

INTRODUCTION

Urolithiasis is a significant source of morbidity, affecting all geographical, cultural, and racial groups of human beings. The lifetime risk of urolithiasis is about 10 to 15% in the developed world, but can be as high as 20 to 25% in the Middle East. The increased risk of dehydration in hot climates, coupled with a diet 50% lower in calcium and 250% higher in oxalates compared to Western diets, accounts for the higher net risk in the Middle East.⁽¹⁾ Uric acid stones are more common than calcium-containing stones in the Middle East region.⁽²⁾

The prevalence of urinary calculi is estimated to be 5 percent in the general population, with an annual incidence of as much as 1 percent.⁽³⁾ In Egypt, according to the available data, the prevalence of urinary stones is 37/10,000.⁽⁴⁾ Men most commonly experience their first episode between 30 and 40 years of age, whereas for women, the age at first presentation is somewhat later.⁽⁵⁾ The age of onset shows a bimodal distribution in women, with episodes peaking at 35 and 55 years.⁽⁶⁾ Recurrence rates are estimated at 50% over a 10-year and 75% over 20-year period,⁽⁷⁾ with some people experiencing ten or more episodes over the course of a lifetime.⁽⁵⁾

Anatomy of the Urinary System

The urinary system is primarily concerned with the removal of nitrogenous wastes from the body. In addition to this excretory function, the kidneys maintain the electrolyte, acid-base, and fluid balances of the blood and are the major homeostatic organs of the body. Malfunction of the urinary system leads to a failure in homeostasis, which is fatal if left uncorrected.⁽⁸⁾

❖ Gross Anatomy of the Human Urinary System

The urinary system consists of the paired kidneys and ureters and the single bladder and urethra. The kidneys filter the blood and manufacture urine in the process. The system's remaining organs provide temporary storage reservoirs or transportation channels for urine.⁽⁸⁾

- The ureters drain urine from the kidneys and conduct it by peristalsis to the bladder.
- The urinary bladder provides temporary storage for urine.
- The single urethra drains the bladder.
- The triangular region of the bladder, which is delineated by three openings (two ureteral and one urethral orifice), is called the trigone.⁽⁸⁾

In males, the urethra is approximately 20 cm long. It has three regions: the prostatic, membranous, and spongy (penile) urethrae. It, also, has a dual function in males: it serves as a urine conduit to the body exterior, and it provides a passageway for semen ejaculation. So, in males, the urethra is part of both the urinary and reproductive systems.⁽⁸⁾

In females, the urethra is only about 4 cm long. The female urethra serves only to transport urine to the body exterior. The external urethral orifice, its external opening, lies anterior to the vaginal opening.⁽⁸⁾

❖ Functional Microscopic Anatomy of the Kidney and Bladder

Kidney

Nephrons are the anatomical units responsible for forming urine. Each kidney contains over a million nephrons. Each nephron consists of two major structures: a glomerulus (a capillary knot) and a renal tubule.⁽⁸⁾

In embryonic development, each renal tubule starts as a blind-ended tubule that slowly encloses an adjacent glomerulus, or capillary cluster. The enlarged end of the tubule encasing the glomerulus is the Bowman's capsule, and its inner wall consists of highly specialized cells called podocytes.⁽⁸⁾

The glomerulus-capsule complex is also known as the renal corpuscle. The rest of the tubule is about 3 cm long. When it emerges from the glomerular capsule, it becomes highly coiled before it enters a collecting duct. The anatomical areas of the renal tubule are (in order from the glomerular capsule): the proximal convoluted tubule, loop of Henle, and the distal convoluted tubule. Most nephrons, called cortical nephrons, are found inside the cortex. Parts of the loops of Henle of the juxtamedullary nephrons penetrate into the medulla. The collecting ducts run downward through the medullary pyramids. Approaching the renal pelvis, the collecting ducts fuse to form larger papillary ducts. These ducts empty the final urinary product into the calyces and pelvis of the kidney.⁽⁸⁾

The nephron function depends on several features of renal circulation. The capillary vascular supply consists of two distinct capillary beds, the glomerulus and the peritubular capillary beds. The vessels leading to and from the glomerulus, the first capillary bed, are both arterioles: the afferent arteriole feeds the bed and the efferent arteriole drains it.⁽⁸⁾

The peritubular capillary bed arises from the efferent arteriole draining the glomerulus. The peritubular capillaries are low pressure porous capillaries that are adapted for absorption rather than filtration and take up the solutes and water reabsorbed from the filtrate by the tubule cells. These two capillary beds of the nephron have different, but complementary, roles: the glomerulus produces the filtrate and the peritubular capillaries absorb most of that filtrate.⁽⁸⁾

Each nephron, also, has a region called a juxtaglomerular apparatus (JGA), which is important in forming concentrated urine. Urine formation results from three processes: filtration, reabsorption, and secretion.⁽⁸⁾

- **Filtration** is a largely passive process where a portion of the blood passes from the glomerular bed into the glomerular capsule. The filtrate then enters the proximal convoluted tubule where tubular reabsorption and secretion begin.⁽⁸⁾
- **Tubular reabsorption** occurs when the filtrate components move through the tubule cells and return to the blood in the peritubular capillaries. Some of the reabsorption is passive, but the reabsorption of most substances depends on active transport processes.

The current composition of the blood and the needs of the body at the time determine which substances are reabsorbed at the time.⁽⁸⁾

- **Tubular secretion** is the reverse process of tubular reabsorption. This process is important for the disposal of substances not already in the filtrate (drug metabolites, etc) and as a way for controlling blood pH.⁽⁸⁾

Bladder

Urine production is a continuous process, but removal of urine from the body is performed when convenient. The urinary bladder receives urine from the ureters and discharges it through the urethra when not temporarily storing it.⁽⁸⁾

Micturition, or voiding, is the process in which urine empties from the bladder. The internal urethral sphincter and the external urethral sphincter control the outflow of urine from the bladder. The internal sphincter is a smooth muscle involuntary sphincter. The external sphincter is skeletal muscle and is voluntarily controlled.⁽⁸⁾

Risk Factors

Renal stones are known to occur with increased frequency in a variety of clinical disorders. Conditions that appear to increase risk include hyperparathyroidism, inflammatory bowel disease, prior bowel resection, strong family history of stone disease, urinary tract abnormalities leading to recurrent infections, and nephrocalcinosis.⁽⁹⁾

Several other risk factors also need to be identified.⁽⁹⁾ Low urine volumes increase urine stasis and also increase the saturation of urine. Diarrhea and hot climates frequently cause volume contraction and may contribute to uric acid and calcium-based stone formation. Certain medications increase the likelihood of nephrolithiasis. Loop diuretics cause increased calcium excretion, whereas triamterene, acyclovir, and indinavir may precipitate as crystals given the proper conditions.⁽⁹⁾

Use of non prescription medications also should be reviewed. Antacids bind phosphate in the intestine, leading to increased availability and absorption of calcium and predisposing to calcium stones. Vitamins A and D taken in excess can lead to hypercalcemia and hypercalciuria.⁽⁹⁾

Vitamin A increases bone resorption, and vitamin D promotes calcium absorption from the gut. Although not convincingly proven, vitamin C may increase urine oxalate levels in some patients.⁽⁹⁾

Certain lifestyles may predispose to stone formation. Soldiers on active duty in desert conditions have been shown to have an increased incidence of nephrolithiasis. Long-distance runners, bicycling enthusiasts, and travelling sales people may limit their fluid intake avoid frequent urination and thus are also at increased risk.⁽⁹⁾

Pathophysiology of Stone Formation

Stone formation is the end result of a multistep process in which the balance of factors that promote crystallization of urinary salts and factors that inhibit crystallization is perturbed.⁽¹⁰⁾ When the urinary concentration of certain salts exceeds their solubility product, the urine becomes supersaturated for that salt. In a state of supersaturation, nuclei of salt crystals are formed in a process called *nucleation*. Often there is another nidus of nucleation, such as the injured surface of renal tubular epithelial cells or a different solute (eg, uric acid) that causes crystal formation (heterogeneous nucleation). Low concentrations of crystallization inhibitors (citrate, nephrocalcin, uropontin, magnesium) may promote the nucleation of salts in saturated but stable solutions. If the nuclei begin to aggregate, crystals begin to form.⁽¹⁰⁾

These crystals continue to aggregate and eventually grow into stones. Retention within the kidney appears to be important for the crystals to grow: If not retained, crystals are passed in the urine. Locations of prior injury, such as renal papillae, are hypothesized to be sites where crystals are retained. Low urine flow or stasis from genitourinary abnormalities or volume depletion also may promote crystallization.⁽¹¹⁾ Stones tend to reside either at the area of prior injury or in gravity-dependent locations, such as the lower pole calices.⁽¹¹⁾

Stone Classification Based on Composition

A wide range of familial, environmental, dietary, and systemic factors contribute to the pathogenesis of renal stones⁽¹²⁾. Stones are composed of a combination of crystals (both inorganic and organic) and proteins (Fig 1). Calcium-based stones, which include calcium oxalate monohydrate, calcium oxalate dihydrate, and calcium phosphate stones, account for 70%–80% of upper urinary tract stones. Struvite stones account for 5%–15% of stones and are composed of magnesium ammonium phosphate. In contrast, uric acid stones are unique in that they can often be dissolved with urinary alkalization; they account for 5%–10% of stones and occur in acidic urine (pH <5.8). Other stones, including cystine, xanthine, and protein matrix stones, as well as drug (eg, triamterene, indinavir)–induced calculi, account for less than 5% of stones.⁽¹³⁾

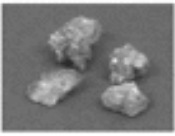
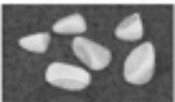
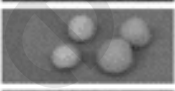
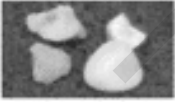
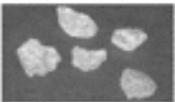
	Composition	Frequency of Occurrence	KUB Radiographic Appearance	CT Appearance/Attenuation (HU)	Associated Etiologic Factors
	Calcium oxalate monohydrate and dihydrate (calcium oxalate dihydrate)	40%–60%	Radiopaque	Opacified/ 1700–2800	Underlying metabolic disorder (eg, idiopathic hypercalcaemia or hyperoxaluria)
	Hydroxyapatite (calcium phosphate)	20%–60%	Radiopaque	Opacified/ 1200–1600	Usually no metabolic abnormality
	Brushite	2%–4%	Radiopaque	Opacified/ 1700–2800	...
	Uric acid	5%–10%	Radiolucent	Opacified/ 200–450	Idiopathic hyperuricemia or hyperuricosuria
	Struvite	5%–15%	Radiopaque	Opacified/ 600–900	Renal infection
	Cystine	1%–2.5%	Mildly opaque	Opacified/ 600–1100	Renal tubular defect

Figure (1): Chart illustrates commonly occurring urinary tract stones and describes their salient features. KUB = kidney, ureter, bladder).

Diagnosis of urinary stones is made on the basis of information obtained from the history, physical examination, urinalysis, and imaging studies.⁽¹⁴⁾ Calcium-containing stones are relatively radiodense, and they can often be detected by a traditional radiograph of the abdomen that includes the kidneys, ureters, and bladder (KUB film).⁽¹⁵⁾ About 60% of all renal stones are radiopaque.^(16,17) In general, calcium phosphate stones have the greatest density, followed by calcium oxalate and magnesium ammonium phosphate stones. Cystine calculi are only faintly radiodense, while uric acid stones are usually entirely radiolucent.⁽¹⁸⁾

Factors Influencing Treatment Decisions

The most important factors influencing decisions regarding urologic intervention are stone location, size, and composition, and patient symptoms (Figs 2, 3).⁽¹⁹⁾ Renal stones (ie, stones located within the renal collecting system, above the ureteropelvic junction) may be treated with shock wave lithotripsy (SWL), flexible retrograde uretero-renaloscopy, percutaneous nephrolithotomy (PCNL) and open surgery (Table). The success of SWL, the least invasive of these four treatments, is related to a number of factors that may be evaluated with CT, including stone location (ie, lower pole of the kidney versus other calices), size, and composition, as well as stone-to-skin distance (SSD).^(20–24) Flexible retrograde uretero-renaloscopy, a transurethral endoscopic procedure that makes use of lasers to fragment stones, is gaining popularity due to high stone-free rates and minimal morbidity.^(20, 25–27) At many centers, flexible retrograde uretero-renaloscopy is performed as an outpatient procedure with modern ureteroscopes as small as 7.4–9.0 F in diameter.⁽²⁶⁾ This procedure is particularly useful in patients with stones that are refractory to SWL, as well as in patients with multiple stones, obesity, and bleeding diatheses. Although flexible

retrograde uretero-renaloscopy can be used for larger renal stones (ie, stones >2 cm), it is most commonly used to treat stones 0.5–1.5 cm in diameter.⁽²⁵⁾ Finally, for larger stones, staghorn calculi, or lower pole stones that are refractory to SWL or flexible retrograde uretero-renaloscopy, PCNL is the treatment of choice.⁽²⁸⁾ PCNL requires percutaneous ultrasonography (US) or fluoroscopically guided puncture of a renal calix, tract dilatation, and stone fragmentation-extraction.^(28, 29) This procedure offers excellent stone-free rates for patients with large stones, and complications in modern series (most commonly, bleeding requiring transfusion or injury to adjacent organs) are low (0.8%–8% of cases).^(28, 29–31) Open surgery is preserved for large complicated staghorn calculi and is less commonly done nowadays.

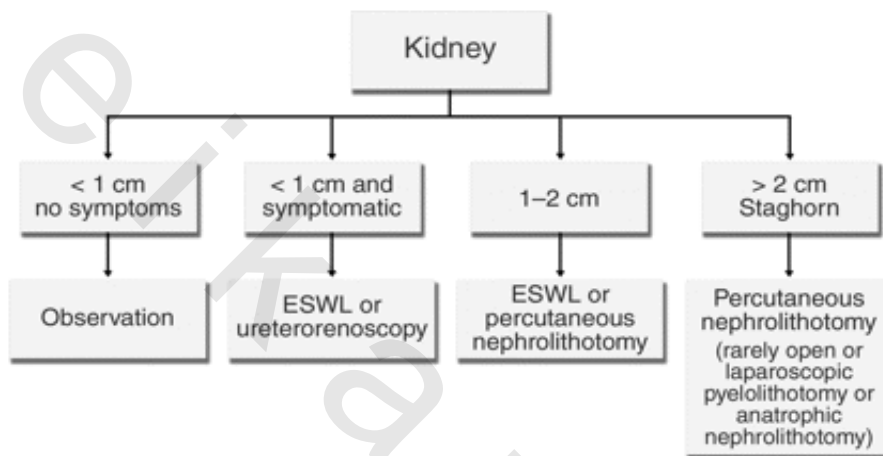


Figure (2a): Flow charts depict treatment decisions based on stone location (kidney in a, ureter in b) and size. ESWL = extracorporeal shock wave lithotripsy, PO = per os (by mouth [ie, nutrition]), URS = ureteroscopy.⁽¹⁹⁾

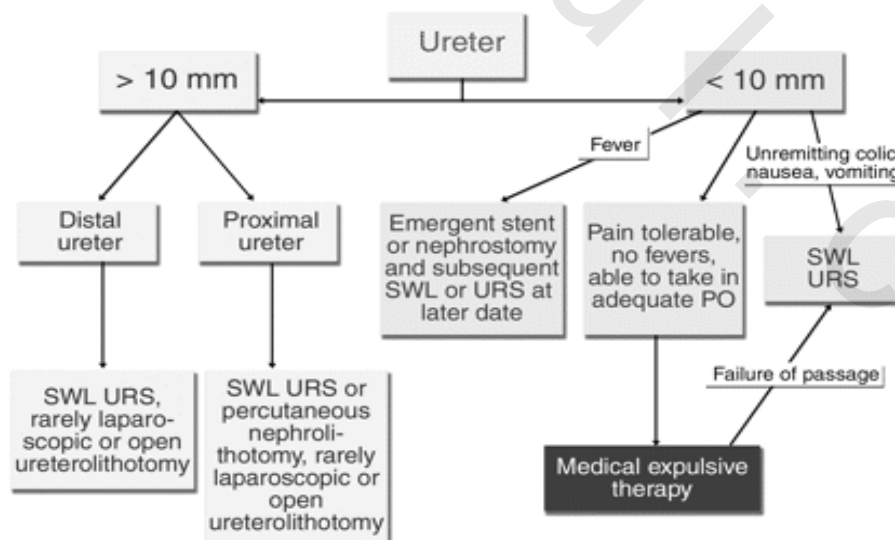


Figure (2b): Flow charts depict treatment decisions based on stone location (kidney in a, ureter in b) and size. ESWL = extracorporeal shock wave lithotripsy, PO = per os (by mouth [ie, nutrition]), URS = ureteroscopy.⁽¹⁹⁾

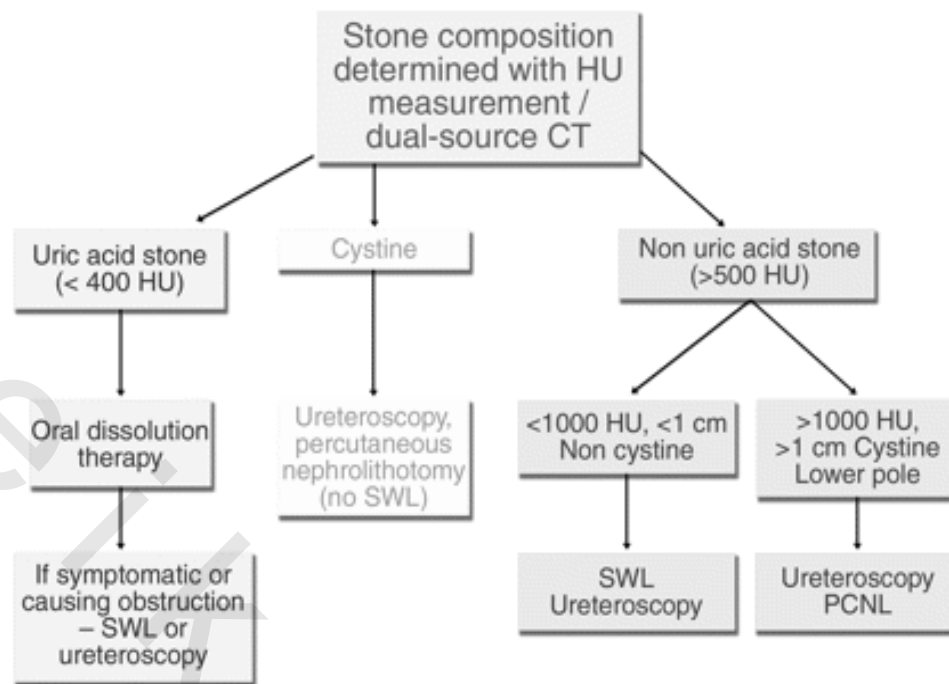


Figure (3): Flow chart depicts treatment decisions based on stone composition. Cystine stones are typically resistant to SWL, with the degree of resistance being variable. *PCNL* = percutaneous nephrolithotomy.⁽¹⁹⁾

With regard to ureteral stones (ie, stones small enough to pass distal to the ureteropelvic junction and into the ureter), treatment often depends on stone size and type of interventional procedure (Figs 2, 3).⁽¹⁹⁾ The first-line treatment is medical expulsive therapy (α -blockers or calcium channel blockers with or without steroids and nonsteroidal anti-inflammatory medications), as well as hydration and analgesia.⁽³²⁾

A meta-analysis by Preminger et al⁽²⁷⁾ revealed that stones 5 mm or less in diameter had a spontaneous passage rate of 68%, whereas stones greater than 5 mm but less than or equal to 10 mm had a spontaneous passage rate of 47%. Larger ureteral stones or those that fail to pass with medical expulsive therapy, cause unremitting pain, nausea, or vomiting and may require intervention with extracorporeal shock wave lithotripsy (ESWL) or ureteroscopy with fragmentation-extraction⁽²⁷⁾. Percutaneous nephrolithotomy (PCNL) is the first-line treatment for large ureteral stones (>15 mm), which are most commonly lodged in the upper ureter⁽²⁷⁾. Laparoscopic or open ureterolithotomy is rarely performed, but it may be used in certain refractory cases⁽³³⁾. As with renal stones, the outcome of ureteral stone treatment is affected by stone size, location, and composition.

Imaging of Urolithiasis

Conventional Imaging Techniques

Conventional abdominal (kidney, ureter, bladder [KUB]) radiography as the sole imaging modality for the evaluation of nephrolithiasis is limited by several factors, including bowel gas, extrarenal calcification, and large patient habitus. These factors

diminish the sensitivity of KUB radiography in the detection of urinary stones. However, KUB radiography is useful for planning fluoroscopically guided SWL and for monitoring the status of stone fragments after extracorporeal shock wave lithotripsy (ESWL), ureteroscopy, and percutaneous nephrolithotomy (PCNL)⁽¹³⁾. Intravenous urography fails to help detect urinary calculi in 31%–48% of cases and carries the risks associated with the injection of iodinated contrast material⁽¹³⁾. Although widely available and cost effective, US has limited diagnostic value in the assessment of patients with suspected renal stones, even when performed by an experienced radiologist, particularly in the evaluation of distal ureteral calculi⁽¹³⁾. Endovaginal and transperineal imaging have been found to be sensitive in the detection of small stones in the distal ureter; however, they are operator dependent and are not widely used⁽³⁴⁾.

Unenhanced helical CT has gained widespread acceptance as the initial investigation of choice for the evaluation of patients with suspected urinary tract calculi^(35,36). Since the first description of its utility by Smith et al⁽³⁷⁾ in 1995, unenhanced CT has been found to have a high degree of sensitivity (95%–98%) and specificity (96%–100%) in the diagnosis of urolithiasis^(38,39–43). CT has several advantages over other imaging techniques: It can be performed rapidly, does not require the administration of contrast material, is highly sensitive for the detection of stones of all sizes, and allows the detection of other unsuspected extraurinary and urinary abnormalities^(34,36,38). Extraurinary abnormalities including appendicitis, diverticulitis, pancreatitis, and gynecologic lesions such as ovarian torsion are often detected at CT in patients with nonspecific abdominal pain mimicking ureteral colic when the diagnosis may not be obvious prior to imaging^(38, 44–46). An additional benefit of CT is its ability to reveal urinary abnormalities such as congenital abnormalities, infections, and neoplasms, whose diagnoses have a greater clinical relevance than does that of stone disease⁽⁴⁶⁾.

The introduction of multidetector CT in 1998 has opened up new prospects for CT in the imaging of urolithiasis. Advances in multidetector CT technology that allow the acquisition of isotropic volume data, and concurrent advances with respect to postprocessing algorithms and imaging workstations that allow multiplanar and three-dimensional evaluation of these isotropic data sets, have empowered radiologists to meet the greater expectations of urologists in the assessment of stone disease. Identification of the number, size, and location of calculi and determination of the presence of hydronephrosis (ie, obstruction) are routinely made with multidetector CT (Fig 4).⁽¹⁹⁾ High-resolution coronal reformatted images generated automatically from isotropic data sets obtained with 16–64-detector CT allow more rapid and accurate detection of urinary stones than do axial images alone^(47,48). The quantification of stone burden with volumetric techniques, made feasible by the near-isotropic resolution of multidetector CT, holds great promise as both a tool for surgical planning and a predictor of treatment response^(24, 49, 50). In addition, multidetector CT helps in the assessment of stone fragility and composition with use of attenuation measurements and characterization of internal structure^(51–55). Differentiation between calcium-based stones and uric acid stones, previously achieved only with standard multidetector CT, has improved and is now also easily achieved with dual-energy CT, an exciting new CT innovation with capabilities of tissue differentiation⁽⁵⁶⁾.

STRUCTURED CT REPORT TEMPLATE FOR UROLITHIASIS

DEMOGRAPHIC DETAILS:

Name: _____ Age: _____ Sex: _____

Date of Examination: _____

Indication for CT study: _____

Prior comparison CTs: _____

FINDINGS:

Stones present: Y / N

Number of stones: _____

- Location:
1. Side: L / R
 2. Kidney: Upper pole / Mid pole / Lower pole / Renal pelvis / Staghorn
 3. Ureteropelvic junction
 4. Ureter: Proximal _____ ;
distal _____ ;
ureterovesical junction _____
 5. Bladder

Size (mm): _____ Volume (cc): _____ Density (HU): _____

Internal structure: Homogeneous / Heterogeneous

Stone to skin distance (cm): _____

Secondary signs:

- a) Hydronephrosis / Hydroureter
- b) Perinephric stranding
- c) Periureteral stranding
- d) Delayed renal excretion

Radiation dose: _____

Figure (4): Structured radiology report template for assessment of urolithiasis with multidetector CT.⁽¹⁹⁾

Multidetector CT Technique

The scanning technique and parameters for unenhanced multidetector CT for urolithiasis should be tailored to the indication. It is also important to keep in mind that a CT protocol for the evaluation of stone disease is not considered equivalent to routine unenhanced abdominopelvic CT. The former should typically include scanning of the entire urinary tract from the upper pole of the kidneys to the base of the urinary bladder⁽⁵⁷⁾. Although bladder distention has been recommended for enhanced visualization of distal ureteral stones, the improved accuracy of multidetector CT due to the availability of coronal reformatted images usually obviates any patient preparation^(47,48,57).

Thinner (1–3-mm) reconstruction sections are recommended for better detection and characterization of urinary calculi—particularly small stones, due to the reduction in partial volume averaging effect^(58,59). However, acquiring 5-mm CT scans along with 3-mm coronal reformatted images has been found to improve stone detection while allowing radiation dose benefits^(49,60,61). Acquiring CT scans with a section thickness greater than 5 mm or scanning at 10 mm can lead to frequent missing of small urinary calculi and can also affect size and attenuation measurements due to partial volume averaging effect resulting in lower average values^(38,58). Therefore, images can be prospectively acquired at 5-mm collimation, and the near-isotropic data set obtained with scanners having 16 or more detector rows can then be reconstructed at a 1–3-mm section thickness to reduce errors in attenuation determination⁽⁵⁸⁾. In our practice, CT for stone evaluation is performed with a tube potential of 100–120 kVp and automatic tube current modulation with tube current ranging from 80 to 500 mAs⁽⁵⁸⁾.

Intravenous contrast material administration is not routinely required for the diagnosis of calculi at CT. In selected cases, however, contrast material administration may be useful for differentiating distal ureteral stones from phleboliths or vascular calcifications⁽⁶⁰⁾. In other scenarios, such as the incidental detection of tumor or other diseases on unenhanced scans, contrast material-enhanced CT may be required^(37,60). Contrast-enhanced CT is also useful in conditions such as ureteral strictures, duplicated system, or ureteropelvic junction obstruction, in which the delineation of aberrant genitourinary anatomy is necessary for effective treatment^(60,61).

Value of Coronal Reformatted Images

Axial imaging data sets are frequently used in the detection of renal stones. Coronal or sagittal reformatted images are used to supplement the axial scans in tracing the entire length of the ureter and in identifying the exact site of stone impaction, as well as in detecting small (1–2-mm) stones at the renal poles. Because the urothelial system is coronally oriented, the detection of urinary stones is not only quicker but also improved with coronal reformatted images (Fig 5)⁽⁴⁷⁾. In addition, the use of coronal reformatted images in conjunction with axial scans has been found to facilitate the differentiation of calcifications such as phleboliths, calcified vascular plaques, and renal parenchymal calcifications from urinary stones⁽⁴⁷⁾. Therefore, coronal reformation has been recommended as a useful adjunct to standard axial scanning, since it improves the detection of urinary stones that go unrecognized on axial scans and enhances radiologists' confidence^(47,48).



Figure (5a): Ureteral stone in a 45-year-old man who presented with acute left flank pain. **(a)** Axial unenhanced multidetector CT scan shows a 4-mm stone in the left distal ureter (arrow). **(b)** Coronal reformatted image shows the left distal ureteral stone (arrow), along with a 2-mm stone in the left upper pole (arrowhead) that was not seen on the axial images. Secondary signs of ureterolithiasis, including perinephric stranding and thickening of the renal fascia, are also seen.⁽⁴⁷⁾



Figure (5b): Ureteral stone in a 45-year-old man who presented with acute left flank pain. **(a)** Axial unenhanced multidetector CT scan shows a 4-mm stone in the left distal ureter (arrow). **(b)** Coronal reformatted image shows the left distal ureteral stone (arrow), along with a 2-mm stone in the left upper pole (arrowhead) that was not seen on the axial images. Secondary signs of ureterolithiasis, including perinephric stranding and thickening of the renal fascia, are also seen.⁽⁴⁷⁾

Multidetector CT Signs

Virtually all stones are visible at unenhanced CT, including those that are radiolucent on conventional radiographs, such as uric acid, xanthine, and cystine stones⁽²¹⁾. These stones have an attenuation value (>200 HU) greater than that of the surrounding soft tissue, and multidetector CT helps accurately localize a stone within the renal pelvicaliceal system or ureter. The only stones that are difficult to visualize at CT are pure matrix stones and stones made of pure indinavir (a protease inhibitor used in the treatment of human immunodeficiency virus infection)^(45,62). These stones have soft-tissue attenuation (15–30 HU) and are likely to be missed at unenhanced CT^(62,63). However, the distinctive clinical manifestation of renal colic in a patient receiving indinavir therapy for human immunodeficiency virus infection, along with the presence of obstructive features at CT, usually helps clinch the diagnosis⁽⁶²⁾. Intravenous contrast material may be administered in equivocal circumstances, with the stones being clearly depicted as filling defects in the contrast material–filled pelvicaliceal system or ureter on delayed phase images⁽⁶³⁾.

The most direct CT sign for ureterolithiasis is a stone within the ureteral lumen, with proximal ureteral dilatation and a normal distal caliber (Fig 6)^(37, 57). Ureteral dilatation may be absent in a small number of cases of ureterolithiasis. Dalrymple et al⁽⁴⁴⁾ reported that in patients presenting with acute flank pain, ureteral stones are most likely to be lodged in the proximal (37% of cases) and distal (33%) portions, as opposed to the midureter (7%) and the ureterovesical junction (18%). The diagnosis of ureterolithiasis can be confirmed on the basis of several secondary signs at CT as well^(45,35). The most reliable signs include hydroureter, hydronephrosis, perinephric stranding, periureteral edema, and unilateral renal enlargement^(45,35). Perinephric fat stranding and dilatation of the intrarenal collecting system have a positive predictive value of 98% and a negative predictive value of 91% for the detection of ureteral calculi⁽³⁵⁾. Less reliable findings include unilateral absence of the white renal pyramid, thickening of the lateroconal fascia, and perinephric edema^(45,35). Differences in renal parenchymal attenuation between obstructed and nonobstructed kidneys have also been used as a secondary sign of obstruction^(45,35).

Ege et al ⁽³⁵⁾ reported that stones greater than 6 mm in diameter in the proximal ureter accompanied by more than five secondary signs of obstruction are more likely to necessitate intervention such as endoscopic removal or lithotripsy than are those with fewer secondary signs.

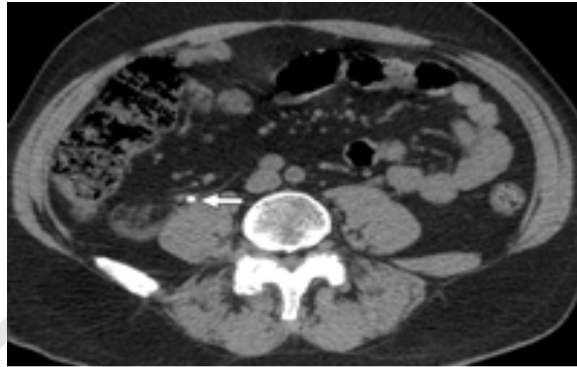


Figure (6a): Ureteral stone in a 47-year-old man with acute right flank pain. (a) Axial unenhanced multidetector CT scan shows a 5-mm midureteral calculus (arrow) with periureteral edema and stranding. (b) Coronal reformatted image shows the calculus (arrow) with proximal ureteral dilatation and periureteral stranding. (c) Axial CT scan obtained at the level of the kidneys reveals secondary signs of ureterolithiasis, including mild renal enlargement, hydronephrosis (arrow), and perinephric stranding (arrowhead). The stone was extracted ureteroscopically, and a stent was placed. ^(37, 57)

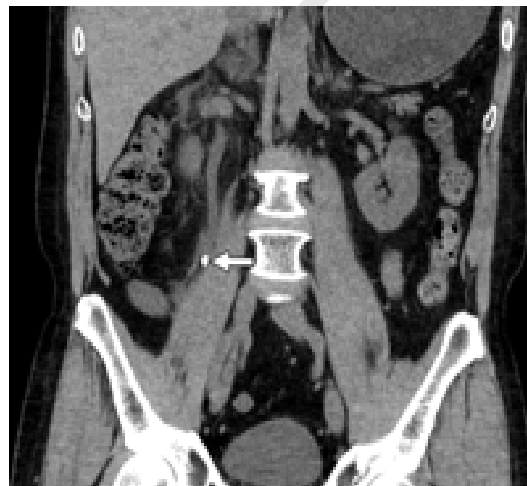


Figure (6b): Ureteral stone in a 47-year-old man with acute right flank pain. (a) Axial unenhanced multidetector CT scan shows a 5-mm midureteral calculus (arrow) with periureteral edema and stranding. (b) Coronal reformatted image shows the calculus (arrow) with proximal ureteral dilatation and periureteral stranding. (c) Axial CT scan obtained at the level of the kidneys reveals secondary signs of ureterolithiasis, including mild renal enlargement, hydronephrosis (arrow), and perinephric stranding (arrowhead). The stone was extracted ureteroscopically, and a stent was placed. ^(37, 57)

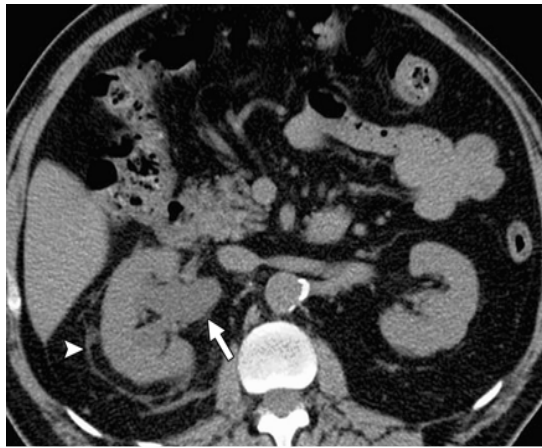


Figure (6c): Ureteral stone in a 47-year-old man with acute right flank pain. (a) Axial unenhanced multidetector CT scan shows a 5-mm midureteral calculus (arrow) with periureteral edema and stranding. (b) Coronal reformatted image shows the calculus (arrow) with proximal ureteral dilatation and periureteral stranding. (c) Axial CT scan obtained at the level of the kidneys reveals secondary signs of ureterolithiasis, including mild renal enlargement, hydronephrosis (arrow), and perinephric stranding (arrowhead). The stone was extracted ureteroscopically, and a stent was placed. ^(37, 57)

Extraordinary abdominal and pelvic calcifications such as phleboliths located in the expected course of the ureter on the symptomatic side may be mistaken for ureteral calculi. The routine use of coronal reformatted images, which allow tracking of the ureteral course, usually permits confident differentiation between calculi and other calcific processes. However, two signs, the “soft-tissue rim sign” and the “comet tail sign,” have been described for the differentiation of ureteral stones from these calcifications ^(35,64). The soft-tissue rim sign consists of a halo of soft-tissue attenuation around a calcific focus and is very specific for ureteral calculi rather than phleboliths ^(35,64). The soft-tissue rim represents the edematous wall of the ureter around the calculus and has a sensitivity of 50%–77% and a specificity of 90%–100% (Fig 7a) ^(35,64). The presence or absence of the rim is found to correlate with the size of the calculus rather than the degree of obstruction ^(35,64). The comet tail sign is created by an eccentric, tapering soft-tissue area adjacent to the calcification and is a reliable feature in the diagnosis of phleboliths (Fig 7b) ^(35,64). Another feature that is helpful in differentiation is the central lucent area seen in phleboliths, in contrast to the opacified centers seen in calculi ^(35,64). After urologic intervention, residual stones often need to be distinguished from in situ stents or nephrostomy tubes for optimal planning of follow-up. In such situations, the use of bone window settings for image interpretation often helps in making a visual distinction between stent and stone (Fig 8) ⁽⁶⁵⁾.

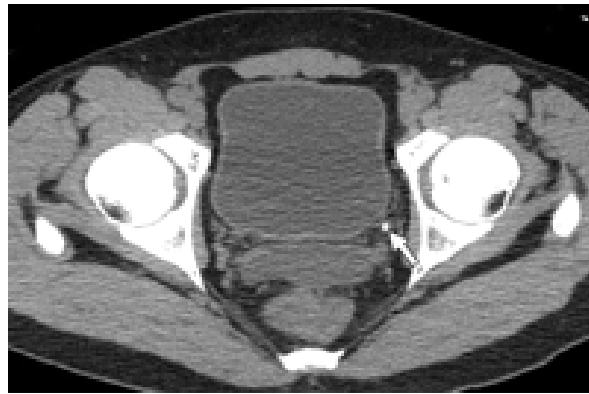


Figure (7a): (a) Soft-tissue rim sign. Axial unenhanced multidetector CT scan obtained in a 44-year-old man with acute left pelvic pain shows a distal ureteral calculus (arrow) with surrounding soft-tissue attenuation that represents edema of the ureteral wall. (b) Comet tail sign. Axial unenhanced multidetector CT scan obtained in a 49-year-old woman shows the comet tail sign, created by an eccentric tapering soft-tissue area adjacent to a calcification (arrow).^(35,64)

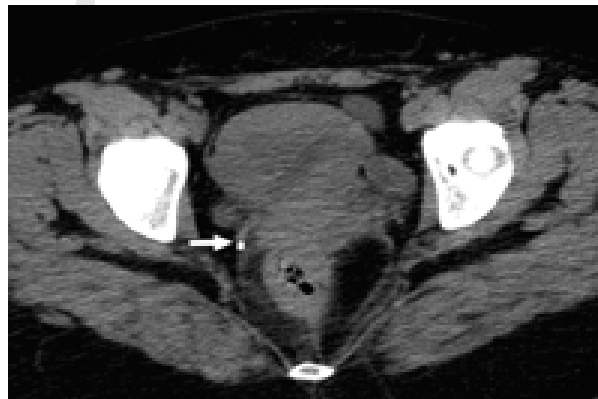


Figure (7b): (a) Soft-tissue rim sign. Axial unenhanced multidetector CT scan obtained in a 44-year-old man with acute left pelvic pain shows a distal ureteral calculus (arrow) with surrounding soft-tissue attenuation that represents edema of the ureteral wall. (b) Comet tail sign. Axial unenhanced multidetector CT scan obtained in a 49-year-old woman shows the comet tail sign, created by an eccentric tapering soft-tissue area adjacent to a calcification (arrow).^(35,64)

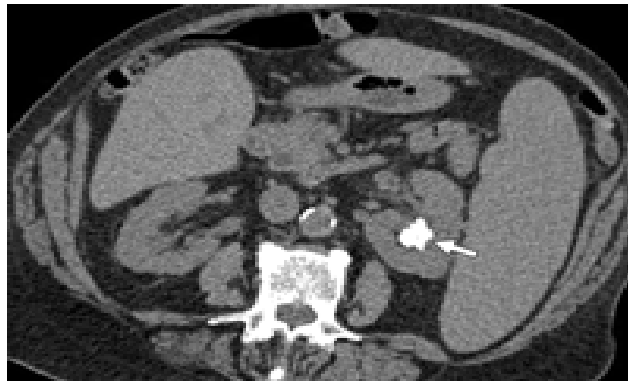


Figure (8a): Ureteral stents. (a) On an axial unenhanced multidetector CT scan (abdominal window settings [window width HU/window level HU = 400/30]), the proximal portion of a stent (arrow) is indistinguishable from ureteric stones. (b) On an axial CT scan (bone window settings [1120/300]), the stones (arrowhead) can be clearly distinguished from the stent (arrow). (c) Axial CT scan (abdominal window settings [400/30]) obtained in a different patient following ureteral stent placement shows a stent in the midureter (arrow). (d) CT scan (bone window settings [1120/300]) shows a 4-mm calculus (arrow) adjacent to but distinct from the stent (arrowhead).⁽⁵⁶⁾

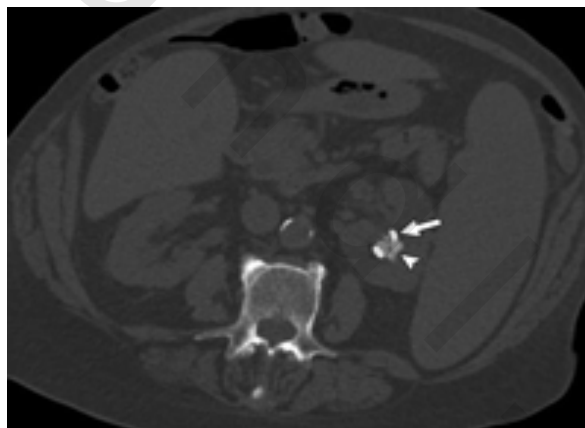


Figure (8b): Ureteral stents. (a) On an axial unenhanced multidetector CT scan (abdominal window settings [window width HU/window level HU = 400/30]), the proximal portion of a stent (arrow) is indistinguishable from ureteric stones. (b) On an axial CT scan (bone window settings [1120/300]), the stones (arrowhead) can be clearly distinguished from the stent (arrow). (c) Axial CT scan (abdominal window settings [400/30]) obtained in a different patient following ureteral stent placement shows a stent in the midureter (arrow). (d) CT scan (bone window settings [1120/300]) shows a 4-mm calculus (arrow) adjacent to but distinct from the stent (arrowhead).⁽⁵⁶⁾



Figure (8c): Ureteral stents. (a) On an axial unenhanced multidetector CT scan (abdominal window settings [window width HU/window level HU = 400/30]), the proximal portion of a stent (arrow) is indistinguishable from ureteric stones. (b) On an axial CT scan (bone window settings [1120/300]), the stones (arrowhead) can be clearly distinguished from the stent (arrow). (c) Axial CT scan (abdominal window settings [400/30]) obtained in a different patient following ureteral stent placement shows a stent in the midureter (arrow). (d) CT scan (bone window settings [1120/300]) shows a 4-mm calculus (arrow) adjacent to but distinct from the stent (arrowhead).⁽⁵⁶⁾

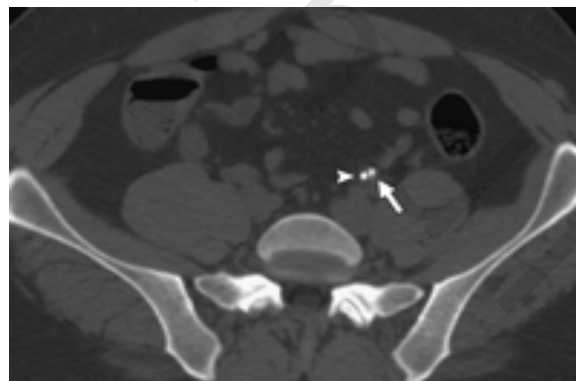


Figure (8d): Ureteral stents. (a) On an axial unenhanced multidetector CT scan (abdominal window settings [window width HU/window level HU = 400/30]), the proximal portion of a stent (arrow) is indistinguishable from ureteric stones. (b) On an axial CT scan (bone window settings [1120/300]), the stones (arrowhead) can be clearly distinguished from the stent (arrow). (c) Axial CT scan (abdominal window settings [400/30]) obtained in a different patient following ureteral stent placement shows a stent in the midureter (arrow). (d) CT scan (bone window settings [1120/300]) shows a 4-mm calculus (arrow) adjacent to but distinct from the stent (arrowhead).⁽⁵⁶⁾

Stone Burden

The size of a concrement (stone burden) can be expressed in different ways. The most common way of expressing size in the literature is to use the largest diameter, i.e. the length of the stone as measured on a plain film. The stone surface area (SA) can be estimated for most stones from the length (l) and width (w) of the stone using the following formula⁽⁶⁶⁾

$$SA = l. w. \pi. 0.25 \quad (\pi=3.14159)$$

With the more common use of cT examinations, it is possible to get an even better estimate of the stone volume (SV) by combining measures of length (l), width (w) and depth (d) using the formula⁽⁶⁶⁾

$$SV = l. w. d. \pi. 0.167 \quad (\pi=3.14159)$$

Stone burden evaluation at CT is one of the most important factors in determining treatment strategies and management in cases of urolithiasis⁽²⁸⁾. The simplest and most common method of assessing stone burden is measurement of stone size. Measurement of stone size at CT is used to plan treatment and also helps accurately predict the rate of spontaneous passage of ureteral stones, as discussed previously^(27,67). Accurate measurement of stone size is of paramount importance because it helps determine whether a patient is a candidate for medical expulsive therapy or urologic intervention, as well as what type of intervention is most appropriate (ie, SWL, ureteroscopy with lithotripsy, or PCNL)⁽²⁷⁾. The greatest dimension of the stone is measured to the closest millimeter at CT. Although measurements have historically been performed with soft-tissue window settings (400/30), a recent study showed that the most accurate way to measure urinary stones is to use bone window settings (1120/300) with magnification (power of 4–5)⁽⁶⁸⁾.

Linear measurement methods commonly used at either spiral CT or conventional radiography pose a problem in the stone burden quantification of irregularly contoured stones such as staghorn calculi⁽²⁴⁾. Measuring the stone volume eliminates this problem because it takes into account the shape and diameter (in all dimensions) of the stone⁽²⁴⁾. Various authors have used different methods to calculate stone volume and hence to estimate stone burden, such as electronically tracing the stone circumference on all stone-bearing images to generate a three-dimensional volume measurement, or using the product of three orthogonal measurements^(24,49,50). Novel semiautomatic segmentation tools can also be used to estimate stone volume. Stone volume has been shown to be valuable for preoperative planning, and it is often useful to perform both linear and volumetric measurements of stone burden^(24,49,50). In addition to being key to appropriate treatment planning, stone burden assessment can also be used to predict treatment success, particularly for procedures such as SWL^(49,50). Wang et al⁽⁴⁹⁾ showed that a stone burden of more than 700 mm³ as determined from the product of the three spatial dimensions is a significant predictor of failure for SWL.

Stone Fragility

Knowledge of the internal structure of stones is another factor that can influence outcome following SWL, and it allows the clinician to be more selective in the choice of therapy. CT can be used to visualize the internal structure of stones, which is best appreciated when viewed with bone window settings and when imaged at high resolution

with thin sections ⁽⁶⁹⁾. At CT, the internal structure can be considered to be either heterogeneous or homogeneous. Heterogeneous stones are characterized by the presence of internal low-attenuation areas (voids or dark areas), whereas homogeneous stones have a uniform internal structure (Fig 9) ⁽⁵³⁾. In vitro studies have shown that calcium oxalate monohydrate and cystine stones that appear heterogeneous at CT are more fragile than those that appear homogeneous and require less comminution with SWL ⁽⁷⁰⁾. It is believed that heterogeneity in stone composition renders a stone susceptible to fragmentation with treatment, since the irregularities in stone structure act as focal spots for shock wave energy and the stone disintegrates more easily ⁽⁷⁰⁾. Conversely, homogeneous stones tend to be more rigid and therefore harder to break, often requiring more comminution and treatment sessions ^(53,70). Indeed, some authors suggest that the internal morphologic features of a stone rather than x-ray attenuation value correlates with the fragility of stones at SWL ^(53,70).

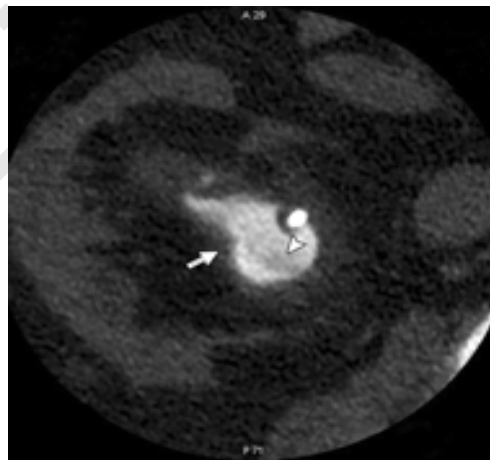


Figure (9): Staghorn calculus in a 63-year-old man. High-resolution CT scan (bone window settings [1120/300]) demonstrates internal inhomogeneities in the form of low-attenuation areas (arrowhead) within the calculus (arrow). ⁽⁵³⁾

Stone Composition

One of the key determinants of appropriate management in patients with urinary calculi is the knowledge of stone composition (Fig 3).⁽¹⁹⁾ Determination of stone composition is of particular importance because (a) uric acid stones may be treated with urinary alkalization as a first-line treatment, with surgical treatment being reserved for stones that do not respond to medical therapy; and (b) stones of certain compositions (eg, cystine stones), as well as calcium-based stones of certain attenuation, are extremely difficult to fragment with SWL ^(53,71–73). Stone composition also affects the efficacy of extracorporeal SWL. Brushite, cystine, and calcium oxalate monohydrate stones are hard and more resistant to fragmentation with SWL ^(52,74–77). Historically, the clinical tools routinely used to infer stone composition have included urine pH, urinary crystals, prior stone history, presence of urea-splitting organisms, and conventional radiography ^(73,79). Ex vivo determination of stone composition is performed with infrared spectrophotometry or x-ray crystallography. More recently, there has been an increase in the use of CT for the assessment of stone composition ^(52,73,77). Determination of stone composition can be accomplished at CT on the basis of the attenuation values of stones and with the help of dual-energy scanning.

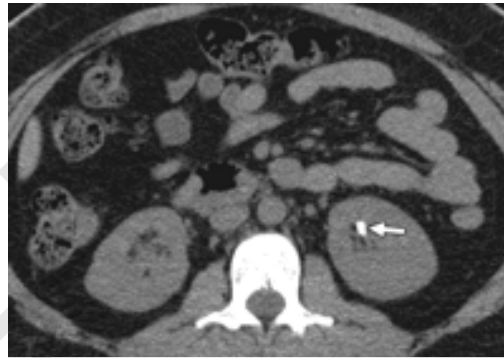
Bellin et al ⁽⁵²⁾ reported that helical CT attenuation as well as stone density can be used to predict stone composition in vitro with 64%–81% accuracy. Uric acid, cystine, calcium oxalate monohydrate, and brushite calculi have been identified in vitro with an accuracy exceeding 85% on the basis of attenuation measurements ^(52,74–76). Although the attenuation values of different types of stones (particularly struvite stones) vary among studies, CT is fairly accurate in helping predict stone composition in vitro ^(13,52,54,73,77). The attenuation values of urinary calculi at 120 kV usually fall within certain ranges: uric acid, 200–450 HU; struvite, 600–900 HU; cystine, 600–1100 HU; calcium phosphate, 1200–1600 HU; and calcium oxalate monohydrate and brushite, 1700–2800 HU ^(50,52,58,72,76).

Differentiation among stones is more complicated and less reliable in vivo. Among other factors, it is dependent on the size and accurate placement of the region of interest. Furthermore, attenuation measurement becomes more complicated in stones of mixed composition (35%–65% of stones) ^(78,79). Because stones of mixed composition, as well as struvite, cystine, and calcareous stones, have overlapping attenuation ranges in vivo, CT attenuation measurements have been most valuable in allowing differentiation of 100% uric acid stones from other stones ⁽⁵⁴⁾. CT has not been shown to reliably help differentiate other types of stones or mixed stones ⁽⁵⁵⁾. Moreover, CT attenuation measurements are affected by the section thickness, as reported by Ketelslegers and Van Beers ⁽⁸⁰⁾, who found that stone attenuation decreased with an increase in section thickness.

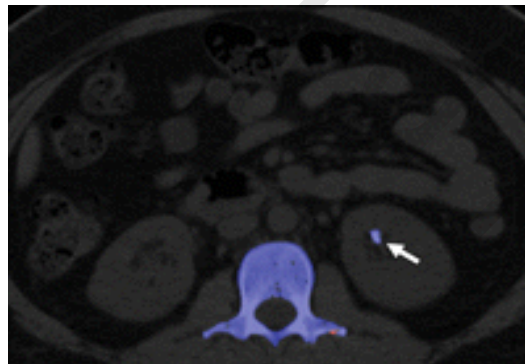
ALSO, the ability to predict stone composition, which influences patient treatment, depends on the accurate measurement of the radiographic attenuation of stones. The measured attenuation values of stones declines with stone diameter. This finding suggested that the size of the stone affects the attenuation. ⁽⁵⁸⁾

Dual-energy CT performed with either a single or a dual x-ray tube represents a unique advance in CT that shows great promise in the determination of stone composition ⁽⁸¹⁾. This technique allows such assessment in a more robust manner, overcoming the limitations of measurements in Hounsfield units. A dual-source CT system is equipped with two x-ray tubes and two corresponding 64-detector arrays mounted on a gantry at a 90° angle ⁽⁸²⁾. Dual-source CT allows concurrent scanning at two different energies (80 and 140 kVp), and the resulting data can be exploited for tissue material characterization ⁽⁵⁸⁾. Differentiation of uric acid stones from other stones at dual-energy CT is facilitated by the inherent variation in the chemical composition of uric acid stones (composed of light elements such as hydrogen, carbon, nitrogen, and oxygen) compared with other types of stones such as calcium oxalate, calcium hydroxyapatite, cystine, and struvite stones, which are made up of heavy elements (eg, phosphorus, calcium, and sulfur) ^(83–85). This difference in chemical composition accounts for the variable x-ray attenuation properties of uric acid stones and other stone types at low and high kilovolt peaks ^(83–85). The dual-energy postprocessing software algorithm exploits this difference and assumes a mixture of water, calcium, and uric acid for every voxel of the scanned tissue ^(83–85). The voxels that have dual-energy behavior similar to that of calcium are color coded in blue, whereas those whose behavior is similar to that of uric acid are color coded in red (Figs 10, 11). ^(83–85) The voxels that demonstrate linear attenuation behavior at the two different energies remain gray ^(83–85). With dual-energy CT, it is possible to differentiate between pure uric acid, mixed uric acid, and calcified stones ^(83–85). It is also possible to differentiate struvite stones from cystine stones by modifying the slope of three material

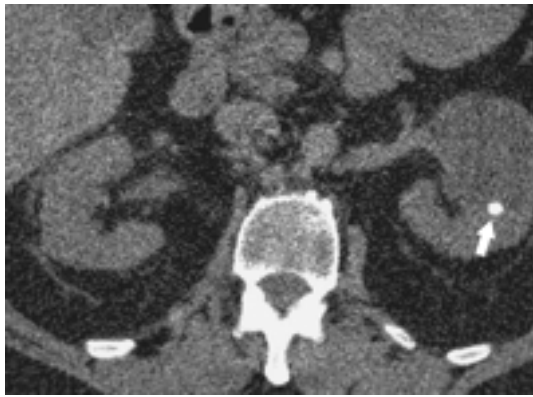
decomposition algorithms^(83–85). In a study involving a phantom model, Primak et al⁽⁸⁵⁾ demonstrated that dual-energy CT can help distinguish uric acid stones from other types of stones with 92%–100% accuracy depending on stone size and patient attenuation. Dual-energy scanning for renal stones involves initial standard unenhanced low-dose multidetector CT of the entire abdomen and pelvis using a single-source technique. Once a stone has been localized, targeted dual-energy scanning (140/80 kVp) of the anatomic region containing the stone is performed to substantially decrease the radiation exposure.



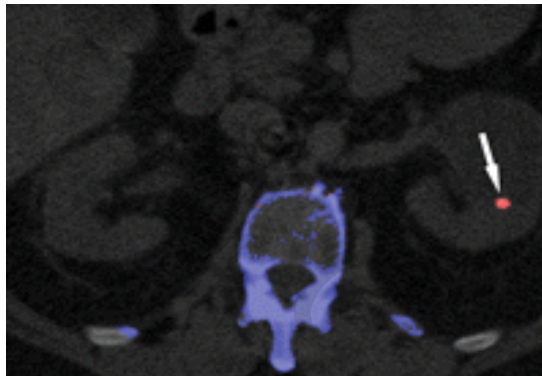
Figures (10a): Calcium-based stone in a 36-year-old man who presented with acute left flank pain. (a) Initial axial unenhanced CT scan shows a calculus in the left midpole (arrow). Dual-energy CT (140/80 kVp) was performed in the region of the stone. (b) On a color-coded postprocessed image, the calculus is shown in blue (arrow), indicating a calcium-based stone^(83–85).



Figures (10b): Calcium-based stone in a 36-year-old man who presented with acute left flank pain. (a) Initial axial unenhanced CT scan shows a calculus in the left midpole (arrow). Dual-energy CT (140/80 kVp) was performed in the region of the stone. (b) On a color-coded postprocessed image, the calculus is shown in blue (arrow), indicating a calcium-based stone^(83–85).



Figures (11a): Uric acid stone in a 46-year-old man who presented with acute left flank pain. (a) Initial axial unenhanced CT scan shows a calculus in the left midpole (arrow). Dual-energy CT (140/80 kVp) was performed in the region of the stone. (b) On a color-coded postprocessed image, the calculus is shown in red (arrow), indicating a uric acid stone ^(83–85).



Figures (11b): Uric acid stone in a 46-year-old man who presented with acute left flank pain. (a) Initial axial unenhanced CT scan shows a calculus in the left midpole (arrow). Dual-energy CT (140/80 kVp) was performed in the region of the stone. (b) On a color-coded postprocessed image, the calculus is shown in red (arrow), indicating a uric acid stone ^(83–85).

Dual-energy scanning can also be performed at single-source CT with rapid kilovolt peak switching, wherein an x-ray tube capable of rapid modulation of kilovoltage and milliamperage allows switching between low (80 kVp) and high (140 kVp) energy levels⁽⁸¹⁾. Unlike dual-source CT, with its image-based dual-energy processing, this technique features dual-energy processing of projection data⁽⁸¹⁾. In theory, this allows accurate material decomposition and monochromatic CT image display, which should potentially facilitate more precise tissue characterization and also substantially minimize imaging artifacts⁽⁸¹⁾. Indeed, initial in vitro experiments have shown reliable results in the differentiation of uric acid, cystine, struvite, and calcium oxalate stones. Stolzmann et al⁽⁸⁶⁾ reported that dual-energy CT had a sensitivity and specificity of 89% and 98%, respectively, for the detection of stones containing uric acid.

Treatment Planning

In addition to providing valuable information about stone characteristics such as size, orientation, and location, multidetector CT also aids in the presurgical planning of interventional procedures such as PCNL⁽⁸⁷⁾. One of the essential steps for successful percutaneous access is localization of the posterior calix⁽⁸⁷⁾. Although lower pole or posterior middle calix access is sufficient to attain a stone-free status for stones in the renal pelvis and inferior calix, access via the superior calix usually facilitates the removal of staghorn calculi, upper ureteral stones, and superior calciceal stones⁽⁸⁷⁾. Multidetector CT not only assists in the selection of an appropriate calix for percutaneous access, but it also helps ascertain a safe path for puncture by depicting the relationship of the kidney to various surrounding organs such as the spleen, liver, and colon⁽⁵⁹⁾. This is crucial, particularly in patients with spina bifida or severe scoliosis, in whom standard fluoroscopic guidance may be unsafe⁽⁵⁹⁾.

Stone to skin distance (SSD) as measured from the center of the stone to the skin surface on axial CT scans has been found to be a reliable predictor of stone-free status following SWL for lower pole renal stones (Fig 12)^(23,72,88). Pareek et al⁽²³⁾ found that an SSD greater than 10 cm often resulted in failure to achieve stone-free status following SWL. Therefore, they suggested that ureteroscopic intervention or PCNL be performed in patients with an SSD greater than 10 cm at CT⁽²³⁾. Although Jacobs et al⁽⁸⁹⁾ did not find conclusive evidence of the reliability of SSD, other authors have highlighted its value at axial CT^(23,72,88).



Figure (12): Measurement of SSD in a 65-year-old man with a left lower pole renal stone. On an axial unenhanced CT scan, the distance from the centre of the stone to the surface of the skin at 0°, 45°, and 90° is 6.40, 7.21, and 7.95 cm, respectively. The mean of these three values is used to represent the SSD (7.2 cm in this case)^(23,72,88).

Post treatment Evaluation

Although it is critical to accurately determine stone characteristics prior to treatment to facilitate the selection of appropriate therapeutic strategies, it is also imperative to perform follow-up imaging after treatment. The purpose of imaging following either urologic intervention or medical therapy is essentially threefold: to confirm stone-free status, to identify the presence of residual stones, and to rule out obstruction in the urinary system⁽⁵⁹⁾. The additional advantage of CT following urologic intervention lies in the detection of complications such as perirenal hematoma and urinoma⁽⁹⁰⁾.

In the conservative management of ureteral stones, it is common practice to follow up patients with conventional radiography at 1–2-week intervals⁽⁴⁵⁾. Although multidetector CT is increasingly being used in the management of urolithiasis, repeat CT may not be the best follow-up option due to radiation concerns⁽⁴⁵⁾. The choice of imaging modality for the follow-up of these patients is usually made based on the visibility of the stone on the CT scout images⁽⁴⁵⁾. If the stone is visible, conventional radiography is used for follow-up, with the CT scout images considered to be the baseline radiograph⁽⁴⁵⁾. The location and character of the stone on the scout images will help locate the stone on follow-up radiographs⁽⁴⁵⁾. If the stone is not visible on the scout images and is less than 5 mm in diameter, it is unlikely to be visible on a conventional radiograph and is likely to pass spontaneously⁽⁴⁵⁾. Stones greater than 10 mm that are not visible on the scout images probably represent uric acid or xanthine stones and usually will not be visible on conventional radiographs either⁽⁴⁵⁾. These patients need to be followed up with CT if management is conservative⁽⁴⁵⁾. However, because most of these patients undergo intervention, this is unlikely to be a cause of concern⁽⁴⁵⁾. Therefore, it seems reasonable to obtain conventional radiographs at the time of the CT study in patients with stones 5–9 mm in size⁽⁴⁵⁾. Reviewing conventional radiographs in conjunction with axial CT scans allows the expected location of the stone to be known precisely⁽⁴⁵⁾. It seems prudent to use a low-voltage technique to obtain CT scout images in patients with suspected ureterolithiasis, since this will increase stone conspicuity⁽⁴⁵⁾.

After urologic intervention, identification of residual stones is important because the recurrence rates are higher with persistent stone fragments (50%–80% of cases) than under stone-free conditions (10%–15%)⁽⁹⁰⁾. Recurrence is more likely when residual fragments persist in the presence of urinary tract anomalies or in cases of infectious stones^(87–94). CT is the preferred method for detecting residual stone fragments following PCNL and SWL, as well as for determining the need for a second-look procedure (Fig 13)^(90,95,96). CT is particularly beneficial when complete stone clearance is desired or when the stones are faint or lucent at conventional radiography⁽⁹⁷⁾. However, Osman et al⁽⁹⁷⁾ reported that CT does not yield additional information when the residual stones are opaque on KUB radiographs or scout images. CT also helps identify the location of residual fragments in relation to the nephrostomy tract, thereby facilitating retrieval of the fragments and reducing stone burden^(59,95,96). In addition, CT can alter the treatment approach on the basis of the detection of residual stones. For example, PCNL may be attempted following a failed SWL.

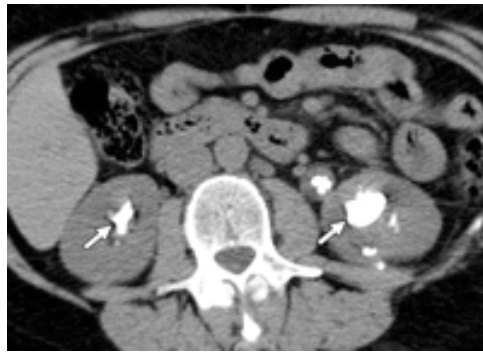


Figure (13a): Bilateral staghorn calculi in a 52-year-old man. (a) CT scan obtained prior to SWL shows bilateral staghorn calculi (arrows) with left proximal ureteral calculi. (b) Posttreatment CT scan shows several residual fragments in both renal pelves (arrows). The patient underwent PCNL for removal of the residual fragments ^(90,95,96).

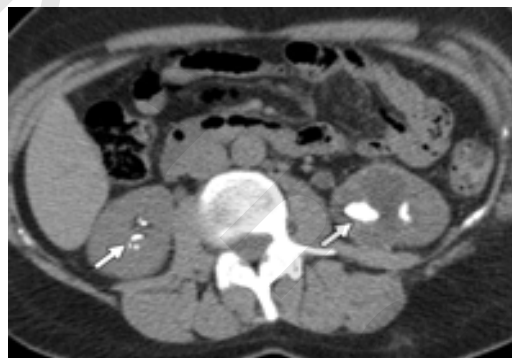


Figure (13b): Bilateral staghorn calculi in a 52-year-old man. (a) CT scan obtained prior to SWL shows bilateral staghorn calculi (arrows) with left proximal ureteral calculi. (b) Posttreatment CT scan shows several residual fragments in both renal pelves (arrows). The patient underwent PCNL for removal of the residual fragments ^(90,95,96).