosis of the stones. Additionally, by measuring attenuation in Hounsfield Units, MDCT enables the assessment of stone composition (HU).[1,6]

MDCT TECHNIQUE

Stone guidelines A non-contrast abdomino-pelvic CT investigation is different from a CT study specifically designed to diagnose urinary stone disease since it uses different scan acquisition parameters. A stone protocol CT's covering region stretches from the upper pole of both kidneys to the base of the bladder. While obtaining CT pictures at a slice thickness of 5 mm in combination with 3 mm coronal/sagittal reformatted images increases stone detection while reducing radiation dosage, while thinner slices (1-3 mm) are preferred.[1] Although automatic tube current modulation (ATCM) with a mA range of 80-500 mA and a tube potential of 100-120 kVp are often employed, it should be noted that the scan acquisition methods are specifically designed for the patient body weight and CT scanner technology.[9]

Iterative reconstruction (IR) technology has made it possible to execute stone protocol CT scans at lower mA and lower kVp, significantly reducing the radiation dose. The CT acquisition settings for suspected renal stone evaluation in the emergency department scanners are slightly different from the standard stone protocol CTs to help ED doctors more thoroughly rule out other potential non-urinary causes of patient complaints. The scan length must be adjusted to more closely resemble the abdomino-pelvic CT scan, which calls for thinner slices.

Despite not being necessary for routine stone diagnosis, contrast administration may be useful for spotting vascular calcifications or telling phleboliths apart from distal ureteral stones.In the stone CT method, it is essential to routinely acquire coronal and sagittal reformatted images with a 3 mm thickness.[10] When interpreting the images, multi-planar reformatted images are combined with traditional axial scans to provide an accurate assessment of the entire urinary tract and the location of the impacted stones. They also make it easier to distinguish between extrarenal calcifications and urinary stones and improve the ability to find small stones, particularly those that are located at the renal poles.

Urolithiasis is detected using CT.

To increase accuracy, the evaluation of urolithiasis with MDCT should consider the analysis of both axial and multi-planar reformatted images. Using an unenhanced CT, it is possible to identify all urinary tract calculi, including stones like uric acid, xanthine, or cystine that would otherwise be radiolucent on a traditional radiograph. Except for a pure matrix stones and stones that patients taking indinavir experience; these stones are frequently not seen in MDCT because they attenuate soft tissue (15–30 HU). In some circumstances, delayed imaging and intravenous contrast injection may be used to aid in the diagnosis.[1,11]

Stone management depends greatly on the stone's location and point of impaction in the ureter, with lower third calculi in the ureter having a higher success rate for treatment. CT allows for the exact detection and localisation of ureteral calculi in comparison to traditional radiography. A common finding is the direct visibility of a stone in the ureteric lumen together with proximal ureteral dilatation and normal distal ureter diameter. The absence of ureteral dilatation has only seldom been documented, and whether it exists or not does not necessarily imply the existence or absence of a urinary tract obstruction.

On a CT scan, a number of secondary symptoms can help diagnose ureteral stones, including less reliable ones like perinephric edema and lateral conal fascial thickening as well as more trustworthy ones like perinephric fat stranding, periureteral edema, hydroureter, and hydronephrosis. Perinephric fat stranding and intra-renal collecting system dilatation have positive and negative predictive values for ureterolithiasis detection that are close to 98% and 91%, respectively. When there is a significant degree of clinical suspicion and a stone is not found, a repeat careful screening for secondary symptoms is required.The likelihood of ureterolithiasis increases in the presence of ureteric dilatation and perinephric stranding, and the potential outcomes include either the passage of a previously obstructing stone or the existence of a stone with size or attenuation features that restrict identification on MDCT.[12] Instead, the absence of these secondary symptoms needs a thorough examination of all other possible explanations of the patient's symptoms, such as extra-urinary diseases that resemble ureteric colic, in order to conclusively rule out urinary stone illness.

CT for the evaluation of stone burden

Stones Size: The estimation of stone burden is a crucial component in the therapy of urological stone disease, which can routinely and significantly affect decision-making. Stone size is a more straightforward criterion for estimating stone burden and is consistently obtained on CT. Determining the size of the stone is a key factor in urological treatment decisions, including whether medicinal expulsive therapy or endoscopic or percutaneous treatments are necessary. The choice of urological procedures, such as shock wave lithotripsy (SWL), ureteroscopy with lithotripsy, or percutaneous nephrolithotomy (PCNL), is also influenced by the size of the stone. The size of the stone can be precisely determined on CT by measuring its largest dimension. Both a bone window and a soft tissue window can be used for measurements (window width: 400 HU, window level: 30 HU) or (window width: 1120 HU, window level: 300 HU).

Volumetry of stone: Even while two-dimensional (2-D) measurements are simple to use for estimating stone burden, they have limitations when it comes to properly determining stone size for large stones with irregular contours, such stag horn calculi. This limitation is overcome by the use of the stone volumetry technique, which enables estimation of the volume of the stones.[13] The stone volume has been calculated using three orthogonal measurements, 3D volume measurements from stone circumference data on various stone-bearing image sets, and more recently, semi-automatic segmentation technologies. In addition to being a useful tool for pre-operative planning, stone volume has also been found to be an accurate indicator of treatment outcome. For instance, it has been demonstrated that patients undergoing SWL can successfully anticipate treatment outcome using a stone volume cut-off of 700 mm^3.

CT is used to assess stone fragility

Assessment of the interior structure of the stone is another imaging factor that may have an effect on the outcome of urological procedures, particularly after SWL. The interior structure and architecture of the stones can be visualized using high-resolution MDCT scans in thin slices and reconstruction using the bone algorithm, especially when viewed through a bone window configuration. Internal homogeneity or heterogeneity may be indicated by the internal architecture as seen on a CT scan.[14] Internally homogeneous stones are more robust, have a consistent internal structure, and are challenging to fracture with lithotripsy. Areas of poor attenuation or internal voids can be seen inside the stone component of stones with internal variability, on the other hand. Internal heterogeneity indicates a high degree of stone fragility, and internal imperfections within stone buildings make it simple for stones to disintegrate on SWL.The existence of heterogeneity has been demonstrated to boost the success of fragmentation using SWL even for the essentially hard brushite, cystine, and calcium oxalate monohydrate stones. Stones with internal homogeneity, on the other hand, are resistant to simple fragmentation and may require numerous treatment sessions.

CT in the determination of stone composition

Urological care of urinary tract calculi depends on a number of variables, including stone size, location, quantity, anatomical structure, and chemical makeup. Urinary stone composition must be precisely determined before to therapy since it has a significant impact on the right course of action. For example, uric acid stones can be treated medically using oral drugs that promote stone breakdown. While calcium oxalate monohydrate and cysteine stones are both somewhat resistant to treatment by SWL, struvite stones are responsive to it.The avoidance of recurrent illness can also be aided by understanding the makeup of the stone. In the past, the composition of stones was predicted using the patient's medical history, urine pH, urinary crystals, urease-positive organisms, and plain radiography. Recently, CT has become more frequently employed to determine the composition of stones in vivo, and the development of new technological advances like DECT has made this possible.

Methods based on regions of interest Placing the ROI over the stone and calculating the attenuation value in HU has been the most often used technique for estimating the composition of stones on MDCT. In in vitro investigations, Bellin and colleagues demonstrated that HU measures based on ROI implantation were accurate in predicting the composition of urinary stones by 64–81%. Similar investigations have demonstrated that calcium oxalate monohydrate, cysteine, and uric acid stones may be consistently identified by HU values obtained using CT with high accuracy (>85%) in in vitro tests.[15]

The HU readings of the various urinary stones frequently fall within the following range at 120 kV : 200–450 HU for uric acid, 600–900 HU for struvite, 600–1100 HU for cysteine, 1200–1600 HU for calcium phosphate, 1700–2800 HU for calcium oxalate monohydrate, and 2800 HU for brushite. Despite CT's high accuracy in determining stone composition in in vitro research, HU measurement is less dependable and more challenging to use to predict stone composition in vivo. The size of the ROI, slice thickness, and precise positioning of the ROI over the stone are frequently required for attenuation values (HU)-based assessments of stone composition in order to counteract partial volume averaging effects.The majority of stones encountered in vivo have diverse compositions, making precise assessment difficult. In addition, overlap in the attenuation measures of distinct stones has reduced the use of ROI-based approaches for classifying different types of stones.

DECT

DECT technology, which was created in the last ten years, has a lot of potential for accurately determining the composition of stones. Dual-energy scanning allows for tissue characterization by simultaneously scanning with two distinct energies. Dual-source DECT (dsDECT) and single-source DECT (ssDECT) are the two types of DECT systems currently used in clinical settings.. Both DsDECT and ssDECT are built with a single X-ray tube that switches quickly between high (140 kVp) and low energy. Two detectors are placed on a single gantry perpendicular to one another and two X-ray tubes (140 and 80 kVp) are used to create the DsDECT.These systems have varied post-processing methods in addition to unique hardware configurations that enable material separation and the creation of images with various X-ray energy (keV).

DECT offers improved ability to analyze stone composition and distinguish between various stone types in addition to its excellent sensitivity for the identification of urolithiasis. One of the most well-known and widely used uses of DECT in the abdomen has been the determination of stone composition. This technology has been proven effective in both in vivo and in vitro experiments employing dsDECT and ssDECT, notably for differentiating between uric acid and non-uric acid stones. Based on the idea that different stones have distinct attenuation characteristics at various X-ray energies depending on their composition, DECT enables assessment of stone composition.It is possible to distinguish between uric acid and non-uric acid (calcium-dominant) stones using DECT because uric acid stones are made up of elements with low atomic numbers (H, C, N, and O) and because their X-ray attenuation profiles at different energies differ from those of non-uric acid stones, which are made up of elements with higher atomic numbers. According to the dsDECT method, every voxel is assumed to be a combination of water, calcium, and uric acid based on this differential behavior. In contrast, a scanner console processes CT data from a ssDECT scan using a two-material (basis pair) decomposition technique to create two picture series, typically made of iodine and water (high and low atomic number materials, respectively).[1,14} Uric acid stones are those that can only be seen on water imaging, whereas non-uric acid calculi are those that can be seen on both water and iodine images. Regardless of the size of the stones, material decomposition photos showed 100% sensitivity and accuracy in differentiating between uric acid and non-uric acid stones. Additionally, vendor-specific workstations (ADW version 4.5; GE Healthcare, Milwaukee, WI, USA) can produce efficient Z (Z_{eff}) pictures for additional study of renal stone composition.By considering the attenuation and atomic number of a particular material, the verified Z_{eff} approach for renal stone characterization makes it easier to identify the dominating material inside mixed stones. Uric acid stones are suggested by low Z_{eff}, whereas non-uric acid stones are suggested by high Z_{eff}. An ever-evolving use of DECT is the accurate sub-categorization of renal stones, and with ever-evolving DECT algorithms, more subtype distinction is becoming available. For instance, adding a tin filter to the high-energy tube of modern dsDECT scanners reduces the overlap between the two energy potentials and enhances spectrum separation, allowing for more in-depth analysis of renal stones with a similar composition.[16]

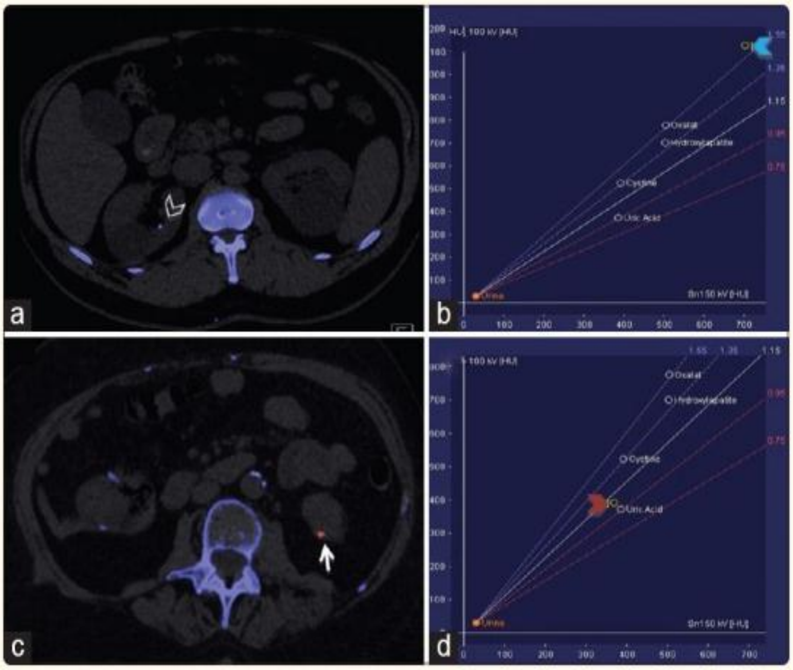


Figure 2

Characterization of kidney stones using dual-energy computed tomography (DECT). DECT helps to distinguish between uric acid and non-uric acid renal stones. a and c are axial images acquired from different patients who presented with flank pain. (a) Axial image showing a non-uric acid renal stone in the right kidney (arrowhead) colored in blue. (b) Graph showing the composition of this stone (blue arrowhead). (c) Axial image showing a uric acid renal calculus in the left kidney (arrow) colored in red. (d) Graph confirms the composition of the stone (red arrowhead)

In order to detect potential calculi in the urinary tract, the current DECT strategy for renal stones involves a low-dose MDCT capture utilizing the single-energy mode, covering the abdomen and pelvis. To reduce the overall radiation dose, a dual-energy acquisition targeted to the anatomical location of the stone is carried out once the urinary stone has been localized.[1] (Figure 2) Following scan capture, the CT console processes the DECT data, creating several image series. By boosting the contrast differences with the surrounding tissues, images with a specific virtual X-ray energy (50-70 keV) are created for better imaging of the renal stones. Compared to single energy CT (SE-CT) studies, DECT studies require more pictures and take longer to reconstruct since each DECT acquisition generates more data sets. Z_{eff} pictures must be created using a vendor-specific workstation using DECT scans. The SE-CT pictures and the resulting DECT images from the reconstruction process can both be seen.[17]

Using DECT to characterize mixed renal stones can be difficult, however current technology enables identification of the main stone type. A decrease in specificity for stones under 3 millimeters and in patients with substantial body habits are among the reported drawbacks of first-generation dsDECT for urolithiasis. These tiny stones, nevertheless, are naturally passed, thus they don't have as much clinical significance.

CT in planning percutaneous interventions

In addition to assisting in treatment planning by identifying the burden, location, composition, and fragility of the stones, MDCT is crucial in the pre-surgical assessment of patients who are good candidates for PCNL and other interventional procedures. The pyelocalyceal system's direction, the position of the kidneys, and their connections to other nearby organs like the spleen, liver, and colon are all assessed by MDCT.

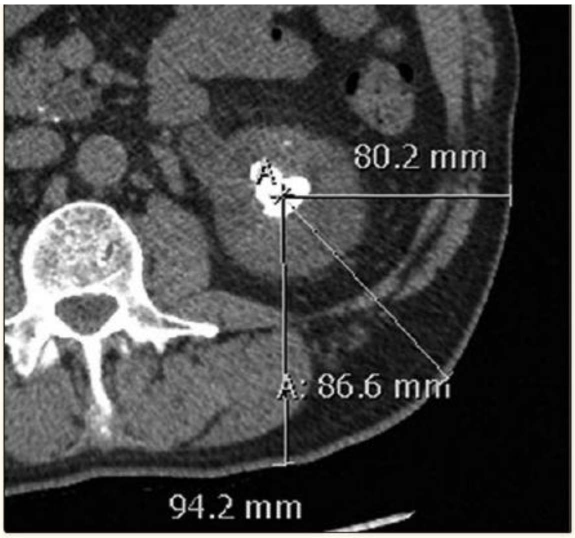


Figure 3

Measurement of stone-to-skin distance (SSD) in a 54-year-old man. On an axial non-contrast computed tomography scan, the distance from the center of the stone to the surface of the skin at 0°, 45° and 90° is 8.0, 8.7 and 9.4 cm, respectively. The mean of these three measurements is used to represent the average SSD, which is 8.7 cm

Using MDCT, it is possible to accurately assess a number of factors that are essential for successful calyceal access during PCNL, including as the location of the posterior calyx and the angle between the calyces. The calyceal system is now precisely and easily shown thanks to the multi-planar reformations and 3-D post-processing. Similar to this, stone-to-skin distance (SSD) is a crucial indicator of stone-free survival in patients who are candidates for SWL. Axial MDCT scans can be used to accurately measure SSD, or the distance between the stone's center and the skin's surface.[1] (Figure 3) It has been demonstrated that an SSD greater than 10 cm on CT increases the failure rate of SWL, hence PCNL or other ureteroscopic treatments may be recommended in these patients.

CT in post-treatment follow-up

The primary goals of CT imaging after urological treatment for patients with stone disease are to
(i) determine whether the patient is stone-free,
(ii) determine whether any residual stones are present,
(iii) rule out urinary system stricture, and
(iv) detect any complications related to urological interventions.

Following interventional treatments like PCNL and SWL, MDCT is the preferred technique for determining the presence of residual stone burden. With the help of CT, remaining fragments in the kidney and ureters can be correctly located, making removal easier. This is crucial because individuals with persistent residual stones have greater recurrence rates (50–80%) than patients with stone-free status. When it comes to the follow-up of stones that are radioopaque on KUB but lucent on conventional imaging, CT plays a crucial role.

The widespread use of DECT is restricted by the belief that DECT scanning exposes patients to more ionizing radiation than traditional CT. However, DECT radiation dose concerns are on par with those made with traditional CT. In fact, ssDECT and dsDECT scanners can perform DECT exams for urolithiasis at less than 5 mSv. Additionally, the adoption of IR methods in DECT scanners has reduced radiation dose while maintaining image quality and the capacity to characterize stones.

Treatment planning

Physicians can now ascertain the make-up of renal stones in vivo using dual energy CT and material decomposition, simplifying treatment. Because of the anatomic information obtained on CT, including stone location, obstructions of the collecting system, and complications related to nephrolithiasis, detailed follow-up on patients can be provided to determine their response to treatment. Uric acid stones make up 10% of all stones and urinary alkalization can aid in their dissolution.[18]

CONCLUSION

Radiological techniques play an vital part in the operation of cases with renal stones. Advances in technology particularly MDCT have enabled these ways to not only give accurate finding but also give the information critical for patient's treatment planning and monitoring response to various interventions. Radiologists and urologists should work together to use imaging ways with other possible indispensable imaging styles or low cure ways to insure an optimal balance between pitfalls and benefits affiliated to imaging for delivering best possible care for patients with stone disease.

In the treatment of urolithiasis patients, MDCT is essential. They can be used for everything from developing treatment methods to pre-treatment diagnosis and follow-up. The discrepancy between urologists' expectations and radiological interpretations is being closed by new developments in CT technology. The radiation dose concerns can be reduced without impacting the diagnostic effectiveness of the CT tests by widely implementing low-dose procedures and iterative reconstruction techniques in everyday clinical practice.

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