Comparison of Different Renal Imaging Modalities: An Overview

Ravinder Kaur and Mamta Juneja

Abstract The kidneys play an important role in our health, and renal dysfunction is identified by a successive loss in renal functionality with passage of time. The term 'uroradiology' is used to describe imaging and interventional techniques involved in the examination of urinary tract. Imaging plays an important role for assessment of different kidney abnormalities. The choice of particular imaging technique is based on the radiation burden, cost involved, possible complications and the diagnostic yield. Various attempts have been made for improving the correctness of renal diagnosis using distinct medical imaging techniques. In this article, we explore the potential of different renal imaging techniques currently employed in clinical set-ups along with their advantages and disadvantages.

Keywords Renal biopsy · CT · Magnetic resonance imaging · OCT · KUB

1 Introduction

Kidneys are bean-shaped organ of human body which remove waste products from blood, help to maintain acid base balance, form urine and support other functions of the body. According to the World Health Organization (WHO), renal dysfunction is a worldwide health crisis and it is feasible to control the growth of renal diseases with early diagnosis and treatment [1–3]. Non-communicable diseases such as renal disorders or heart diseases have taken place of communicable diseases such as AIDS in increasing the mortality and morbidity rates globally. The common indications for renal imaging are abnormal renal function tests that suggest the need of imaging. Different types of imaging techniques are being used by clinicians to

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investigate different diseases. The choice of particular imaging technology depends on the type of disease to be diagnosed. In this paper, we discuss about different imaging techniques that are used to investigate different renal abnormalities.

2 Renal Imaging Modalities

In the last few decades, imaging techniques are consistently enforced for determination and analysis of renal disorders. There are different renal imaging modalities that are widely used such as CT, US, MRI, OCT, angiography and nuclear medicine. Each of these modalities has merits and demerits which will be explained in related section. The choice of particular imaging modality depends on the diagnostic output, pricing requirement, effect of radiation and complexity of disease. CT, US, MRI, US, DCE-MRI and angiography are susceptible to computerized analysis, and much of work is done on the automatic handling of images from these imaging techniques [4–6]. In contrast, less number of attempts has been made by researchers for computerized analysis of nuclear medicine and OCT. Here, we discuss distinct kidney imaging modalities which generate different images for analysis and detection of diseases.

2.1 Plain Abdominal Radiographs

Imaging work initially started with abdominal radiograph which is the first imaging modality that was used in 1972 [7]. Plain abdominal fluoroscopy or kidneys, ureters and bladder (KUB) X-ray, as shown in Fig. 1, is one of the important imaging modalities for detection of radio-opaque stones. However, the growing use of US, CT and MRI has confined the usage of abdominal radiographs; still, they are used in the administration of severe abdominal pain. The problem with the plain radiographs is that they are unable to distinguish phleboliths present in pelvis from the actual kidney stones. The limitation of technique is that 10% of stones (known as radiolucent stones) are not detected and smaller renal calculi are often overlooked.

2.2 Intravenous Urogram (IVU)

Intravenous urogram, also known as intravenous pyelography, is a procedure in which iodinated contrast medium is injected into the patient body and serial radiographs are taken that allows visualization of the renal tract as shown in Fig. 2. If there is any interruption in the one-sided flow of contrast agent through the renal pelvis and ureter, then it would be evidence of blockage. If flow is two-sided, then

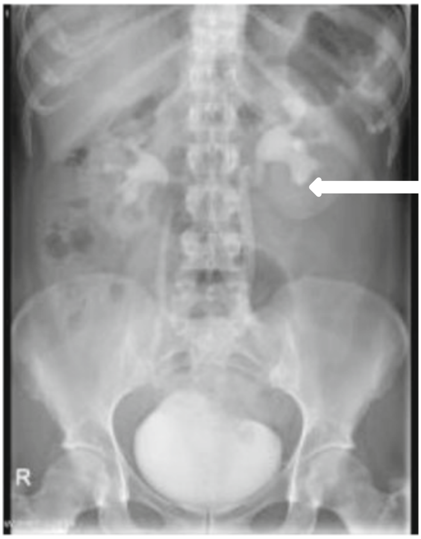

Fig. 1 KUB X-ray of kidney (*arrow* pointing towards kidney)

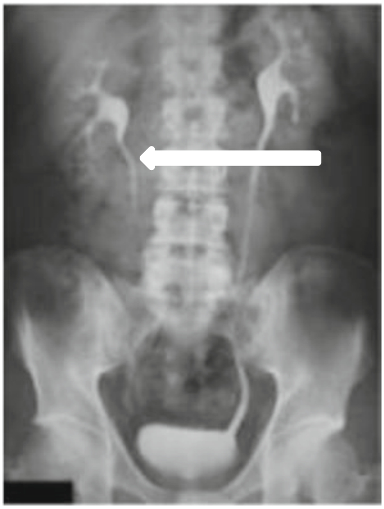

Fig. 2 IVU of kidney showing kidney drainage with contrast (*arrow* pointing towards kidney)

intrinsic problems, such as low renal perfusion or function, can be examined [8]. So the degree of delay in the passage of contrast agent can be used to find the degree of obstruction. Intravenous urogram (IVU) further assists radiologists in the ferreting out inborn anomalies of the human kidney, such as renal agenesis, renal hypoplasia and renal dysplasia. The limiting factor of IVU is that it cannot be used for pregnant women, paediatric patients or if patients have allergy due to contrast agent. The advantage of an IVU is it helps us to confirm obstructions present in collecting duct system of kidneys. The limitation of technique is that it requires more radiation dose as compare to plain radiographs and administration of contrast agent.

2.3 Ultrasonography (US)

Ultrasonography has taken place of IVU as the first-line analysis of renal diseases. It is non-invasive, quick and inexpensive imaging modality that provides 2D images of body internal organs and tissues using high-frequency sound waves. It evades the use of ionizing radiation and can precisely measure renal size without the enlargement effects associated with IVU. Figure 3 shows a normal human kidney using US imaging modality. The real-time images of US helps for assessment of renal biopsy, renal stones, renal cysts, renal mass lesions and interventional procedures. In chronic kidney failure, US show abnormal echo pattern and the kidneys become smaller. An irregularity in renal size is an indication of renal artery stenosis which can be confirmed using Doppler interrogation. US images usually possess a texture pattern termed as speckle. These texture patterns are dependent on the anatomy of the organ and distinctive imaging specifications. Speckle pattern is formed as an outcome of interference of sound waves from many dispersers that are small fragments of size proportionate to its wavelength, i.e. ultrasound wave wavelength. These disperser particles not only refract or reflect the wave although they produce a complicated diffused scattering that forms the primitive approach for formation of speckles. Speckle is an immanent attribute of US imaging modality that has multiplicative noise which makes the US images deceitful and therefore reduces its diagnostic value. Speckle tracking methods use same speckle patterns to evaluate internal tissue movement. Doppler ultrasound imaging is also employed for computation of renal blood flow (RBF), and when this technique is adapted to obtain images of tissue, it is known as tissue Doppler imaging (TDI) [9].

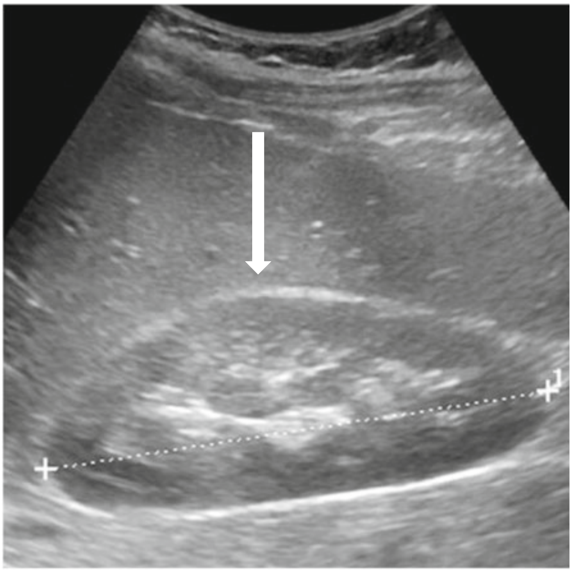

Fig. 3 Ultrasound of kidney (*arrow* pointing towards kidney)

The benefit of using ultrasonography is that there is no exposure of subject to radiation and it is cost-effective. The limitation of technique is that it requires optimal image quality in corpulent patients and it is operator dependent.

2.4 Computed Tomography (CT)

Computed tomography imaging becomes invaluable means for diagnosis of any pathology affecting kidneys as it provides images with high contrast and good spatial resolution. In many departments, IVU is being replaced by CT imaging modality to obtain detailed images of body organs as they provide more anatomical and functional information than standard X-rays as shown in Fig. 4. CT scan is a non-invasive approach of imaging which provides different views of same body organ or tissue (often called slices) within seconds. Modern CT devices perform scan of abdomen within few seconds, thereby reducing breath-hold time, and data after acquisition are forwarded to allocated work stations for further diagnosis [9]. Renal multi-detector computed tomography (MDCT) has ability to capture pictures of the entire abdomen with thin slice collimation in one gantry rotation. Initial series of CT scanners allow taking only one or two slices in a single gantry revolution and undergo through the problems such as motion artefacts due to respiration and loss of IV contrast agents. Presently, multi-detector CT scanners moderately raised number of detectors such as 64, 128 or 256 detector CT scanners, thereby reducing acquisition time, and dual-source CT imaging is feasible with numerous gantry revolutions per second acquiring different CT slices (such as 128 slices for a 128 detector row scanner). CT angiography (CTA) is extremely responsive for detection of deep vein coagulation, renal artery stenosis and aneurysm. Kidney CT scanners are now extensively used in kidney diagnostic centres irrespective of its expense. New advances in CT include spectral (dual-energy) CT that has possibility to use

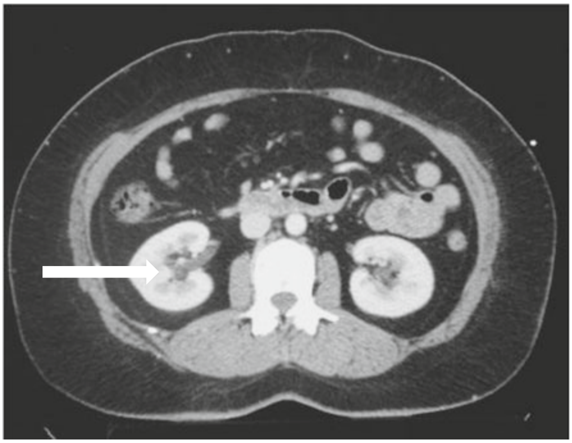

Fig. 4 CT scan of kidney (*arrows* pointing towards kidneys)

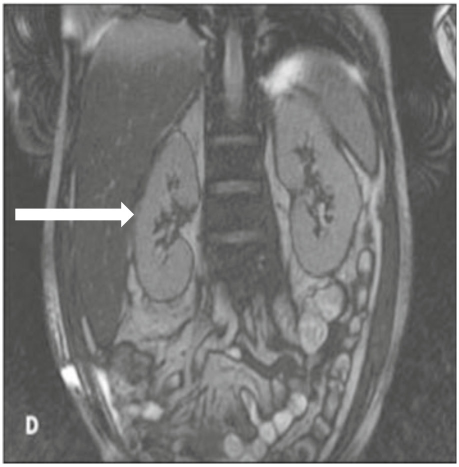

Fig. 5 MRI of kidneys (*arrow* pointing towards kidney)

the spectrum of X-ray energies in order to carry out characterization of tissue and lesion detection [10]. The benefit of using CT modality is that it provides high-resolution images with good anatomical details and provides access to all abdominal insights. Limitation of using CT modality is that patient is exposed to radiations that may have side effects.

2.5 *Magnetic Resonance Imaging (MRI)*

Magnetic resonance imaging (MRI), as shown in Fig. 5, is a non-obtrusive imaging method which utilizes radio frequency waves and strong magnetic field to generate elaborative description of different organs and tissues. MRI is considered as non-invasive technique as it does not use ionizing radiation. However, contrast agents may be injected for augmentation of different parts of organ under consideration. MRI is contraindicated for patients having artificial valves, pacemaker, stunts or any other implanted medical devices. However, there are no known biological hazards, but the technique is expensive. MRI is an excellent procedure of imaging of tumour coagulum in renal veins as it can easily differentiate between angiomyolipoma, simple cyst, complex cysts and renal cell carcinoma. MRI is also helpful for the evaluation of possible renal donors prior to renal transplantation. In comparison with CT, MRI is suitable for pregnant and younger patients as it does not involve the use of ionizing radiations. It is also useful in those who are intolerant of iodinated agents because of allergy. In contrast to other imaging modalities, MRI provides assessment of human kidney perfusion and it allows you to acquire images with different orientations that do not require further image processing which makes it a good choice for imaging. An MRI imaging protocol named DCE-MRI uses gadolinium-based contrast agent which is injected into kidney and images are taken rapidly and repeatedly. One drawback of this technique is that due to fast scanning, spatial resolution of dynamic MR images is low and it suffers from motion introduced by patient breathing. MRI techniques that make use of contrast agent may be harmful to patient with kidney diseases. In order to avoid these problems, researchers investigated MRI technique known as diffusion MRI, which is non-invasive functional modality that relies on the movement of water molecules inside the organ as it provides indirect information about the structure of organ surrounding these water molecules. Diffusion-weighted MRI (DW-MRI) is being considered by researchers for assessment of kidneys because of its major role in filtering the water and blood of body [11]. DW-MRI is an emerging area and computer vision researchers have made efforts to check out its usefulness in the classification of kidney lesions [12–16], renal infections [17] and renal parenchymal disease.

As in case of CT, MRI does not involve any radiations while scanning and useful for detection of abnormalities in soft tissues. However, MRI scans are susceptible to patient movement and it is difficult to complete the procedure as patient feel claustrophobic based on the kind of study being accomplished.

2.6 Nuclear Medicine (Isotope Imaging)

Radio-isotope scanning approaches such as positron emission tomography (PET) and spectral positron emission tomography (SPECT) use gamma rays or radiotracer in order to investigate functional and qualitative details of kidney rather than anatomical details. PET images possess lower spatial resolution as compared to CT and MRI and it provide quantitative information about tissue abnormalities and structures by accumulating emitted photons from a radiotracer. Isotope imaging of renal falls in two broad categories, i.e. static and dynamic renal scans [8, 9]. Dynamic renography is useful for measurement of glomerular filtration rate (GFR) and differential renal blood flow (RBF) and provides the quantitative evaluation of renal function. It gives information about degree of obstruction and is used in assessment of the filtration, perfusion and drainage of renal transplants. Static renography is useful in children for detecting cortical scars in kidney with urinary tract infections (UTIs) (Fig. 6).

Among different isotopes, fluorodeoxyglucose (FDG) is the most frequently used PET radiotracer for the assessment of various neoplasms as well as in the planning of radiotherapy in kidney cancer. It usually recognizes abnormalities in initial stages of disease maturation—long before with any other diagnostic examination. Nuclear medicine scans are usually conducted by radiographers. Albeit nuclear studies involve some threats to the patient health, yet they turn out to be intensely capable with good specificity and sensitivity in the evaluation of subjects with renal artery disorder and in investigating the flaws related to perfusion. Nuclear imaging methods (specifically PET) are extravagant, and moreover, they provide images with low resolutions that may be the reason less work has been done on this modality by computer vision researchers [18]. Isotope imaging helps

Fig. 6 Nuclear medicine scan of kidney (*arrow* pointing towards kidney)

you to get both anatomical and functional details of organ under consideration, but these medicine scans are more sensitive as compare to other imaging modalities.

2.7 *Optical Coherence Tomography (OCT)*

Optical coherence tomography (OCT) is evolving scanning procedure as it provides real-time high-resolution cross-sectional images of tissues structures. An OCT scan of kidney is shown in Fig. 7. Optical coherence tomography is closely related to ultrasonography, with the exception that it works with echo deferment of light waves in place of sound waves to create pictures [19]. This modality has been employed in various biomedical applications incorporating, cardiology [20, 21],

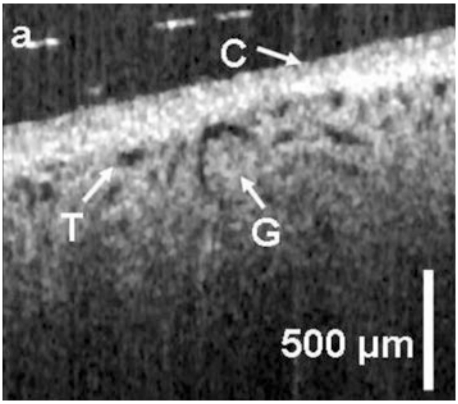

Fig. 7 OCT image of the human kidney in which glomeruli (*G*), tubules (*T*) and the kidney capsule (*C*) are discernible

Table 1 Comparison of renal imaging modalities

	X-ray	IVU	US	CT	MRI	Nuclear medicine	OCT
Cost involved	Low priced	Low priced	Low priced	Moderate cost	High cost	High cost	High cost
Radiation risk	Less radiation is involved	Less amount of radiation is involved	No radiation is involved	Moderate radiation is involved	No radiation is involved	Less amount of radiation is involved	No radiation is involved
Time involved	Scanning takes less time duration	Scanning takes less time duration	Scanning takes less time duration	Scanning takes less time duration	Scanning takes more time duration	Scanning takes more time duration	Scanning takes less time duration
Spatial resolution	Low	Low	High	High	High	Low	High

gastroenterology [22, 23], dermatology [24], dentistry [25], urology [26] and others.

OCT has high-powered modality which integrates physical and functional information that can be utilized to investigate renal condition in vivo studies and at the time of medical procedures. OCT imaging of renal donor prior to renal transplant can help the surgeons to predict transplant outcomes. The adaptability of OCT imaging procedures makes it a perfect procedure to acquire images of the kidney in situ as it provides high-resolution facilities and increased depth examination, in comparison with other modalities [27]. Table 1 shows comparison of different renal imaging modalities based on cost, radiation risk, time involved and spatial resolution. Only few studies have been observed on assessment of kidney function using OCT, and it is new area for researchers to explore.

3 Conclusion

In the last two decades, we have seen major improvements in the diagnosis of kidney disorders with the improved imaging procedures. Different imaging modalities can be used to diagnose different kinds of renal disorders. Advancements in imaging techniques continue to evolve the role of imaging in decreasing the mortality and morbidity rates due to kidney disorders. Presently, researchers are investigating imaging techniques at the molecular level which will assist in understanding the nature of disease growth and development. It has been observed in the literature that one technique is not entirely suitable for investigation of all renal diseases. Thus, investigation is persistently being performed in order to upgrade the current imaging techniques and to invent new techniques.

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