Abdominal Imaging

Published online: 14 January 2004

Abdom Imaging (2004) 29:312–319
DOI: 10.1007/s00261-003-0104-0

INVITED UPDATE

Radiologic evaluation in planning surgery of renal tumors

R. Pozzi-Mucelli, A. Rimondini, A. Morra

Department of Radiology, University of Trieste, Ospedale di Cattinara, Strada di Fiume 447, Trieste, Italy

Abstract

The evolution in diagnostic imaging modalities, mainly in computed tomography (CT) and magnetic resonance imaging (MRI), have made it possible to extend the applications of these techniques from diagnosis to staging and surgical planning. Nowadays, the possibility to present images on different planes with an intrinsic resolution close to that of the original axial sections allows presentation of the kidney on sagittal, coronal, and oblique planes. Three-dimensional reconstructions can be obtained with different methods and have attained excellent image quality. Multidetector spiral CT presently is the best technique for planning surgery, but MRI also enables high-quality images to be obtained if state-of-the-art equipment is available. This update reviews the current status and possibilities of diagnostic imaging modalities in planning surgery of renal tumors.

Key words: Renal tumors—Surgical planning—Computed tomography—Magnetic resonance imaging—Ultrasonography

The past few years have seen major advances in diagnostic imaging modalities that most involve diagnosis of renal tumors [1]. At the same time, the management of renal tumors has evolved in part from classic radical nephrectomy to kidney-sparing surgery and, more recently, to laparoscopy. New therapeutic approaches, such as cryosurgery and radiofrequency ablation, are under investigation [2–8]. Although initially limited to only a few centers, this new surgical approach based on nephron-sparing surgery soon spread as a well-recognized alternative for small renal tumors, bilateral renal tumors, and single kidney [9–13].

The development of partial nephrectomy was made possible in part by modern imaging modalities, in particular ultrasonography (US) and computed tomography (CT) [1, 14]. Although magnetic resonance imaging (MRI) recently has become important in the diagnosis of renal tumors, its role compared with that of US and CT is still limited [15–19].

Correspondence to: R. Pozzi-Mucelli; *email:* ropozzi@gnbts.univ.trieste.it

Thanks to technical developments, all imaging modalities can now play a significant role not only in the diagnosis but also in staging and surgical planning of renal tumors. Therefore, the aim of this update is to evaluate the contribution of imaging modalities from the perspectives of diagnosis and surgical planning for renal tumors.

Ultrasonography

The contribution of US to the diagnosis of renal masses has concentrated more on detection than on the staging or management of renal tumors. In many centers, US currently represents the first step in diagnosis of renal masses [20–22]. It allows detection and characterization of renal masses in a large number of cases, including asymptomatic patients. Despite good results with US, some limitations exist with small renal tumors, mainly when the echo structure is similar to or the same as that of the renal parenchyma or for small lesions that are totally intraparenchymal. Advances in US, such as its improved sensitivity with color Doppler, harmonic tissue imaging, and compound imaging, have reduced the number of false negative diagnoses [22–24]. The role of contrast medium in imaging the kidney is under investigation, but it is likely that it will be helpful in characterizing renal masses because it provides clear evidence of lesion vascularization, although this has to be proved in a large series of patients [24].

Despite the evolution of modern US equipment, this technique is not used for staging or guiding the decision on the type of surgical intervention. Nevertheless, US can provide adequate visualization of tumor thrombus in the renal vein (mainly on the right) and in the inferior vena cava. The definition of the upper extent of the thrombus and its relation to the hepatic vessels and the right atrium can be clearly defined by using standard B-mode imaging and power Doppler imaging. US can be used intraoperatively to assist the urologist during the extraction of a tumor thrombus (Fig. 1). US also may be useful to define the relation of an upper pole lesion to the liver or spleen. However, data on staging are usually incomplete with US, so additional imaging with CT

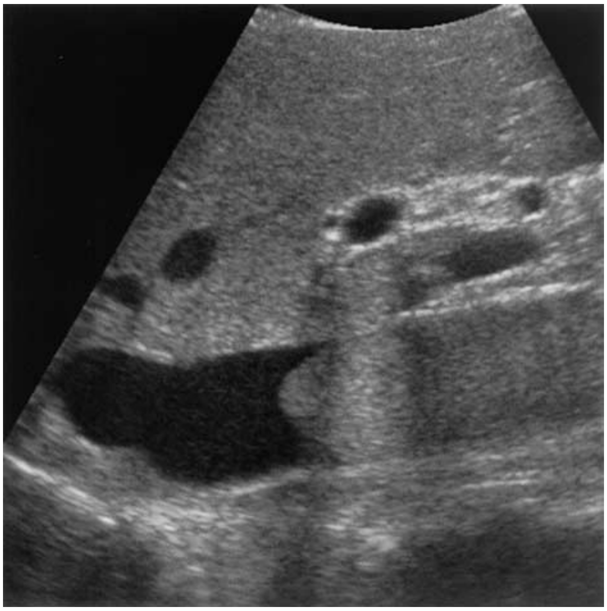

Fig. 1. Intraoperative US shows a thrombus in the inferior vena cava. The upper limit of the thrombus is clearly defined.

or MRI is mandatory for complete evaluation of disease extension and to decide on the most appropriate surgical approach.

US also plays a support role in surgery for tumors that are completely intrarenal and therefore not visible or palpable from the surface. US is used to define the optimal line of parenchymal transection [25].

Computed tomography

The rapid evolution of CT started with spiral CT in the early 1990s, and the current improvements in multidetector CT have expanded the role of this technique in renal imaging.

It is widely accepted that CT is the most sensitive modality in the detection of small renal tumors [1, 26, 27]. If a careful imaging technique is used, with thin slices and appropriate timing of the scans after contrast enhancement, CT is also accurate in characterizing renal masses, even when small [27–29]. These results have been achieved by reducing imaging misregistration artifacts, decreasing volume averaging artifacts, and allowing image acquisition during different phases of contrast enhancement [29–38].

Spiral and multidetector CT scanners have changed the visualization of CT images from exclusively (or almost exclusively) axial to multiplanar and three dimensional. This capability is helpful in some, but not in all, conditions. In the kidney, this multiplanar capability has proved its value in imaging patients with renal colic by allowing urography-like images to be obtained [39, 40]. The application of multiplanar and three-dimensional (3D) imaging to renal masses recently has become important, with several studies investigating the usefulness of these images in preoperative planning [41–44]. The appeal of these capabilities of CT is directly correlated to the early diagnosis of renal tumors and the widespread use of nephron-sparing surgical techniques that require a more detailed understanding of renal anatomy [41, 42]. Therefore, in addition to the information concerning tumor margin and extension, involvement of renal fascia, adjacent organs, renal vein, and inferior vena cava, which form part of staging, other preoperative information is needed to plan this type of surgical intervention: e.g., the position of the kidney in relation to the lower rib cage, spine, and iliac crest; the tumor location and depth of tumor extension into the kidney; the relation of the tumor to the collecting system; and renal arterial and venous anatomy [42].

This information can be obtained with a careful examination technique, as high-quality images in the acquisition plane and on reformatted and 3D images have to be generated. Correct timing of the images with respect to contrast medium administration is another crucial requirement.

Examination technique

The examination technique in CT is rapidly changing with the evolution of multislice CT, which, within few years, has evolved from two to four, to eight, to 16 slices. One effect of multislice CT is the growing use of thin slices. The introduction of four-row multislice CT has led to the use of 1-mm slices in the kidney, and this capability is becoming increasingly feasible with new multi-row (8–16) multislice CT scanners. The thinner slice positively affects image resolution, although it increases image noise. The thinner slice also reduces partial volume effects and is fundamental for multiplanar and 3D reconstructions.

The examination should include noncontrast and contrast-enhanced phases. The noncontrast examination can be performed with a medium slice thickness because it will not be used to obtain the reformations in the sagittal or coronal plane or on 3D images. Therefore, a slice thickness between 3 and 5 mm is recommended. Pitch value will depend on the type of scanner (single-slice spiral or multislice): with spiral CT units, a pitch between 1.4 and 1.6, with table increments of 5 and 7 mm, respectively, is a good choice if the reconstruction index is 2.5 to 5. With multislice CT, the slice thickness may be the same or thinner, depending on the type of scanner. The following data refer to a four-row detector: slice thickness, 2.5 mm; table increment, 3.75 mm; and pitch, 3 (with the possibility to reconstruct 1.2-mm-thick slices). The contrast-enhanced CT examination has to be performed with thinner collimation and a smaller reconstruction index to obtain good-quality images on the reformatted and 3D images. With single-slice spiral CT, the slice should be no thicker than 3 mm, so the table increment will be 3 to 5 mm (pitch, 1–1.6). The reconstruction index for a slice thickness of 3 mm will be 1.5 mm, and that for a slice thickness of 2 mm will be 1 mm. With multislice CT, the main difference will be the slice thickness, which may be reduced down to 1 mm.

Contrast-enhanced CT must be performed in two phases, the vascular, or cortical, phase and the nephrographic phase [29–32, 34, 35]. It is widely recognized that the nephrographic phase is the most sensitive for detecting renal masses [29, 30, 32, 37], particularly small renal lesions. This phase is also more accurate for characterizing indeterminate lesions [29, 30, 32, 37]. However, the vascular phase provides excellent visualization of the renal arteries, which are important in surgical planning. The renal veins are also well visualized, whereas the inferior vena cava is best imaged during the nephrographic phase because in the vascular, mainly arterial, phase opacification of the vena cava is still inhomogeneous, mimicking tumor thrombosis. The key point in the contrast-enhanced examination is the correct timing of the acquisition of the scans with regard to the bolus injection. Although this is particularly true for multislice CT due to the small temporal window typical of these scanners, it is also important for single-slice spiral CT. Different options can be used depending on the available technology. The simplest option, available on all systems, is to perform a small bolus injection (20 mL) at a rate of 3 to 4 mL/s and to begin the acquisition of a series of scans at the single level, in general, the celiac axis, without table incrementing, to calculate the time of arrival of the contrast bolus. Once the arrival time has been calculated, a new bolus is injected and the incremental scans (from the upper pole to the lower pole of the kidneys) are obtained. An additional delay of 5 s (to be added to the arrival time) has been proposed to allow venous opacification [41]. Other solutions have been suggested by different manufacturers based on automatic or semiautomatic methods to detect the arrival of the contrast bolus in the abdominal aorta by using a region of interest that measures the density in a single plane. Compared with the previous method, these alternatives have the advantage of being faster and simpler.

Whatever the method used, the contrast bolus should be injected with a power injector at a relatively high speed (3–5 mL/s). The amount of contrast material to be used ranges from 100 to 130 mL. Scans for the vascular phase are generally obtained at 25 to 40 s from the start of the bolus injection. The nephrographic phase is imaged at 160 to 180 s.

Once the acquisition of the different phases has been completed, the images are transferred to the workstations for evaluation and reconstruction.

Multiplanar reformations (MPRs) are easily obtained. In general, the coronal plane is the most useful because it provides an immediate and comprehensive view of the kidney and the tumor mass. The position of the tumor within the renal parenchyma can be demonstrated on contiguous MPR coronal sections, which can be simultaneously visualized at the computer console. Alternative techniques are maximum intensity projection (MIP), surface-shaded display (SSD), and volume rendering (VR) [40–44] (Fig. 2). These different techniques offer advantages and disadvantages.

MPRs are bidimensional reconstructions obtained from the interpolation of axial images; the volume of data thus created can then be sectioned in different planes to obtain sagittal, coronal, oblique, or curvilinear reconstructed images (Fig. 2A). MPRs are easily performed (with the exception of curvilinear reformations). Image quality depends on the slice thickness, pitch, and reconstruction index.

MIP, SSD, and VR images are tridimensional reconstructions realized in two phases: the editing and the rendering.

By the editing it is possible to exclude from the volume of data the structures that are not interesting and to include only those that one wants to be represented on 3D reconstructions (Figs. 2C–E, 3A,B). There are different techniques of editing, such as the use of threshold, or manual segmentation, or interactive morphologic proceeds.

Rendering is the technique of 3D visualization of the structure of interest, previously selected by editing from the volume of data. MIP, SSD, and VR are different kinds of 3D visualization.

The MIP technique is based on the calculation of the higher value of density along every line of voxels of the image and then to show these values, represented in a gray scale, on a bidimensional plane. The technique is fast and simple, with high intrinsic contrast. However, the 3D perception is rather low, although it can be improved by rotating the object on the monitor of the workstation.

The SSD technique is based on the calculation of a mathematical model of the surface that joins the adjacent pixels at the level of the outlines of the object. The surface of interest is identified by the introduction of a threshold by the operator.

The SSD reconstructions are bidimensional images: the 3D effect derives from the application of shading. This operation is called *depth coding*. The technique produces an effective 3D perception with a nice outline of the surfaces of the organs. The disadvantages of SSD are the relative complexity (as opposed to MPR and MIP), some degree of operator dependency in the choice of the threshold value, and the preliminary editing when applied to the kidney and the abdominal organs. Further, the information is limited to the surface of the organ.

The VR technique uses the values of all voxels without any loss of data. With this technique, it is possible to visualize the different anatomic structures by modifying the mutual relations of opacity and transparencies, which are present in the volume of data, between the different structures. This is possible by the modulation of a curve, which relates the different degrees of opacity of the structures to the level and window, expressed in Hounsfield units. This technique permits exclusion of some structures, thus making them transparent, and consideration of others, making them opaque. The shape of the curve permits the use different techniques of 3D visualization, such as the fly-around technique, which allows external visualization of the structure, or the fly-through technique for an internal endoscopic-like visualization.

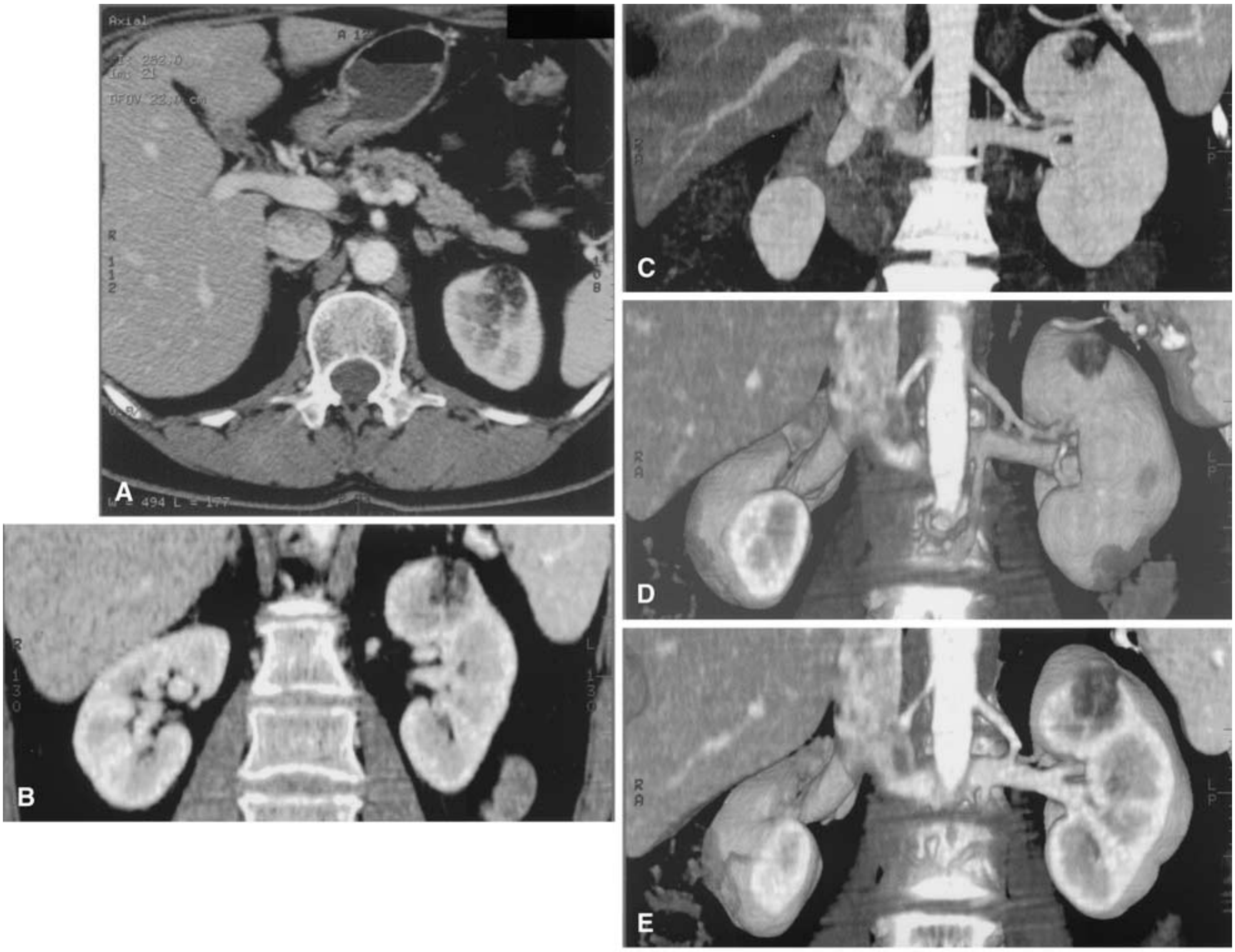

Fig. 2. **A** Axial CT shows a small renal tumor at the superior pole of the left kidney. **B** Coronal MPR. **C** Volume-rendered image shows the upper pole mass. The renal arteries and the retroaortic left renal vein are visible. **D** Volume-rendered image demonstrates improved perception of the kidneys, the mass, the renal arteries, and the renal veins. On the left, the gonadal vein joins the renal vein. **E** Volume-rendered image obtained with a "cut" function: the relations of the left renal mass with the renal cortex and medulla are better demonstrated. **F** Volume-rendered image on the axial plane with "cut" function shows the retroaortic renal vein on one image.

Contribution of CT in staging and surgical planning

The contribution of CT in the staging of renal tumors has been discussed extensively in the literature [45–48]. Most studies have dealt with conventional CT, so the additional contribution of spiral or multislice CT is not clearly defined. The thinner slice, the better image resolution, and the larger number of slices have increased the sensitivity and specificity of CT in the detection of renal lesions, whereas staging with regard to effects has increased diagnostic confidence for questionable findings, such as the infiltration of the Gerota fascia and adjacent organs, and the evaluation of the extension of the thrombus in the inferior vena cava [43].

The additional contribution of MPR and 3D images, however, is more substantial in surgical planning than in staging [41, 42].

MPR and 3D VR images provide immediate visualization of tumor site and extension, including that of the renal sinus. The position of the tumor relative to the ribs, the spine, the iliac crest, and the major vessels is readily appreciated.

In a series of 60 cases, all examined with 3D CT before nephron-sparing surgery, Coll et al. [42] found that the most

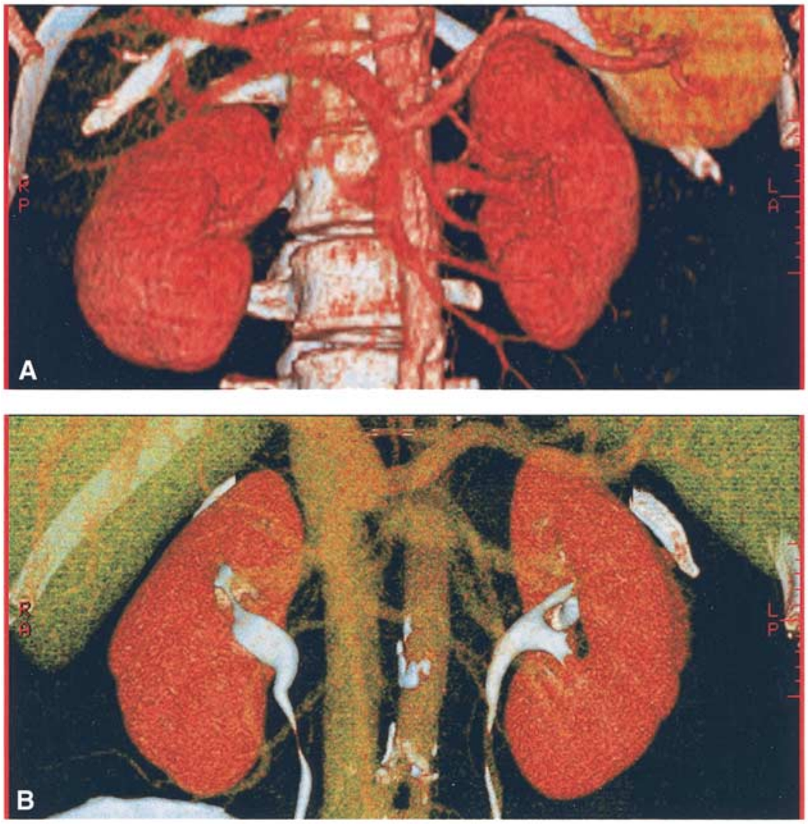

Fig. 3. **A** Volume-rendered image of the kidneys and major abdominal vessels. **B** Volume-rendered reconstructions shows the vessels, kidneys, and the renal pelvis and ureters in one image.

important contributions of this technique were the accurate 3D rendering of the renal vasculature, the definition of the relations with the collecting system, and the depiction of anatomic variants. Of 77 multiple renal arteries found at surgery, 74 were detected by 3D CT VR images. Of 69 renal veins identified at surgery, 64 were detected by 3D CT. 3D CT was as accurate as arteriography in the identification of the arteries but was superior in demonstrating venous anatomy and anatomic variants.

Magnetic resonance imaging

In comparison with US and CT, the role of MRI in the diagnosis of renal masses is more limited, even though the results of MRI have significantly improved with technologic advances of the past few years. Because the vast majority of renal masses are detected with US and CT, the contribution of MRI is focused on staging rather than on detection [49–53]. However, with its recent improvements, CT can provide all the information required for staging and, as previously shown, for adequate surgical planning.

The indications for MRI are limited to cases in which iodinated contrast medium are contraindicated, such as patients with known allergy to contrast agents or patients with renal failure. Despite these restrictions, MRI has an advantage over CT because it does not use ionizing radiation. Due to the increasing concern about the use of x-rays, the indications for MRI likely will increase in the near future.

There are two major areas of application of MRI in the imaging of renal masses: the characterization of undetermined renal masses and the staging of renal tumors. This second indication, as for CT, also includes the preoperative evaluation for the most appropriate surgical approach.

Examination technique

To be comparable with CT, MRI requires state-of-the-art equipment and precise examination technique. High field strength and high-power gradients are essential requirements for high-quality images. Phased-array coils are recommended to improve signal-to-noise ratio. These technologic advances have significantly reduced acquisition time so that breath-hold images of the abdomen can be obtained in most patients. Recent advances in the acquisition process associated with phased-array coils have further reduced imaging time.

The examination technique includes noncontrast and contrast-enhanced examinations.

There is no general consensus about the sequences for imaging renal tumors. The noncontrast-enhanced examination is based on fast (turbo) spin-echo T2-weighted sequences. Additional sequences may include spin-echo T1 or fat-suppressed sequences. T1- and T2-weighted sequences are important when characterization of a renal mass is needed, as in the case of a suspected hemorrhagic cyst.

Table 1. MRI sequences and main scanning parameters used for imaging renal tumors (1.5 Tesla, 30 mT/m gradient strength)

Pulse sequence (scan plane)	TR (ms)	TE (ms)	Flip angle	NSA	FOV (mm)	Matrix scan	Slice thickness (mm)	Acquisition time[a]
Gradient echo (axial)	253	4.6	80°	1	375	256	5	19.7''
Gradient echo fat suppressed (axial)	274	4.6	80°	1	375	256	5	1':25.5''
Turbo spin echo fat suppressed (axial)	677.3	165	90°	1	375	256	5	20.3''
Gradient echo (coronal)[b]	130	1.42	80°	1	400	256	5	17.5''[c]

[a]All sequences with SENSE (Sensitivity Encoding)
[b]Without and with contrast enhancement at 0'', 25'', 55'', and 175'' post Gd injection
[c]acquisition time for 22 slices

Fat-suppressed sequences are useful to characterize an angiomyolipoma. The noncontrast examination also includes the first phase of the turbo gradient-echo sequence before the injection of the paramagnetic contrast agent. Table 1 lists the scanning parameters in the case of a 1.5-T system with 30-mT/m gradient strength.

The contrast examination is based on the turbo gradient-echo sequence performed after injection of 0.1 mmol/kg of a gadolinium chelate. The coronal plane is the most widely used in MRI and is completed by axial scans.

The MRI examination can be completed with an angiographic acquisition and MR urography.

Contribution of MRI in staging and surgical planning

CT is recognized as the most effective modality for the staging of renal tumors. Its accuracy is approximately 90% [48]. MRI, however, yields results similar to those of CT in the staging of renal tumors and is considered superior in detecting venous tumor involvement in the renal vein and inferior vena cava and involvement of adjacent organs [50–54].

Among the advantages of MRI in surgical planning, the direct multiplanar capability has been considered an advantage over CT because image resolution is the same in the sagittal, coronal, and axial planes (Fig. 4). The coronal plane is usually preferred when imaging the kidney because it allows the simultaneous visualization of both kidneys, depicts the relation with adjacent organs such as the liver, the spleen, and the adrenals, and provides good visualization of the aorta and the inferior vena cava. However, spiral and mainly multislice CT scanners have reduced the gap between CT MPRs and direct sagittal and coronal images of MRI, so that today the coronal images of the two techniques are equally effective.

An interesting feature is that MRI can demonstrate the pseudocapsule. The pseudocapsule consists of fibrous tissue and compressed renal parenchyma that may be associated with small renal tumors, usually of low grade [53–55]. Pretorius et al. [53] detected the pseudocapsule in about 60% of cases, mainly on T2-weighted images and then on post-gadolinium spoiled gradient-echo images. MRI is superior to CT in demonstrating this feature, which may represent an additional finding in favor of nephron-sparing surgical techniques.

Comments

The new possibilities offered by modern imaging modalities are extremely interesting from the perspective of diagnosis and surgical planning and have expanded the role of imaging, which until recently was limited mainly to diagnosis.

However, some problems concerning the use of imaging modalities for surgical planning need to be considered. These include the complexity of reformations and reconstructions, the equipment required to obtained these types of images, the personnel involved and the time needed for image reconstruction, the type of documentation (film or video), and the global cost.

The complexity of reformation and reconstruction is quite variable. MPRs are generally very easily obtained and rapidly visualized. The quality of these images is also quite variable and depends mainly on slice thickness, table increment (pitch), and the reconstruction index. Because multislice scanners enable more, thinner slices to be obtained compared with single-slice spiral CT, MPR images are of better quality with this type of scanner. The same is also true for other types of reconstruction (SSD and VR) because the thinner slice is the fundamental parameter to reduce the artifacts usually present on all types of reconstruction. SSD and VR are more complex to obtain than are MPR images and require, in most circumstances, preliminary editing of the axial images. This means that the results will depend not only on the previous parameters (slice thickness, pitch, and reconstruction index) but also on the expertise of the operator at the workstation.

The equipment required to obtain these images is essentially the workstation. In general, most CT and MR scanners are equipped with an off-line dedicated computer for image processing. These computers, usually referred to as workstations, run dedicated software for image processing, such as MPR, MIP, SSD, and VR.

The personnel performing the reconstruction may be the radiologist or the technician. However, there are definite advantages if the radiologist performs the reconstructions of the images. First, in some cases, reconstructed images are useful to solve diagnostic problems (e.g., contact or infiltra-

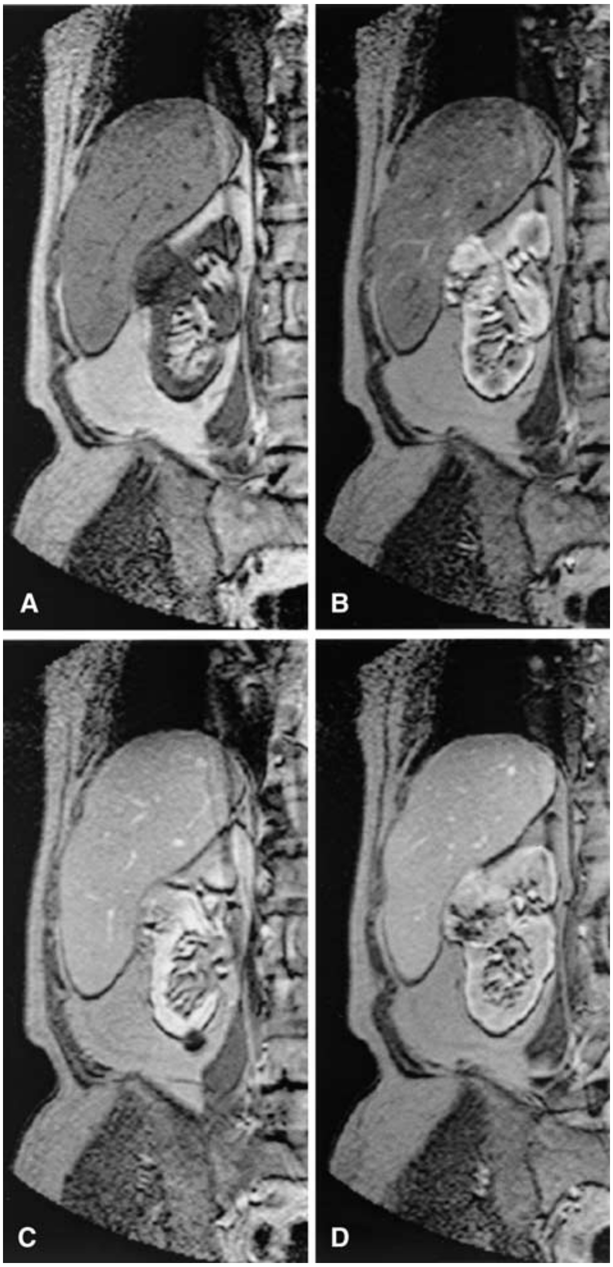

Fig. 4. Coronal dynamic MRI (gradient-echo sequence) of the kidneys: (**A**) noncontrast and contrast-enhanced MRI in the (**B**) cortical, (**C**) medullary, and (**D**) nephrographic phases. Hypervascular tumor is on the lateral aspect of the right kidney. Contact with the liver is well demonstrated on the direct coronal sections.

tion with the liver or spleen in the case of a mass at the upper pole of the kidney). Second, the radiologist knows exactly what needs to be demonstrated in the reconstructed images and therefore can select one or more images that show the additional information. Third, it is obvious that it is easier for the radiologist to respond to the urologist's query. However, it has to be considered that imaging time may be long, mainly in cases of SSD and VR. Therefore, cooperation between radiologists and technicians can improve results and reduce imaging time.

Documentation may be in the form of film or video. The best visualization is on the workstation because it has all the facilities for reconstructing and visualizing the images. Films are simple but limited because the operator has to choose the most significant images. However, in many cases, films are adequate to provide the urologist with the information needed. Videos are more complete because all the data used in the multiple reconstructions can be stored on one format (e.g., CD-ROM and DVD). Images also can be transferred directly to the operating room if it has visualization equipment. Although ideal, this solution is rather expensive.

The greatest problem connected with this type of reconstruction is the cost. The cost is related to equipment (workstation), software, maintenance, upgrading of the equipment and the software, and the cost of personnel. It is not easy to quantify the global cost. However, with the increasing diffusion of multislice CT and the new MRI equipment, the radiologist cannot avoid performing this type of imaging. Therefore, a revision of the costs of CT and MRI examinations must be performed for studies requiring image reconstruction.

References

1. Zagoria J (2000) Imaging of small renal masses: a medical success story. AJR 175:945–955
2. Russo P (2000) Renal cell carcinoma: presentation, staging, and surgical treatment. Semin Oncol 27:160–176
3. Paparel P, Rouviere O, Lezrek M, et al. (2002) Treatment of renal tumors with radiofrequency: preliminary results. Prog Urol 12:1194–1203
4. Remer EM, Herts BR, Veniero JC (2002) Imaging for nephron-sparing surgery. Semin Urol Oncol 20:180–191
5. Debra A, Gervais MD, Francis J, et al. (2003) Renal cell carcinoma: clinical experience and technical success with radio-frequency ablation of 42 tumors. Radiology 226:417–424
6. McGovern FJ, Wood BJ, Goldberg SN, Mueller PR (1999) Radiofrequency ablation of renal cell carcinoma via image-guided needle electrodes. J Urol 161:599–600
7. Gervais DA, McGovern FJ, Wood BJ, et al. (2000) Radio-frequency ablation of renal cell carcinoma: early clinical experience. Radiology 217:665–672
8. Walther MC, Shawker TH, Libutti SK, et al. (2000) A phase 2 study of radio frequency interstitial tissue ablation of localized renal tumors. J Urol 163:1424–1427
9. Licht MR, Novick AC (1993) Nephron sparing surgery for renal cell carcinoma. J Urol 149:1–7
10. Steinbach F, Stockle M, Hohenfellner R (1995) Clinical experience with nephron-sparing surgery in the presence of a normal contralateral kidney. Semin Urol Oncol 13:288–291
11. Campbell SC, Novick AC (1995) Surgical technique and morbidity of elective partial nephrectomy. Semin Urol Oncol 13:281–287
12. Lerner SE, Hawkins CA, Blute ML, et al. (1996) Disease outcome in patients with low stage renal cell carcinoma treated with nephron sparing or radical surgery. J Urol 155:1868–1873
13. Steinbach F, Stockle M, Hohenfellner R (1995) Current controversies in nephron-sparing surgery for renal-cell carcinoma. World J Urol 13:163–165
14. Bosniak MA (1991) The small (3.0 cm) renal parenchyma tumor: detection, diagnosis, and controversies. Radiology 179:307–317
15. Scialpi M, Di Maggio A, Midiri M, et al. (2000) Small renal masses: assessment of lesion characterization and vascularity on dynamic contrast-enhanced MR imaging with fat suppression. AJR 175:751–757
16. Tello R, Davison BD, O'Malley M, et al. (2000) MR imaging of renal masses interpreted on CT to be suspicious. AJR 174:1017–1022

17. Israel GM, Krinsky GA (2003) MR imaging of the kidneys and adrenal glands. Radiol Clin North Am 41:145–159
18. Ho VB, Allen SF, Hood MN, Choyke PL (2002) Renal masses: quantitative assessment of enhancement with dynamic MR imaging. Radiology 224:695–700
19. Yamashita Y, Miyazaki T, Hatanaka Y, Takahashi M (1995) Dynamic MRI of small renal cell carcinoma. J Comput Assist Tomogr 19:759–765
20. Dalla Palma L, Pozzi-Mucelli R, Magnaldi S, Pozzi-Mucelli F (1988) Diagnostica per immagini dei tumori renali di piccole dimensioni. Radiol Med (Torino) 76:590–596
21. Vallencien G, Torres LO, Gurfinkel E, et al. (1990) Incidental detection of renal tumors by abdominal ultrasonography. Eur Oncol 18:94–96
22. Helenon O, Correas JM, Balleyguier C, et al. (2001) Ultrasound of renal tumors. Eur Radiol 11:1890–1901
23. Jinzaki M, Ohkuma K, Tanimoto A, et al. (1998) Small solid renal lesions: usefulness of power Doppler US. Radiology 209:543–550
24. Quaia E, Siracusano S, Bertolotto M, et al. (2003) Characterization of renal tumours with pulse inversion harmonic imaging by intermittent high mechanical index technique: initial results. Eur Radiol 13:1402–1412
25. Campbell SC, Fichtner J, Novick AC, et al. (1996) Intraoperative evaluation of renal cell carcinoma: a prospective study of the role of ultrasonography and histopathological frozen sections. J Urol 155: 1191–1195
26. Smith SJ, Bosniak MA, Megibow AJ, et al. (1988) Renal cell carcinoma: earlier discovery and increased detection. Radiology 170:699–703
27. Jamis-Dow CA, Choyke PL, Jennings SB, et al. (1996) Small (< or = 3-cm) renal masses: detection with CT versus US and pathologic correlation. Radiology 198:785–788
28. Bosniak MA, Rofsky NM (1996) Problems in the detection and characterization of small renal masses. Radiology 198:638–641
29. Szolar DH, Kammerhuber F, Altziebler S, et al. (1997) Multiphasic helical CT of the kidney: increased conspicuity for detection and characterization of small (< 3-cm) renal masses. Radiology 202:211–217
30. Kauczor HU, Schwickert HC, Schweden F, et al. (1994) Bolus-enhanced renal spiral CT: technique, diagnostic value and drawbacks. Eur J Radiol 18:153–157
31. Cohan RH, Sherman LS, Korobkin M, et al. (1995) Renal masses: assessment of corticomedullary-phase and nephrographic-phase CT scans. Radiology 196:445–451
32. Birnbaum BA, Jacobs JE, Ramchandani P (1996) Multiphasic renal CT: comparison of renal mass enhancement during the corticomedullary and nephrographic phases. Radiology 200:753–758
33. Zeman RK, Zeiberg A, Hayes WS, et al. (1996) Helical CT of renal masses: the value of delayed scans. AJR 167:771–776
34. Kopka L, Fischer U, Zoeller G, et al. (1997) Dual-phase helical CT of the kidney: value of the corticomedullary and nephrographic phase for evaluation of renal lesions and preoperative staging of renal cell carcinoma. AJR 169:1573–157
35. Yuh BI, Cohan RH (1999) Different phases of renal enhancement: role in detecting and characterizing renal masses during helical CT. AJR 173:747–755
36. Macari M, Bosniak MA (1999) Delayed CT to evaluate renal masses incidentally discovered at contrast-enhanced CT: demonstration of vascularity with deenhancement. Radiology 213:674–680
37. Urban BA (1997) The small renal masses: what is the role of multiphasic helical scanning. Radiology 202:22–23
38. Yuh BI, Cohan RH (1999) Different phases of renal enhancement: role in detecting and characterizing renal masses during helical CT. AJR 173:747–755
39. Smith RC, Verga M, McCarthy S, Rosenfield AT (1996) Diagnosis of acute flank pain: value of unenhanced helical CT. AJR 166:97–101
40. Smith PA, Marshall FF, Corl FM, Fishman EK (1999) Planning nephron-sparing renal surgery using 3D helical CT angiography. J Comput Assist Tomogr 23:649–654
41. Coll DM, Uzzo RG, Herts HR, et al. (1999) 3-Dimensional volume rendered computerized tomography for preoperative evaluation and intraoperative treatment of patients undergoing nephron sparing surgery. J Urol 161:1097–1102
42. Coll DM, Herts HR, Davros WJ, et al. (2000) Preoperative use of 3D volume rendering to demonstrate renal tumors and renal anatomy. Radiographics 20:431–438
43. Sheth S, MD, Scatarige JC, Horton KM, MD, et al. (2001) Current concepts in the diagnosis and management of renal cell carcinoma: Role of multidetector CT and three-dimensional CT. Radiographics 21:S237–S254
44. Johnson PT, Heath DG, Bliss DF, et al. (1996) Three-dimensional CT: real-time interactive volume rendering. AJR 167:581–583
45. Dinney CPN, Awad SA, Gajewski JB, et al. (1992) Analysis of imaging modalities, staging systems, and prognostic indicators for renal cell carcinoma. Urology 36:22–29
46. Thrasher JB, Paulson DF (1993) Prognostic factors in renal cancer. Urol Clin North Am 20:247–26
47. Johnson CD, Dunnick NR, Cohan RH, Illescas FF (1987) Renal adenocarcinoma: CT staging of 100 tumors. AJR 148:59–63
48. Bechtold RE, Zagoria RJ (1997) Imaging approach to staging of renal cell carcinoma. Urol Clin North Am 24:507–522
49. Patel SK, Stack CM, Turner DA (1987) Magnetic resonance imaging in staging of renal cell carcinoma. Radiographics 7:703–728
50. Semelka RC, Shoenut JP, Magro CM, et al. (1993) Renal cancer staging: comparison of contrast-enhanced CT and gadolinium-enhanced fat-suppressed spin-echo and gradient-echo MR imaging. J Magn Reson Imaging 3:597–602
51. Choyke PL (1997) Detection and staging of renal cancer. Magn Reson Imaging Clin North Am 5:29–47
52. Pretorius ES, Siegelman ES, Ramchandani P, et al. (1999) Renal neoplasms amenable to partial nephrectomy: MR imaging. Radiology 212:28–34
53. Pretorius ES, Wickstrom ML, Siegelman ES (2000) MR imaging of renal neoplasms. Magn Reson Imaging Clin North Am 8:813–836
54. Takahashi S, Ueda J, Furukawa T, et al. (1996) Renal cell carcinoma: preoperative assessment for enucleative surgery with angiography, CT, and MRI. J Comput Assist Tomogr 20:863–870
55. Yamashita Y, Honda S, Nishiharu T, et al. (1996) Detection of pseudocapsule of renal cell carcinoma with MR imaging and CT. AJR 166: 1151–1155