Imaging In Urology

Imaging investigations play a vital role in the management of patients with kidney stones. The techniques available include plain x-ray of the abdomen, ultrasound scan, intravenous urogram, computed tomography (CT) and magnetic resonance imaging, amongst others. All of these techniques have their own individual roles to play and also have limitations. CT has been establishing itself as the imaging technique of choice and some exciting developments are on the way ***(smith et al., 2000)***.

Goals Of Imaging:

The primary goal of imaging in urolithiasis is the detection of all urinary stones in urinary tract, other goals include stone characterization, surveillance of stone evolutionor migration, guidance and monitoring of therapy, such lithotripsy, diagnosis of underlying anatomic variants predisposing to stone formation, such as atrophy, pyonephrosis and pyelonephrosis, evaluation of the opposite kidney and collecting system, and detection of other conditions that may present with flank pain and mimic renal colic such as appendicitis or diverticulitis. As all imaging techniques have some limitations or may be contra-indication in certain patients, a combination of examinations is often necessary ***(Smith and varanelli, 2000).***

Plain x-ray of the kidney, ureter and bladder:

In the past the frist imaging study requested in patiens with acute flank pain was frequently a plan radiograph(also known as a conventional abdominal film, abdominal flat plate, or KUB; the latters refer to inclusion of kidneys, ureters and bladder in the field of view).Detectability of stones on conventional radiographs depends on size and composition as well as factors relating to technique, patient body habitus and over lying structures, such as bowel contents ***(Thoranbury et al, 1982).***

The great majority of stones is composed, at least in part, of calcium-containing salts and should be visible on plane film (radioopaque or faint radio-opaque), the exceptions to these roles are radiolucent stones (i.e. those with a predominant uric acid or matrix component) or those composed of the antiretroviral drugs in dinavir and ataznavir ***(Sandhu et al., 2007).***

In practice, the plan radiograph is limited in the evaluation of renal colic because multiple radio-densities can mimic stones (e.g., gall stone, costocondral calcifications, bone islands, and fecal densities) and stones may be easily missed (e.g., radioluecent stones, and stones obscured by bowel contact or bone).Bowel preparation has been traditionally thought to improved detection of stones, but a recent randomized study failed to confirm these hypothesis ***(Schuster et al., 1995)***.

The reported sensitivity and specificity of plan abdominal radiography in the detection of calculi in patients with acute renal colic and no history of urolithiasis is limited (45% - 58% and 60% - 77%, respectively there for, as a primary diagnostic method, KUB alone is not sufficiently reliable in diagnosing calculi in this subset of patients ***(Shokeir et al., 2002).***

But, the plan radiograph remain useful in the planning and the guidance of shock-wave lithotripsy (SWL) and in monitoring the progress of stone treated conservatively or stone fragments after lithotripsy, provided the stone can be seen on plan radiographs and has been confirmed by CT ***(Jessica et al., 2011).***

In some centers, digital radiographs (DR) and computed radiographs (CR), including CT scout radiographs, serve as an alternative to conventional film screen-based radiograph for stone detection and follow up. The scout radiograph, obtained at the time of a diagnostic CT, may be used as baseline study in those patients to be followed with plan radiographs and may help predicting the success of radiographs for monitoring the progress of stone passage and whether stone opacity is adequate to allow radiographic or fluoroscopic guidance of lithotripy planning ***(Chu et al., 1999).***

Digital scout radiographs may also help in predict stone composition, as a large stone seen in CT but not evident on the scout view likely contains little calcium and a high concentration of uric acid or xanthine ***(Chu et al., 1999).***

Intravenous urogram:

There are some who argue that in this modern era, intravenous urogram (IVU) is an out-dated investigation and has no place in the management of renal stones. The reasons given for this are: (1) it is time consuming, (2) even with modern non-ionic contrast media, there is still a small risk of severe allergic reaction, (3) there is a serious risk of metabolic disturbance if given inadvertently to patients taking metformin, (4) there is a high radiation dose when compared to ultrasound (US) scan or magnetic resonance imaging (MRI), (5) it is a poor test to assess individual renal function (when compared to an isotope renogram), and (6) the anatomical details seen are poor***(Pfister et al., 2003)***.

Despite the above criticisms, IVU is still useful for confirming and determining the location of calculi within the collecting system, and for the preliminary planning of treatment, as it provides important information such as anatomy of the collecting system, anatomical abnormalities, infundibulo-pelvic angle in case of lower pole calculi and for assessing the length and diameter of the infundibula of the calyces ***(Elbahnasy et al., 1998).***

Ultrasound:

A wave frequency of 1 cycle/s (cps) is called a hertz (Hz). Sound frequencies greater than 20 kHz are beyond the range of human hearing and are called ultrasound. Medical sonography uses ultrasound to produce images. The frequencies commonly used in medical sonography are between 3.5 and 15 MHz. ***(Mallek et al., 1996).***

Ultrasound waves for imaging are generated by transducers, devices that convert electrical energy to sound energy and vice versa. These transducers are special piezoelectric crystals that emit ultrasonic waves when they are deformed by an electrical voltage and, conversely, generate an electrical potential when struck by reflected sound waves. Thus, they act as both sonic transmitters and detectors. In general concept, medical sonography resembles naval submarine sonar. ***(Mallek et al., 1996).***

Ultrasound images are reflection images formed when part of the sound that was emitted by the transducer bounces back from tissue interfaces to the transducer. The sound reflected by stationary tissues forms the data set for anatomic gray-scale images. The sound reflected by moving structures (eg, flowing blood in a vessel) has an altered frequency due to the Doppler effect. By determining the Doppler shift, vascular flow direction and velocity can be encoded graphically (spectral Doppler) or by color (color Doppler). ***(Mallek et al., 1996).***

A more sensitive method of detecting flow, called power mode Doppler, is available on modern equipment. This technique displays the integrated power of the Doppler signal rather than the mean Doppler frequency shift. Direction or velocity of flow is not displayed in the power mode. ***(Fowler et al., 2002).***

Reflected sound received by the transducer is converted into electrical signals that are analyzed by computer algorithms, and rapidly converted into video images viewed directly on a real-time display. Images are rapidly updated on the display, giving an integrated cross-sectional anatomic depiction of the site studied. Individual frames may be frozen during an examination for motion-free analysis and recording, or continuous images may be recorded as digital or conventional video. ***(Rodgers et al., 1992).***

Clinical Applications:

Ultrasound is commonly used for the evaluation of the kidney, urinary bladder, prostate, testis, and penis. Ultrasound is useful for assessing renal size and growth. It is also helpful in triaging patients with renal failure. For example, small echogenic kidneys suggest renal parenchymal (medical) disease, whereas a dilated pelvocaliceal system indicates an obstructive, and potentially reversible, cause of renal failure. ***(Agrawal A et al., 2000).***

Renal ultrasound is useful in detection and characterization of renal masses. Ultrasound provides an effective method of distinguishing benign cortical cysts from potentially malignant solid renal lesions. Since the most common renal lesion is a simple cortical cyst, ultrasound is a cost-effective method to confirm this diagnosis. Ultrasound may also be used to follow up mildly complicated cysts detected on CT, for example, hyperdense cysts or cysts with thin septations. ***(Agrawal A et al., 2000).***

The differential diagnosis for echogenic renal masses includes renal stones, angiomyolipomas, renal cortical neoplasms (including carcinoma), and, less commonly,abscesses and hematomas. All echogenic renal masses should be correlated with clinical history and, if necessary, confirmed with another imaging modality or follow-up ultrasound. Echogenic lesions smaller than 1 cm are more difficult to characterize by CT owing to partial volume averaging; in the correct clinical setting, follow-up ultrasound rather than repeat CT may be more useful. ***(Caoili EM et al.,2002).***

Doppler sonography is useful for the evaluation of renal vessels, vascularity of renal masses, and complications following renal transplant. It can detect renal vein thrombosis, renal artery stenosis, and ureteral obstruction prior to the development of hydronephrosis, arteriovenous fistulas, and pseudoaneurysms. Perinephric fluid collections following renal transplantation, extracorporeal shockwave lithotripsy, or acute obstructions are reliably detected by ultrasound. ***(Bateman et al., 2002).***

Developments in other imaging modalities have decreased the use of ultrasound in several clinical scenarios. Most patients with suspected renovascular hypertension are evaluated with CTA or MRA rather than Doppler ultrasonography. Unenhanced helical CT is now the initial procedure of choice for the evaluation of the patient with acute flank pain and suspected urolithiasis. ***(Baxter GM, 2001).***

In addition to rapidly and sensitively detecting renal stones without the need for intravenous contrast medium, helical CT also has the potential for identifying other causes of flank pain such as appendicitis and diverticulitis. In the past, a combination of KUB and ultrasound was advocated for the evaluation of hematuria, but recent studies indicate that IVU, CT (CTU), or both are the preferred modalities to evaluate this common clinical problem.
(Datta SN et al., 2002).

Applications of bladder sonography include assessment of bladder volume and wall thickness, and detection of bladder calculi and tumors. The suprapubic transabdominal approach is most commonly used. The transurethral approach during cystoscopy has been recommended for tumor detection and staging. ***(Shokeir et al., 2000).***

Ultrasound examination of the testis has become an extension of the physical examination. The superficial location of the testis allows the use of a high-frequency transducer (10–15 MHz), which produces excellent spatial resolution. The addition of color Doppler sonography provides simultaneous display of morphology and blood flow. Normal low-resistance intratesticular arterial blood flow is consistently detected with power or color Doppler. Sonography is highly accurate in differentiating intratesticular from extratesticular disease, and in the detection of intratesticular pathology. ***(Dohle et al., 2000).***

Ultrasound is commonly used to evaluate acute conditions of the scrotum. It can distinguish between inflammatory processes, inguinal hernias, and acute testicular torsion. In addition, epididymitis not responding to antibiotics within 2 weeks should be investigated further with scrotal ultrasonography. ***(Pavlica et al., 2001).***

Advantages & Disadvantages:

The main advantages of ultrasound are ease of use, high patient tolerance, noninvasiveness, lack of ionizing radiation, low relative cost, and wide availability. ***(Palmer et al., 2005).***

Disadvantages include a relatively low signal-to-noise level, tissue nonspecificity, limited field of view, and dependence on the operator's skill and the patient's habitus. ***(Palmer et al., 2005).***

Computed tomography:

In recent years, CT has gained popularity and has rapidly been establishing itself as the investigation of choice in the imaging of kidney stones. The technique for maximising information with respect of both renal and ureteric stones is well described. No oral or intravenous contrast is used and a spiral scan is performed from the kidneys up to the symphysis pubis. Usually 5 mm reconstructions are used, but finer reconstructions are possible and should be used when looking for smaller stones. Whilst non-contrast CT is the norm, intravenous contrast may give useful information when investigating some stone types, such as those in a calyceal diverticulum, or if 3-D reconstruction is contemplated ***(Kluner et al., 2006).***

Indications for CT in cases of renal stones:

- Diagnosis of acute colic
- Diagnosis of radiolucent stones
- Defining renal anatomy
- Outlining perirenal and other anatomy
- Detection of other renal problems related to stone (e.g. abscess)

➢ Assessing the interrelationship between nephrostomy track and stone.

Whilst CT is undoubtedly a very useful tool, there are some pitfalls. For example, indinavir stones are CT lucent. The characteristic patterns of medullary sponge kidney and tuberculosis are less easily recognized, and it does not provide physiological information. The higher radiation dose may also be a limiting factor ***(Cullen et al., 2008).***

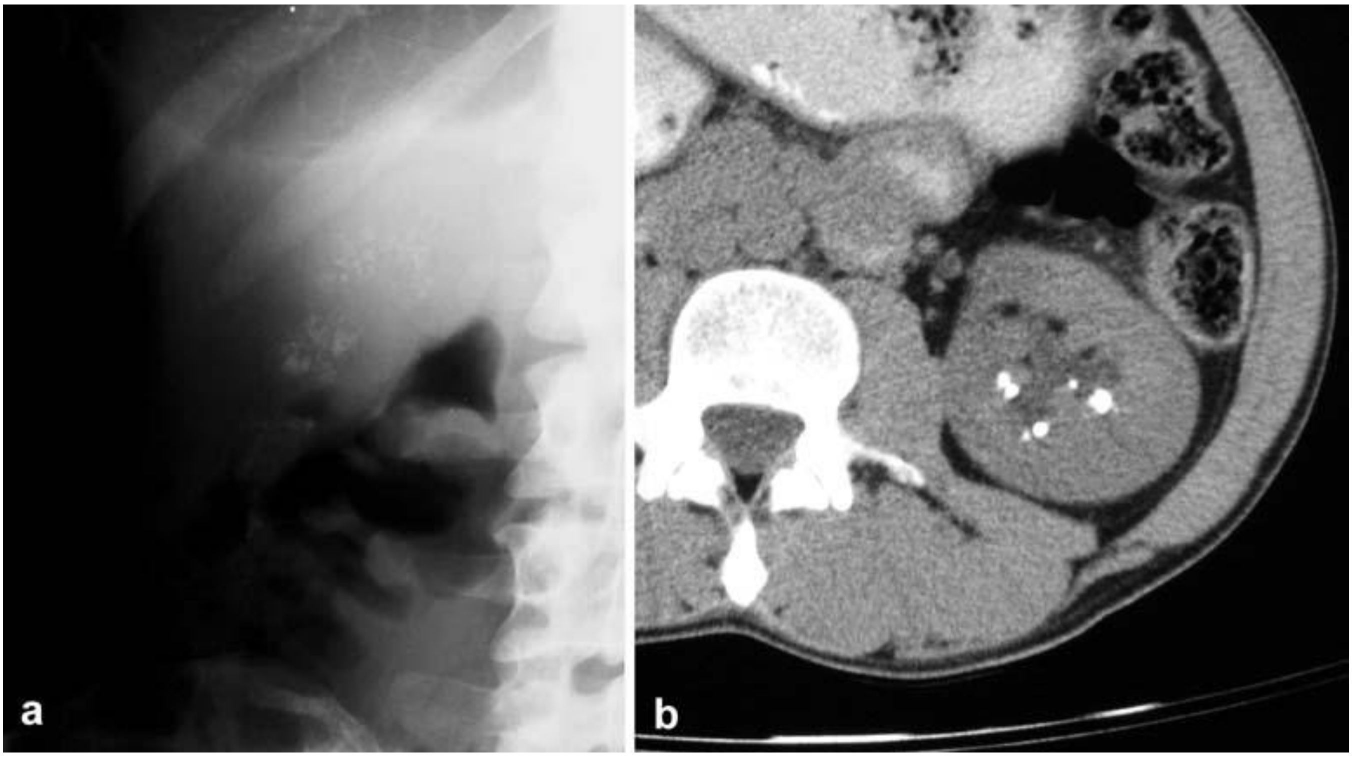

Figure (9): Nephrocalcinosis in medullary sponge kidneys KUB and CT (different patien ***(Quoted from Rao, 2004).***

Randall's plaques:

Randall suggested that stones originate as sub-epithelial calcific plaques in the juxta-papillary regions. When the epithelial covering erodes, the plaque is exposed to urine in the collecting system and eventually grows to become a stone. This theory did not gain much acceptance until recently. With the introduction of retrograde pyeloscopy, experienced endoscopists not uncommonly see these plaques both in the sub-epithelial tissue and with the epithelium partially eroded. It is important to bear this in mind, as these plaques may be interpreted as stones.

Figure (10): Randall’s plaque (the larger one is a stone and the smaller a Randall’s plaque—confirmed by retrograde pyeloscopy ***(Quoted from Rao, 2004).***

Although conventional non-enhanced CT is a vital tool in the investigation of renal stones, the information obtained from the axial sequences is still limited. It is possible to take advantage of recent advances in computer software, to obtain more detailed 3-D images using contrast enhancement. Not only axial, but also coronal and sagittal images, including ‘‘IVU like’’ images can be reconstructed. An even more exciting future possibility is the creation of ‘‘virtual endoscopy’’ images ***(Takebayashi et al., 2000).***

Hounsfield Scale:

The density measurements are standardized using the Hounsfield scale, named after Sir Godfrey Hounsfield, the inventor of first clinically viable CT scanner ***(Barnes et al., 1998).***

This scale assigns radiopacity of water as CT number, or Hounsfield Unit (HU), of zero, and assigns all other tissue values ranging from -1000 to approximately +2000, depending on their attention relative to water ***(Barnes et al., 1998).***

Using this scale, air is -1000 HU, fat is approximately -50 to -100 HU, fluid is 0 to + 20 HU, soft tissue is between +1000 and +2000 HU. CT numbers may vary slightly between manufactures and are a function of scanner KV ***(Barnes et al., 1998).***

In urology Hounsfield units provide information regarding a number of properties of urinary stones. Computed tomography is currently used most commonly to predict the type of stone and assess the potential efficacy of extracorporeal shock wave lithotripsy treatment. However, it might also assist urologist to decide which of shock wave lithotripsy(SWL), percutaneous nephrolithotomy(PCNL), uretreorenoscopic, uretrolithotripsy and medical expulsive therapy should be used to treat a patient ***(Gücük et al., 2014).***

Moreover, a number of studies have assessed the curative threshold of HU. Calcium oxalate monohydrate and cystine stones are generally considered resistant to SWL. Thus, understanding stone composition is important in SWL treatment, although this is challenging before treatment. To this end, some studies have reported that urinary stone HU values may predict stone composition ***(ouzaid et al., 2012).***

Magnetic resonance imaging:

When compared to CT, magnetic resonance imaging (MRI) is of limited value in the investigation of renal calculi. The advantages of MRI are that the imaging is quick and there is no risk of ionising radiation. There is also no need for intravenous contrast media as the collecting system can be visualised by distending it with intravenous frusemide. It is important to remember that on MRI, stones are seen as a signal void and can not be differentiated from a tumour or a blood clot. MRI may miss small calyceal stones**.** In general CT is superior to MRI in the investigation of renal and ureteric stones. One situation where MRI is invaluable is in pregnancy when it is advisable to avoid exposure to radiation ***(Sudah et al., 2002).***