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Non-contrast CT in the Evaluation of Urinary Tract

Stone Obstruction and Haematuria

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Abstract

Non-contrast computed tomography (CT) abdomen has emerged as a first line investigation in suspected upper urinary tract obstruction. Underlying causes can usually be ascertained on computed tomography of kidneys, ureters and bladder (CT KUB). However, further investigations may be required to delineate/confirm underlying pathology like ureteropelvic junction obstruction (UPJ), differentiation between obstruction and residual dilatation. Actual protocol of CT KUB for evaluation of stone disease and haematuria vary on institutional guidelines. CT KUB is not only extremely sensitive and specific in the diagnosis of stone; it is now used in the pre-operative nomograms in predicting success of various endourological interventions like percutaneous nephrolithotomy (PCNL) and shock wave lithotripsy (SWL). Determination of stone density, stone volume, stone composition, skin to stone distance, presence of ureteral wall oedema, perinephric oedema are highly predictive of stone free rate. CT recognition of various anomalies, presence of retro-renal colon, horse-shoe kidney, malrotation, etc. can help in better planning to avoid complications. One of the major limitations of CT is the radiation dose, besides cost and availability. Modification in technique and technological innovation has resulted in significant dose reduction from 4.5 to about 1 mSv.

Keywords: CT KUB, non-contrast-enhanced CT, low-dose CT, endourology, PCNL, SWL, NCCT

1. Introduction

Computed tomography of kidneys, ureters and bladder (CT KUB) is a quick non-invasive technique for diagnosis of stone disease. It was initially used in the evaluation of radiolucent stones only however, Smith et al. [1] in 1995 showed CT has superiority over intravenous urography (IVU). CT KUB subsequently became the first choice in the diagnostic imaging of urinary tract for obstruction of stones. It has replaced IVU almost completely in the last two decades [2]. It is usually considered the initial imaging modality for suspected acute renal colic and dipstick positive haematuria in an emergency setting and initial diagnostic evaluation of upper tract obstruction. CT KUB has certain clear advantages over other urinary tract imaging for stones. It is not dependent on stone chemical composition; all stones are well seen on CT except for the Indinavir stones [3], it does not require contrast, it can be rapidly performed and can be used in planning endourological treatment.

Actual protocol of CT KUB for evaluation of stone disease and haematuria will vary depending on institutional guidelines. The general parameters are (i) non-contrast examination is performed on multi-detector computed tomography scanner; (ii) supine or supine and prone patient positioning (prone has the advantage of assessing stones near the VUJ); (iii) data interpretation with the use of axial, coronal, sagittal and sometimes curved oblique images for proper evaluation; (iv) scan parameters which includes slice thickness (recommended 5 mm or less), field of view: patient size algorithm: standard technique (120 kV/Auto MA .5 rotation); Anatomical start point: 1 cm above the liver Anatomical stop through inferior pubic rami).

2. Technique/protocols

CT KUB is a quick non-invasive technique for diagnosis of stone disease. It is usually considered the initial imaging modality for suspected acute renal colic and dipstick positive haematuria in an emergency setting. Unenhanced CT is also increasingly being used for treatment planning and post-treatment surveillance for stone recurrence.

This is a study without intravenous or oral contrast, relatively low-dose (in CT terms), and has a very high sensitivity for the detection of renal and ureteric stones. CT KUB allows a rapid, contrast-free, anatomically accurate diagnosis of urolithiasis with a sensitivity of 97–98% and a specificity of 96–100%.

The effective dose of a standard CT KUB examination has been estimated to be between 3 and 5 mSv, which is up to three times that for intravenous pyelography. However, radiation dose in CT KUB is gradually decreasing with the introduction of ultra-low radiation dose CT KUB (0.5–0.7 mSv). These doses are almost comparable to plain film KUB and have shown favourable outcomes similar to standard radiation dose CT KUB. Reductions in CT dose inherently create an increase in image noise. Therefore, a balance has to be found between image quality (signal-to-noise ratio) and restraining the radiation dose.

In comparison to conventional CT, spiral CT is significantly faster. It thus allows acquisition of a complete data set in a single breath-hold and prevents the misregistration of slice location

that is typical of conventional CT. In addition, multi-slice spiral CT reduces the time needed for image acquisition, allowing for thinner slice collimation and retrospective reconstruction of thin slices to review challenging areas of analysis.

From the top of the kidneys through the base of the bladder (mid-liver [T-12] through symphysis pubis), data acquisition is uninterrupted using a maximum of 5-mm collimation with table speed of 5 mm/s. Slice collimation with multi-slice CT is usually 2.5–3 mm with table speed up to 5 mm/s.

Multislice technique allows slices as thin as 1 mm to be obtained for problem solving. The thinner slices can be viewed retrospectively without rescanning the patient. Thin slices enable identification of extremely small sized calculi that may be overlooked if the slices are thicker.

Turning the patient to a prone position permits differentiation of stones impacted at the ureterovesical junction from stones that have already passed into the bladder.

Actual protocol of CT KUB for evaluation of stone disease and haematuria will vary depending upon institutional guidelines but following are the general parameters:

- Non-contrast examination is performed on multi-detector computed tomography scanner.
- Supine or prone patient positioning. Prone has the advantage of assessing stones near the VUJ. Some institutions may perform a limited pelvic scan in prone if the supine scan shows a calculus near the VUJ.
- Data interpretation with the use of axial, coronal, sagittal and sometimes curved oblique images for proper evaluation.

Scan parameters:

- Slice thickness: 5 mm
- Field of view: patient size
- Algorithm: standard
- Technique: 120 kV/Auto MA .5 rotation
- Anatomical start: 1 cm above the liver
- Anatomical stop: through inferior pubic rami
- Filming/windowing: soft-tissue window with 3 mm coronal and sagittal reconstructions.

Dual-energy CT scanning is a new technique that can more correctly distinguish different stone types. It involves acquiring CT data at two different X-ray energies (80 and 140 peak kilovoltage [kVp]). Post-processing software can make use of the different attenuation properties of calculi of various chemical compositions at low and high X-ray energies.

Decreased exposure is most commonly achieved by modifying tube current and applying new image reconstruction algorithms. Low-dose CT has been shown to maintain diagnostic accuracy compared with standard-dose CT, even in overweight and obese patients when using automated tube current modulation.

2.1. Indication and uses of CT KUB

A clinical decision to order CT KUB has to be made in two different clinical presentations. First is a patient with flank pain presenting in emergency department. The classic clinical presentation of a young man writhing in pain is usually distinctive. However, atypical presentations are not uncommon. CT KUB is still reasonable first-line investigation for all patients presenting in emergency with flank pain as it increases diagnostic accuracy in atypical cases and can detect other pathologies. In a study of 1500 consecutive CT examinations in patients with flank pain, 14% had CT findings other than stone requiring immediate or deferred treatment [4]. Although this diagnostic superiority of CT KUB for flank pain is well established, recent studies have questioned whether it influences management decision in emergency setting. A multicentre, randomised controlled trial of carefully selected patients with suspected nephrolithiasis compared ultrasound with CT KUB and concluded that initial ultrasound decreases cumulative radiation exposure by obviating need of CT in some patients without significant difference in missing high-risk diagnoses, serious adverse events and re-admissions [5].

In a clinical setting, the choice of CT KUB versus ultrasound for initial diagnostic imaging in patients with flank pain should be individualised. Patients who are obese, clearly sick or have associated gross/microscopic haematuria are more likely to benefit from CT scan. On the other hand, children, pregnant women and those assessed to have musculoskeletal pain clinically are more appropriate for ultrasound first approach. Available local resources, for example, expert sonologist should also be taken into account when making this decision.

3. Evaluation of obstruction

Second clinical setting requiring CT KUB is incidental finding of hydronephrosis on ultrasound. The decision to request CT KUB will depend on information available on ultrasound and suspected cause of underlying obstruction. In some cases, ultrasound will provide sufficient information to decide further management. For instance, in classic ureteropelvic junction obstruction (UPJO) in a child, ultrasound alone would provide enough anatomical detail to proceed for radionuclide imaging. Similarly small ureterovesical junction stone seen clearly on ultrasound combined with clinical picture is usually sufficient to proceed for management decision. CT KUB is suitable if renal or ureteric stones are suspected as underlying cause of hydronephrosis or a benign pathology, for example, ureteric stricture/retroperitoneal fibrosis is presumed after history and examination. If an upper tract tumour or extrinsic malignant obstruction is suspected, a contrast-enhanced study is more appropriate.

Upper tract obstruction may lead to derangement in renal function and it is not uncommon to find raised creatinine in such patients especially if obstruction is bilateral. European Society of Urogenital Radiology recommends that an estimated glomerular filtration rate (eGFR) of less than 45 ml/min/1.73 m² particularly with other risk factors, for example, diabetic nephropathy and dehydration increases the risk of contrast-induced nephropathy (CIN) [6]. This effectively precludes contrast-enhanced study in such patients. CT KUB is helpful in excluding calculi

and may even provide a definitive diagnosis in up to 40% cases of non-calculus obstruction [7]. MR urography will be required for making a definitive diagnosis in remaining cases.

CT KUB is currently considered as the first line imaging in the evaluation of stone and obstruction (**Figure 1**) and is preferred over an IVU [2]. This is in view of high sensitivity and specificity of CT over other imaging modalities. It is particularly useful in the diagnosis of ureteral stones (**Figures 1** and **2**) with sensitivity of 95–98% and specificity of 96–98% [8, 9]. It is of particular value in patients with renal failure, which precludes use of intravenous contrast, and ultrasound has limited value [10]. The sensitivity of ultrasound in the evaluation

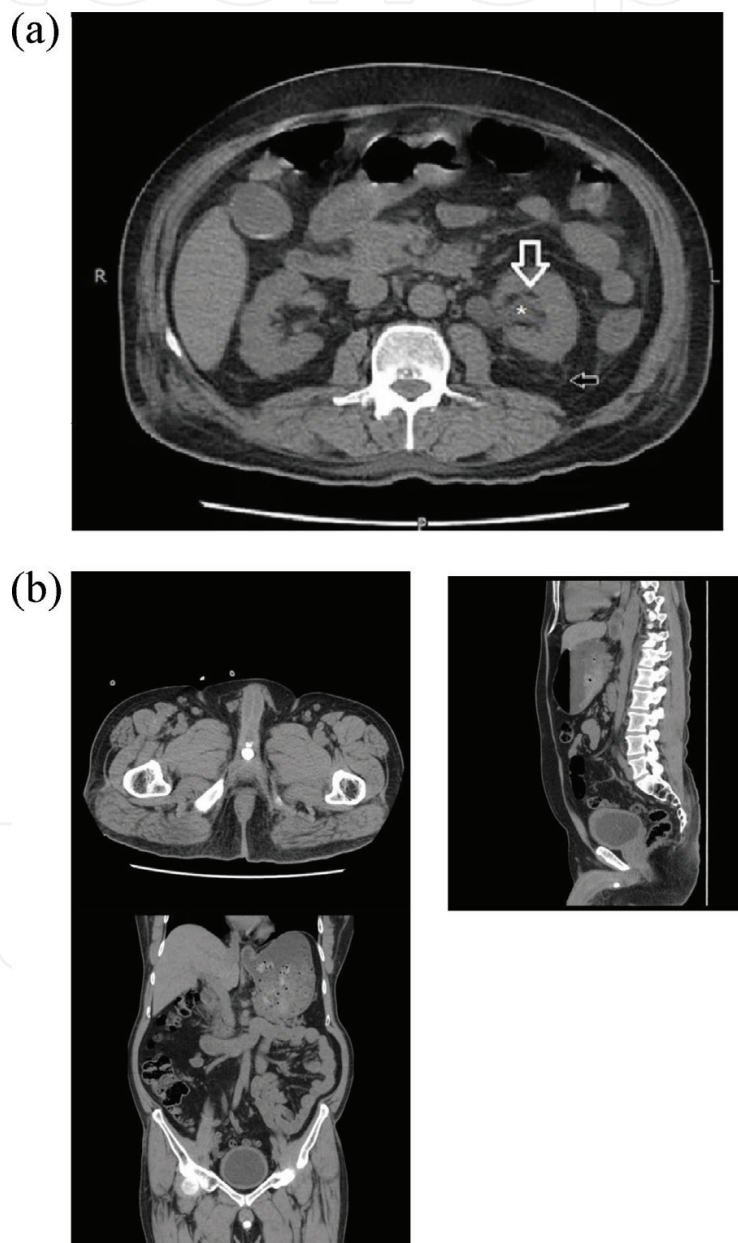


Figure 1. (a) Hydronephrosis (asterik), reduced peripelvic fat (white arrow) and increased perinephric fat stranding (black arrow) as compared to contralateral side and (b). CT KUB axial, sagittal and coronal sections demonstrating multiple calcific densities near the bulbar urethra likely representing urethral diverticulum with stone formation.

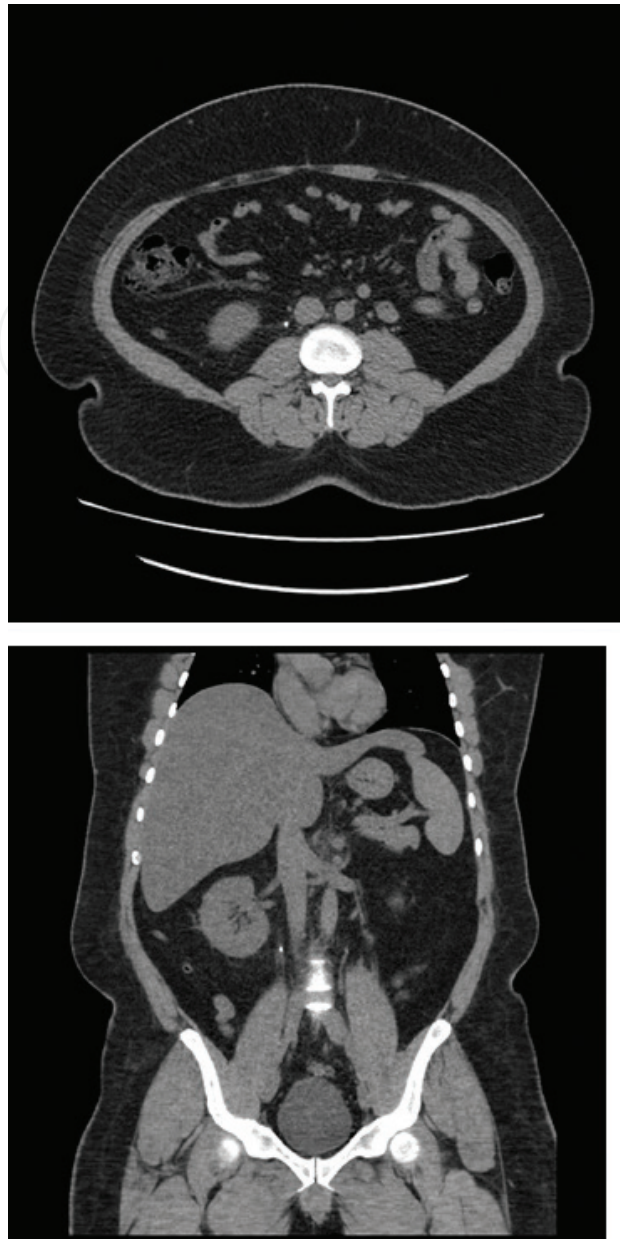


Figure 2. CT KUB axial and coronal sections demonstrating an obstructing right proximal ureteric calculus.

of ureteral stones when compared with CT KUB is only 46% and for hydroureter in half of the cases. CT KUB in the evaluation of ureteral stones is able to identify ureteral dilation in 83%, hydronephrosis in 80% and perinephric oedema in 59%, and ipsilateral nephromegaly in 57.2% of cases [11].

4. Evaluation of haematuria

In addition to diagnosis of stone and obstruction, it is also used in the work up haematuria. Asymptomatic micro-haematuria (AMH) is relatively common and is often not associated

with urinary tract malignancies. The current guidelines indicate evaluation of upper urinary tract with contrast-enhanced CT (CECT). This often leads to identification of extra-urinary tract abnormalities. The diagnoses of such conditions often require extensive work for most conditions, which are inconsequential [12]. These are often observed on non-contrast CT imaging as well [13]. In vast majority of cases, ASH is idiopathic followed small renal stones (**Figure 3**) and other benign causes. Ultrasound is often the initial imaging, however, CT KUB can be used in lieu.



Figure 3. CT KUB axial and coronal sections demonstrating a left renal pelvis calculus (a and b) and left distal ureteric calculus (c).

4.1. In emergency room setting

Acute onset flank pain suggestive of ureteral obstruction is a common presentation in the emergency room (ER) setting. Introduction of CT has decreased the time in decision-making [14] about the possible aetiology of cause of flank pain [15, 16]. Clinical evaluation and ultrasound often makes it difficult to differentiate ureteral obstruction from other pathologies. However, CT not only quickly identifies urolithiasis but also identifies other causes of flank pain [17]. This includes both genitourinary and extra-genitourinary abnormalities. Stones from ureter-vesical junction sometimes pass into the urethra (**Figure 4**) without significant changes in symptoms, these can be diagnosed by careful inspection of the CT.

Initial clinical evaluation including dipstick test for micro-haematuria also lack sensitivity. Li et al. [18] noted during the period of 4 years that there were 159,083 emergency visits. During this period, 397 had urolithiasis, in these patients absence of haematuria was noted in 9% (95% confidence interval 7–12%). The next step in the management of patients with stone

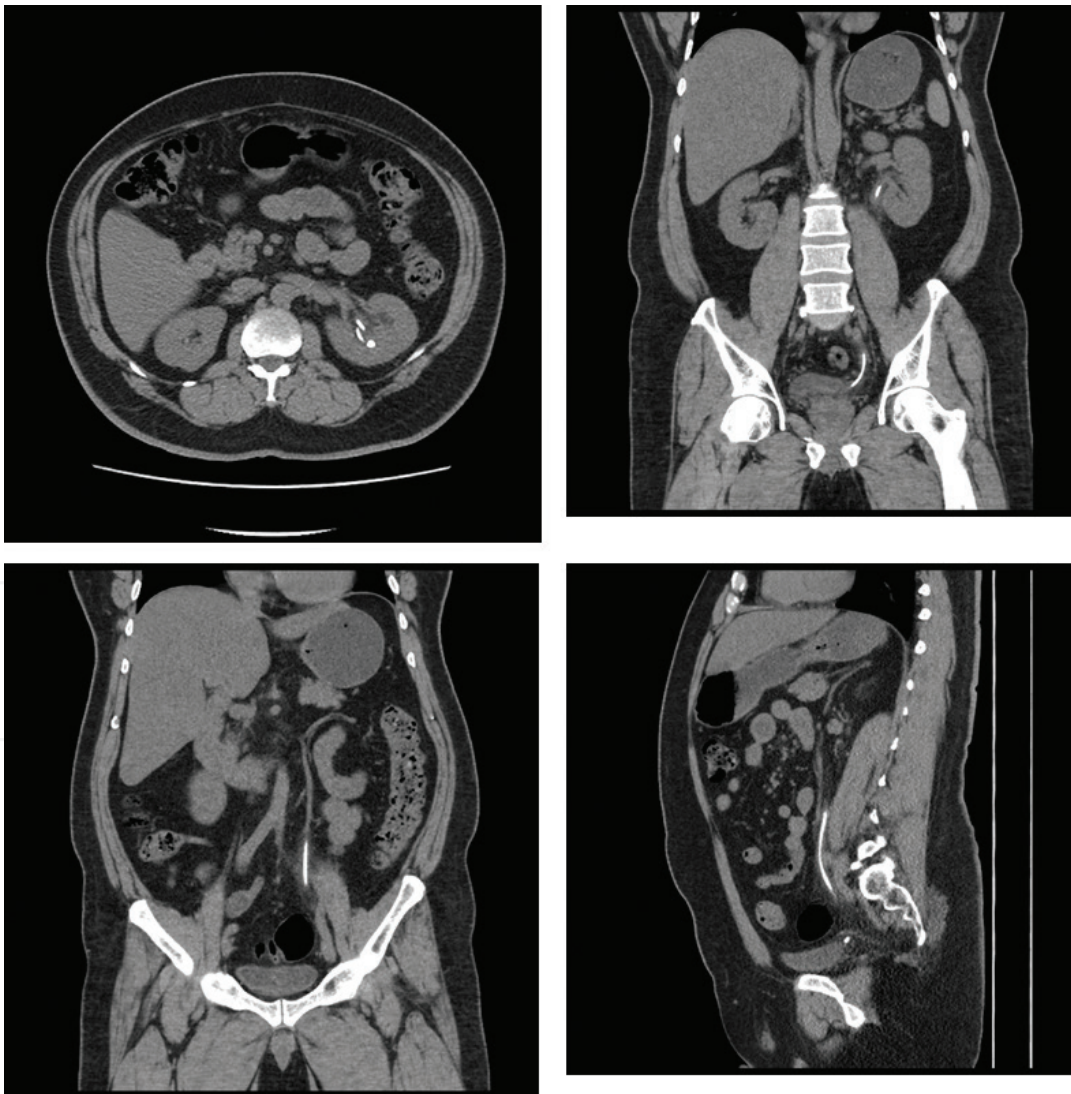


Figure 4. CT KUB axial, coronal and sagittal sections demonstrating a calculus in the prostatic urethra.

is to determine the extent of obstruction and of any complications from obstruction and stone. None of the conventional imaging, that is, IVU, ultrasound and plain X-ray KUB is sensitive enough to answer the question. CT KUB due to its high specificity and sensitivity to diagnose ureteral stones is ideal imaging in such a situation. However, CT without contrast has limitations being a non-contrast study. Secondary signs of obstruction like perinephric, periureteral stranding and unilateral nephromegaly are sometimes helpful. Bird et al. [19] in a study assess the significance of secondary signs of obstruction on CT KUB and noted that they do not correlate with degrees of obstruction on MAG-3. The authors suggested use of CT KUB in combination with radioisotope scans [9]. This is cumbersome particularly in an emergency room setting. As an alternate, Kravchick et al. [20] suggested the use of dynamic renal sonography in combination with CT KUB, particularly in patients with raised white cell count and stone larger than 4 mm. This is particularly useful in triaging patients who need admission in the hospital.

4.2. In elective clinical situation

Modern endourological interventions are becoming increasingly minimally invasive. Percutaneous nephrolithotomy is performed with 24–30 Fr. Amplatz; however, finer nephroscope has led to the introduction of mini (2001), micro (2011) and ultra mini (2013) [21]. Planning for these interventions require precise pre-operative assessment of stone size, location and anatomical abnormalities including caliceal narrowing, presence of caliceal diverticulum, etc. CT can be instrumental in making pre-operative assessment. It has been seen that increasing stone volume can influence post-operative complication rate. It is being observed that >4 cm stones are associated with significantly higher rate of post-operative pyrexia and need for transfusion [13].

4.3. Radiological signs of urinary obstruction

4.3.1. CT beyond the diagnosis of stone

The sensitivity and specificity of CT in the diagnosis of stone is well established. Even small stones, which would otherwise be missed on most other imaging, can be identified on CT. However, CT has utility beyond recognising the presence of stone in the urinary tract. It can be used in planning endourological interventions. Stone size, composition, location, skin to stone distance, etc. are some of the well recognised parameters used in the risk stratification and predicting success of treatment [22].

Shock wave lithotripsy (SWL) is the most minimally invasive treatment in the management of urolithiasis. Prediction of success for renal stones is often done on a CT KUB using estimation of stone volume, density (using Hounsfield Units) and skin to stone distance [23]. In a recent work, Park et al. [24] noted that BMI and perinephric oedema in addition to stone density are independent predictors of success of SWL. Ureteral stones requiring interventional treatment are either treated by SWL or ureteroscopy. Success of ureteral stone is dependent on stone size [25]. The success of treatment is assessed not only by stone free rate but also need for ancillary treatment and number of sessions required to clear the stone [26]. One important factor responsible for failed medical SWL for ureteral stone is stone impaction,

defined as stone stuck in one location for over 1 month. Sarica et al. [27] recently noted that of all the evaluated stone- and patient-related factors, only ureteral wall thickness at the impacted stone site independently predicted shock wave lithotripsy success.

Stone size is one of the most important parameter in deciding the management of ureteral stone. In a recent work, Soomro et al. [28] compared the mean stone size, as measured on bone window versus standard soft-tissue window setting using multi-detector computed tomography (MDCT) in patients with a solitary ureteric stone. They noted that the stone size measured using the soft-tissue window setting on a MDCT is significantly different from the measurement on the bone windows. Earlier work also indicated that the transverse stone diameter on axial images of CT KUB underestimates the size of ureteric stone [29]. The authors suggested that coronal reformatted images be used for size estimation.

Percutaneous nephrolithotomy (PCNL) is a minimally invasive treatment modality used in the management of >20 mm kidney stones, and as such, is considered as the primary modality by EAU and AUA guidelines [30, 31]. Predicting complications and success of percutaneous surgery for urolithiasis can now be reliably done using one of the several nephrolithometry scores [22]. Nephrolithometry scoring systems are based on pre-operative stone and patient features and they demonstrate and stratify relationships between kidney's anatomy and stones. Currently there are three scoring systems; Guy's score [32] described in 2011, S.T.O.N.E. nephrolithometry system [33] and CROES nephrolithometry nomogram [34] in 2013. In a recent work by Choi et al. comparing these three scoring systems for tubeless PCNL, noted that Guy's stone score was the only significant predictive factor for stone free and complication rates. However, Tailly et al. [35] earlier noted no difference in the ability to predict stone free rate comparing the three scoring systems after PCNL.

PCNL is safe surgical procedure and is not associated with high grade on Clavien grading. The most frequently reported complication following PCNL is infection and haemorrhage, however one of the most devastating complication is a surrounding organ injury including bowel injury. According to the Clavien-Dindo classification of surgical complications, colonic injury is regarded as a stage IVa complication. The incidence of colon injury is reported to be 0.3–0.5%, however in a large recently reported series, AslZare et al. [36] noted 11 cases in 5260 cases of PCNL. Colonic injuries are seen in patients with retro-renal colon, the prevalence of retro-renal colon in males to be 13.6% on the right and 11.9% on the left, whilst in females it was 13.4% on the right and 26.2% on the left [37]. CT KUB is instrumental in recognising retro-renal colon prior to PCNL. Most of the colonic injuries are now managed conservatively with drainage of colon via percutaneous drain, insertion of JJ stent to drain kidney, intravenous antibiotics and bowel rest by giving intravenous nutrition.

4.4. Features of upper tract obstruction

Once a CT KUB abdomen is ordered for suspected upper tract obstruction, it should be reviewed for secondary radiological signs of obstruction, site of obstruction and underlying pathology. Moreover, associated findings, for example, dilated appendix, ovarian cysts, spinal pathologies should be considered and systematically reviewed.

Classic secondary radiological signs on CT KUB suggesting upper tract obstruction include: dilatation of renal pelvis, dilated ureter and perinephric stranding (**Figure 1a** and **b**). Renal pelvis is identifiable as area of low attenuation compared to adjacent renal parenchyma. Dilatation of renal pelvis (hydronephrosis) usually appears as anterior and medial bulging of this low attenuation structure. In some cases, dilated renal pelvis may be difficult to differentiate from a prominent extra renal pelvis. However, dilated calices that obliterate the renal sinus fat help in making this differentiation. CT is also valuable in differentiating between stone and stent (**Figure 5**), particularly with the use of bone windows.

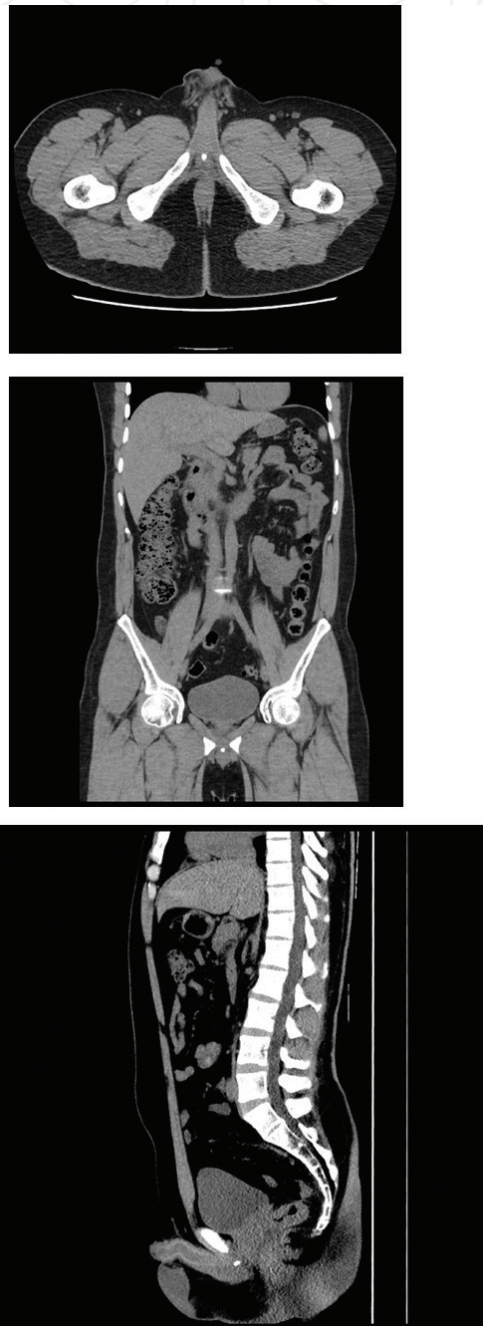


Figure 5. CT KUB axial, coronal and sagittal sections demonstrating a left-sided double J stent in place.

An assessment of degree of obstruction can also be made on CT KUB (**Table 1**). The Society of Foetal Ultrasound first described the grading system for hydronephrosis [38]. Similar description has also been applied to other imaging modalities like intravenous urography and CT [39].

Dilatation of ureter when present should be traced down to the site of obstruction, to differentiate between phloolith and stone (**Figure 6**). The dilated ureter is usually traceable from

Grade	Degree	Description
Grade 0		No dilation caliceal walls opposed to each other
Grade 1	Mild	Dilation of renal pelvis without dilation of the calyces
Grade 2	Mild	Dilation of renal pelvis and calyces, no cortical thinning
Grade 3	Moderate	Dilation of the renal pelvis and calices with blunting of papillary impression with or without cortical thinning
Grade 4	Severe	Gross dilation of the renal pelvis and calices with associated cortical thinning

Table 1. Degree and grade of hydronephrosis and its description.

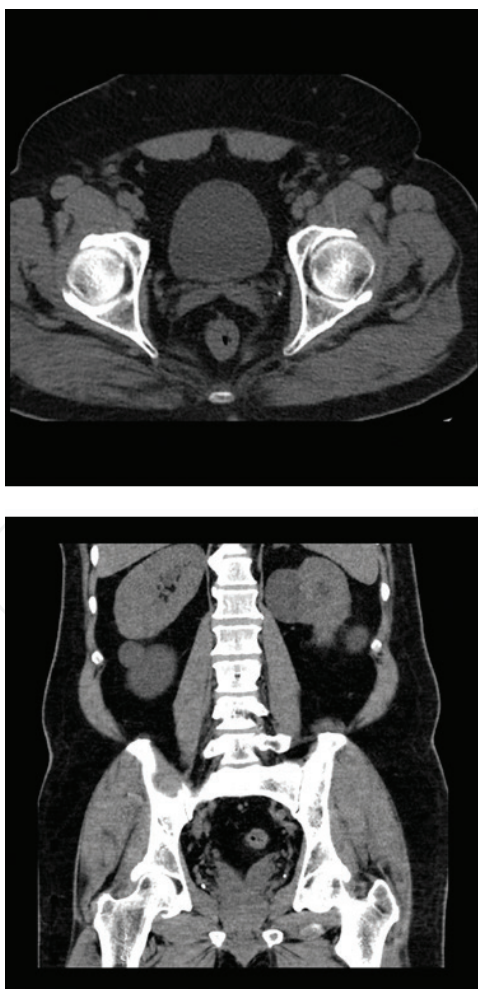


Figure 6. CT KUB axial and coronal sections demonstrating stones in the pelvis.

ureteropelvic junction when viewing coronal sections at a workstation. However, combining information from both axial and coronal images may be needed, especially for the lower ureter obscured by bowel loops or iliac vessels (**Figure 6**). Curved planar re-formatted images have been utilised to provide images mimicking a contrast-enhanced study and improve diagnostic yield for ureteric lesions [40]. UVJ stones could be differentiated from vesical stones by prone CT of the bladder area (**Figure 7**).

Once tracing the dilatation of ureter identifies site of obstruction, it should be reviewed for intraluminal, luminal or extra luminal obstructing lesions. Intraluminal pathologies include stones, blood clot and papilla. Fortunately the most common obstructing lesion, that is, stone is almost always CT dense and easily identifiable. In the absence of obstructing stone and positive radiological signs of obstruction, one should consider differential diagnosis of passed

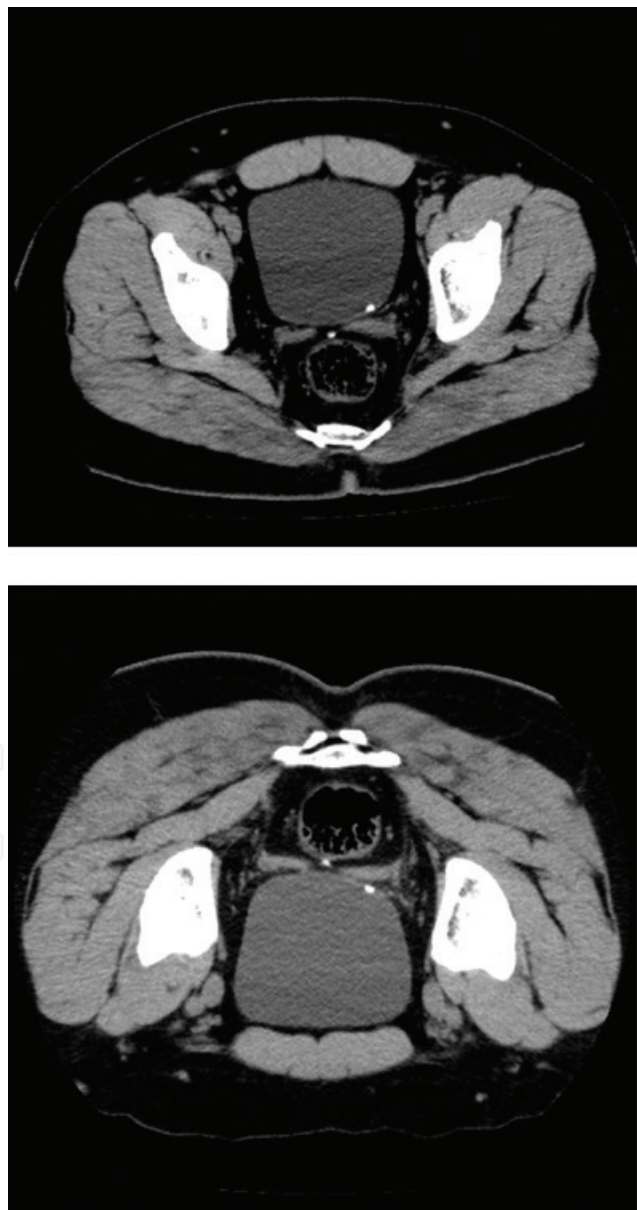


Figure 7. CT KUB axial supine and prone positions demonstrating a left-sided VUJ calculus.

stone, pyelonephritis or obstruction caused by lesion not visible on CT KUB. Such lesions include blood clot, papilla and Indinavir stone. Reviewing clinical picture can narrow these differentials. For instance, Indinavir stone occurs only in patients treated with this protease inhibitor for HIV and papillary necrosis is more common in diabetic patients with analgesic nephropathy.

Presence of ureteric thickening or narrowing at the site of obstruction is suggestive of ureteric stricture. Differentiating benign from malignant strictures would require a contrast-enhanced study or endoscopy. Extramural lesions causing obstruction include pelvic tumour, retroperitoneal mass and retroperitoneal fibrosis. Retroperitoneal fibrosis is classically seen as irregular, well-defined iso-dense mass surrounding aortic bifurcation. It usually follows the common iliac arteries and expands laterally to trap ureters. Differentiation from retroperitoneal malignancies may be difficult even after contrast-enhanced study. Enhancement after contrast administration is variable and depends on degree of metabolic activity and on-going fibrosis. Presence of bone destruction and displacement of major vessels will be suggestive of malignant process [41].

4.5. Limitations of CT KUB in diagnosis

Limitations of CT KUB include the fact that CT has limited spatial resolution. Therefore, its negative predictive value in completely excluding sub-millimetre calculi and small stone fragments is significantly less than its negative predictive value in excluding larger calculi (>4 mm). In addition, repeated use of CT in patients with recurrent urolithiasis can result in a substantial cumulative dose.

Details of pelvicalyceal anatomy may not be apparent on non-contrast-enhanced study. Intravenous urography or CT urography may be required if specific anatomical details are needed for making a management decision, for example, bifid system, stone in a calyceal diverticulum or narrow lower pole infundibulum.

CT KUB is a static study and the abnormalities related to urinary dynamics, that is, UPJ obstruction, obstructive versus residual dilatation of the collecting system, etc. cannot be appreciated. Complementing CT KUB with either MAG3 scan or dynamic Doppler ultrasound are some of the modifications recommended.

The other major limitation of the CT KUB is the risk of radiation exposure. Dose reduction by various technical modifications has been recommended [42]. In a systematic review, Xiang et al. [43] noted that lowering the dose of radiation of CT does not negatively impact the sensitivity and specificity in the diagnosis of stone and obstruction. They noted that low dose CT KUB has a cumulative sensitivity of 93% and specificity of about 97% [19].

In a meta-analysis reported by Niemann and colleagues [44] some 9 years back, they noted that dose reduction attempts resulted in mean dose of less than 3 mSv without jeopardizing the pooled sensitivity (97%) and specificity (95%). However in the last decade, there has been significant interval improvement with iterative reconstruction techniques, detector series and arrangements. These modifications have allowed a further reduction in dose to <1 mSv [45]. This is quite comparable to plain X-ray KUB at 0.7 mSv [46].

5. Conclusions

Non-contrast CT abdomen has emerged as first line investigation in suspected upper tract obstruction. Underlying cause can usually be ascertained on CT KUB. However, further investigations may be required to delineate/confirm underlying pathology like UPJ obstruction, differentiation between obstruction and residual dilatation, etc. CT KUB is not only extremely sensitive and specific in the diagnosis of stone; it is now used in the pre-operative nomograms in predicting success of various endourological interventions like PCNL and SWL. Determination of stone density, stone volume, stone composition, skin to stone distance, presence of ureteral wall oedema, perinephric oedema are highly predictive of stone free rate. CT recognition of various anomalies, presence of retro-renal colon, horse-shoe kidney, malrotation, etc. can help in better planning to avoid complication. One of the major limitations of CT is the radiation dose. Modification in technique and technological innovation has resulted in significant dose reduction from 4.5 mSV to about 1 mSv.

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