Contemporary Imaging of the Renal Mass

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Published online: 15 October 2010
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Abstract Renal masses increasingly are detected incidentally in asymptomatic individuals. Accurate characterization of these lesions is important for clinical management, planning intervention, and avoiding unnecessary procedures. Ultrasonography, computed tomography (CT), and magnetic resonance imaging (MRI) are the mainstays of renal mass detection and characterization. Ultrasonography is useful for distinguishing cystic from solid lesions and can detect lesion vascularity, especially with use of ultrasound contrast agents, but is less sensitive, less specific, and less reproducible than CT and MRI. CT, with and without intravenous contrast, is the primary imaging test for characterization and staging of renal lesions, and is utilized more often than MRI. Current multidetector CT technology provides near isotropic acquisition, with three-dimensional reformating capabilities. Due to lack of exposure to iodinated contrast and ionizing radiation and superior soft tissue contrast, MRI is being increasingly utilized as a problem-solving tool for diagnosis, staging, and preoperative planning for renal malignancies. Future directions for imaging of primary renal neoplasm include accurate characterization of renal cell cancer subtype, assistance with treatment planning, and evaluation of treatment response.

Keywords Magnetic resonance imaging · Computed tomography · Ultrasonography · Renal mass · Renal cell carcinoma

Introduction

As use of medical imaging rises, renal masses increasingly are discovered incidentally [1, 2]. Of small renal masses, 80% are malignant, with renal cell carcinoma (RCC) representing 85% to 90% of renal malignancies [3]. In turn, increased detection of RCC has prompted increased demand for less invasive treatment strategies. Computed tomography (CT) and magnetic resonance imaging (MRI) can demonstrate important anatomic features that guide selection of appropriate treatment and aid surgical planning immensely, particularly when utilizing minimally invasive methods. This review discusses the major modalities used for imaging renal masses, including ultrasonography, CT, and MRI. Recent trends and innovations in imaging of RCC also are reviewed.

Evaluation of Renal Cell Carcinoma

Ultrasonography

The advantages of ultrasonography include accessibility, low cost, and avoidance of intravenous contrast administration and ionizing radiation. This modality often is used for initial screening evaluation when renal disease is suspected. Ultrasonography can be useful to discriminate cystic from solid lesions, to monitor growth of a lesion, and to evaluate lesions found on CT that are probably hyperdense cysts [4]. Detection of small renal lesions with ultrasonography is limited. Lesions less than 3 cm in diameter are detected only 67% to 79% of the time by conventional ultrasonography [5]. Renal malignancies may have similar echogenicity (isoechogenicity) to normal renal parenchyma, and therefore, can be difficult to detect when there is no distortion of the normal renal contour or protrusion into the central renal sinus.
fat. RCC also can be hypo- or hyperechoic to renal parenchyma. Because angiomyolipomas are classically described as hyperechoic masses, there is overlap between these benign lesions and RCC on ultrasonography [6]. Characterization of cystic lesions requires examination for thickened internal septa, calcifications, vascularity, and mural nodularity; these features indicate malignancy [7]. When a lesion found on ultrasonography does not show a characteristic appearance for a simple cyst (a round anechoic lesion with a smooth well-defined wall, without internal debris, showing increased through-transmission), further evaluation with contrast-enhanced CT or MRI is necessary.

Contrast agents for ultrasonography potentially can improve sensitivity for detection of small renal masses, but are not approved in the United States for noncardiac applications. The technique involves intravenous injection of commercially available microbubbles, which act as a highly echogenic medium as they travel through tissues. In a study comparing contrast-enhanced ultrasound (CEUS) to contrast-enhanced CT for characterization of cystic renal lesions; the accuracy of CEUS was higher than CT, but this was not statistically significant. However, compared to CT, CEUS was able to better visualize the number of septa, septa and/or wall thickness, presence of a solid component, and enhancement in some cases, resulting in upgrade of Bosniak classification and affecting treatment planning [8]. Color and power Doppler imaging also have been shown to improve detection of renal masses [9].

Computed Tomography

CT remains the modality of choice in characterizing and staging renal masses. CT examination is highly sensitive for even small renal masses (>90%), and may detect smaller lesions than MRI due to higher spatial resolution. The latest generation of scanners, called multidetector CT (MDCT), uses multiple rows of detectors, which provide nearly isotropic data sets. Consequently, the volume of data can be reformatted in various planes with near-equal resolution. The technology now is widely available and routinely utilized in clinical practice.

The current standard MDCT protocol for evaluation of a renal mass consists of noncontrast and postcontrast acquisitions. This postcontrast acquisition can be acquired at multiple time points (arterial/corticomedullary, nephrographic, and delayed phases), and the protocol can be tailored to answer a specific clinical question. For example, a noncontrast and a postcontrast acquisition in the nephrographic phase of enhancement (acquired about 70 to 80 seconds after contrast injection usually) are sufficient to diagnose the presence or absence of a renal lesion and assess its enhancement (Fig. 1), but arterial and urographic phases may provide additional valuable information for

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Fig. 1 Seventy five-year-old woman presenting for evaluation of a renal lesion. CT examination of the abdomen and pelvis performed (a) before and (b) after iodinated intravascular contrast administration in axial plane with (c) coronal reformatted image demonstrates a complex enhancing left renal mass (arrows). CT—computed tomography
presurgical planning. However, a drawback of multiphase CT examination is an increase in radiation dose to the patient.

Lesion size, shape, and borders can be evaluated on postcontrast CT acquisition, but enhancement is the most important factor in determining the likelihood of malignancy. CT enhancement is defined as an attenuation increase of at least 15 to 20 Hounsfield units (HU) from the corresponding noncontrast image. Lesions demonstrating an increase of 10 to 20 HU are not definitively categorized as enhancing hypovascular masses because of the potential phenomenon of renal cyst pseudoenhancement on contrast-enhanced images [7, 10]. Pseudoenhancement appears particularly problematic in MDCT. Hypovascular malignancies, such as papillary RCC, which enhance minimally, can be mistaken for renal cysts. When a lesion increases in density 10 to 20 HU after contrast administration, other features supporting malignancy according to the Bosniak classification system may be helpful [11]. Further evaluation with MRI also may help characterize these lesions due to better soft tissue contrast.

Another important recent development in CT technology is dual-energy scanning. Dual energy CT (DECT) scanners allow for simultaneous acquisition of CT data at two different energies (peak tube voltages) [12, 13]. By scanning at different photon energies, differences in material composition can be assessed based on differences in photon absorption. This technique relies on attenuation differences of materials with large atomic numbers like iodine. One important application is the ability to identify and remove the iodine information from a postcontrast image, thus generating a “virtual noncontrast” data set. Studies demonstrating the ability of this “virtual noncontrast” data set to replace a true noncontrast acquisition in the evaluation of renal lesions, thereby decreasing radiation dose, recently have been published. Graser et al. [14••] demonstrated that a single-phase postcontrast DECT examination, when reviewed in conjunction with virtual noncontrast data set, had an accuracy of 94.6% in diagnosing malignant renal lesions. This was similar to dual-phase CT examination (including acquisition of true noncontrast data set), which had an accuracy of 96%. Of note, single-phase DECT examination resulted in reduction in radiation dose of 47% compared to dual-phase CT examination in this study. Although these preliminary results are very encouraging, clinical use of this technology is in its early stages.

Magnetic Resonance Imaging

Similar to CT examination, detection of enhancement and presence/absence of bulk fat allows for appropriate characterization of renal lesions on MRI. The lack of ionizing radiation is a major benefit given the increasing awareness of cumulative radiation exposure from medical procedures [15]. The study also serves as an alternative to CT in patients with allergies to iodinated contrast. MRI often is used as a problem-solving technique when a mass remains indeterminate after CT evaluation. Gadolinium contrast is necessary to confidently diagnose enhancement in a renal lesion. Although gadolinium contrast is considered non-nephrotoxic at the dose used for MRI, caution is advised in patients with impaired renal function due to the recently described association between nephrogenic systemic fibrosis (NSF) and use of gadolinium-contrast agents [16]. Cases of NSF are extremely rare in patients with glomerular filtration rates over 30 mL/min/1.73 m² [17]. The US Food and Drug Administration has issued a black-box warning for use of gadolinium-based contrast agents in patients with severe renal insufficiency.

MRI of the kidneys is usually performed on 1.5 or 3 T strength magnets, which are widely available. Advances in MRI hardware and software over the past two decades have resulted in the ability to image faster, such that most sequences/acquisitions through the kidneys can be acquired in a breath-hold (with suspended respiratory motion). As a result, comprehensive renal MRI can be performed within 30 min and consists of multiple breath-hold acquisitions. Free-breathing techniques, which will be useful in patients who are unable to suspend their respiration, are being developed. Spatial resolution in state-of-the-art MRI also has significantly improved, although CT remains superior in this regard. Standard sequences in MRI evaluation of a renal mass include T1-weighted imaging (with and out of phase sequences), T2-weighted imaging in two planes, and fat-suppressed T1-weighted gradient echo acquisition before and after contrast administration at multiple time points, including arterial/corticomedullary, nephrographic, and urographic phases. At our institution, we also include diffusion-weighted imaging in our renal mass MRI protocol (Table 1).

As with CT, enhancement is the major determinant of possible malignancy in a non-fat-containing renal mass. Detecting enhancement in renal masses can be improved with analysis of subtraction images (generated by subtracting the precontrast image from the postcontrast images), especially in lesions that are small or are already T1 hyperintense on precontrast images; the resulting images demonstrate high signal only in the areas of enhancement (Fig. 2). A study from our institution showed that subtraction imaging was superior for detection of malignancy compared to quantitative enhancement ratio calculation. Sensitivity of subtraction imaging was 99% for diagnosis of a malignant lesion compared to 95% for quantitative evaluation [18].

Compared with CT, MRI has shown higher sensitivity in detecting certain features of cystic lesions, namely the
presence, thickness, and enhancement of septa. A recent study compared the outcome of applying the Bosniak criteria to MRI. Cystic lesions were upstaged in 10% of cases due to features detected on MRI [19]. MRI also has shown higher sensitivity and accuracy in determining tumor involvement of perirenal fat and presence of venous invasion, which can be credited to outstanding soft tissue contrast and multiplicity of sequences.

MRI also helps with detection of both macroscopic and microscopic fat when diagnosing angiomyolipoma. Macroscopic fat is seen on the T1-weighted out-of-phase sequence when there is a black outline around the lesion, called an “india ink artifact.” In a study by Israel et al. [20], this india ink artifact was seen in 100% of angiomyolipomas and 4% nonangiomyolipoma renal lesions. Chemical shift (in- and out-of-phase) imaging also is useful for detection of microscopic amounts of fat not discernible on CT. In such cases, signal loss from the in-phase to opposed-phase images can increase confidence in the diagnosis of angiomyolipoma with minimal fat. However, these images should be interpreted with caution because the neoplastic cells of the clear cell subtype of RCC may contain intracytoplasmic glycogen/lipid that also demonstrates signal loss on opposed-phase imaging. Furthermore, in our experience, thin section noncontrast CT may be able to detect very small amounts of bulk fat (not detected on MRI) due to higher spatial resolution.

Recent Advances

**Diffusion-Weighted Imaging**

Diffusion-weighted imaging (DWI) quantifies thermally induced motion of water molecules, known as Brownian motion, in tissues. This restriction of water motion or diffusion can be qualitatively or quantitatively evaluated by means of apparent diffusion coefficient (ADC) measure. DWI previously has been evaluated as a potential alternative to gadolinium-enhanced MR in evaluation of renal lesions. Studies have shown lower ADC in the malignant masses compared to the benign lesions, presumably due to higher cellularity or complex architecture of the neoplastic lesions (Fig. 3) [21, 22]. Recent studies have also shown that high-grade clear cell RCCs have lower ADC compared to low-grade tumors [23]. DWI is easy to perform, does not require gadolinium injection, and provides information about tumor micro environment. Hence, this novel technique is generating considerable interest in the radiology community.

**Predicting Renal Cell Carcinoma Subtype on Imaging**

Various studies have tried to differentiate between the clear cell and papillary subtypes of RCC based on the degree of enhancement on contrast-enhanced CT as well as MRI. Some of these studies have shown excellent accuracy, with higher early enhancement in clear cell renal cancers [24]. In addition, clear cell RCC has a strong association with necrosis and retroperitoneal collateral circulation that is best seen on MRI [25]. On the other hand, papillary RCCs show homogenous low-level enhancement on both CT and MRI [24, 26]. Studies also have shown that papillary RCCs are hypointense on T2-weighted imaging, likely due to old blood products, whereas clear cell RCCs tend to be T2 iso- to hyperintense.

**Staging and Preoperative Planning**

Once a solid or complex cystic mass with enhancement is identified, both CT and MRI provide additional information for staging and preoperative planning. Overall staging by MDCT and MRI is similarly accurate. Ultrasonography can be used for staging RCC, but overlying bowel gas and body habitus often limit visualization of the renal vein, inferior vena cava (IVC), and retroperitoneal lymph nodes.
CT and MRI further aid surgical planning, especially with use of multiplanar reformations, maximal intensity projections, and angiographic techniques. Angiographic techniques can demonstrate feeding arteries to a mass or vascular invasion. Preoperative planning can be expanded upon further with delineation of tumor proximity to the hilum or collecting system on urographic acquisitions. A recently introduced scoring system proposes to standardize the reporting of these

Fig. 2 Seventy-five-year-old woman presenting for evaluation of a renal lesion. T1 gradient echo 3D sequence with fat suppression performed (a) prior to and (b) after gadolinium injection, (c) with subtraction technique confirms the enhancing left renal mass seen in Fig. 1 (arrows). 3D—three-dimensional

Fig. 3 Seventy-five-year-old woman presenting for evaluation of a renal lesion. Diffusion-weighted acquisition at b-value (in sec/mm²) of (a) 100 and (b) 600, (c) with corresponding ADC map. DWI shows restricted diffusion peripherally (low ADC) with central area of necrosis with higher diffusivity (high signal on ADC map) in the left renal mass seen in Figs. 1 and 2 (arrows). Pathology confirmed the diagnosis of a clear cell carcinoma. ADC—apparent diffusion coefficient; DWI—diffusion-weighted imaging
salient features of renal masses to facilitate surgical planning [27].

The major criteria of staging RCC on imaging include local extent of disease and the presence of regional and distant metastases. Using the TNM staging system, evaluation of tumor involvement beyond the renal capsule or Gerota’s fascia may be better evaluated with MRI because perirenal fat invasion and fat planes with adjacent structures are better depicted [28, 29]. Hence, MRI may offer better delineation than CT between stages T2 and T3a, as well as T3 and T4 [29]. The presence of lymphadenopathy in the abdomen is equally detected with contrast-enhanced CT and most sequences on MRI [30]. However, diagnosis of lymph node metastasis is based on size criteria, and hence, CT and MRI have limited accuracy due to inability to detect metastasis in normal size lymph nodes. The renal vein and IVC must be examined for the presence of thrombus and is best seen on contrast-enhanced T1-weighted sequences of MRI as a low-signal filling defect. Moreover, enhancement of the filling defect within the veins on postcontrast imaging can suggest presence of tumor rather than bland thrombus. The reported sensitivity of MRI in detection of venous invasion is 100%, compared with 79% to 85% for CT, although the studies were performed before the wide availability of MDCT and current sensitivity may be more similar to MRI [31]. MRI may be better in assessing the cranial extent of venous thrombus, as CT often does not demonstrate sufficient opacification of the IVC to accurately evaluate extension. The negative predictive value of tumor involvement in the renal vein or IVC approaches 100% with MRI [32].

Positron emission tomography (PET) is another modality sometimes used for staging, although it is not standard imaging in RCC. Specificity is high in the setting of known RCC. However, sensitivity is limited with the radiotracer fluorine-18 fluorodeoxyglucose, and a negative study generally is insufficient to exclude metastasis [33].

Follow-up Imaging and Surveillance

Imaging plays a central role in surveillance of small renal masses. CT and MRI generally are favored over ultrasonography (which is user dependent) for watchful waiting in poor operative candidates and for postoperative follow-up imaging. In younger patients or those with genetic predisposition to RCC, cumulative radiation may be of consideration in favoring MRI for serial follow-up examinations. Surveillance with serial CT or MRI scans every 6 months to 1 year may be chosen, with no strong consensus to date regarding the optimal interval.

Postsurgical imaging with CT and MRI is performed to exclude recurrent/residual or metastatic disease. There is no consensus regarding when and how often to perform postsurgical imaging. At our institution, we routinely perform the first postsurgical examination within 6 months after surgery, and thereafter, sequential examinations are performed at 6- to 12-month intervals. MRI is favored for follow-up imaging due to the lack of exposure to ionizing radiation. Tumor recurrence in one study was found to occur in most patients within 2 years after surgery. In the same study, frequent tumor recurrence sites were the lung and bone, followed by the nephrectomy surgical bed. Diagnosis of recurrence in the surgical bed can be made by demonstrating the presence of enhancing soft tissue [34].

Conclusions

Imaging plays a central role in the diagnosis and management of patients with known or suspected RCC. CT and MRI are routinely used for renal lesion detection and characterization, in preoperative planning, and for postoperative follow-up evaluation. Use of advanced imaging techniques, such as dual-energy CT and diffusion-weighted MRI, to improve diagnosis and management of RCC is of tremendous interest and currently is being investigated.

Disclosures  Dr. S. K. Kang: none. Dr. D. Kim: none. Dr. Hersh Chandarana has received a Radiologic Society of North America Seed Grant.

References

Papers of particular interest, published recently, have been highlighted as:

• Of importance

• Of major importance