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Ultrasound of renal tumors

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Abstract Despite the limitations of US in providing a complete evaluation of renal tumors before treatment planning, initial screening, characterization of renal masses and staging of RCCs can benefit from some recent advances of the technique. One of the most relevant clinical benefits of US is the increased early detection of RCCs. Recent technical improvement of gray-scale imaging has increased US performance in the detection of small renal tumors. Combined gray-scale and color Doppler US findings may strongly suggest the histopathologic nature of a renal tumor with respect to the size, the US attenuation characteristics, and the vascular distribution of the lesion. Ultrasound contributes additional diagnostic information for differential diagnosis of some renal masses that remain equivocal at CT, including: atypical cystic lesions; solid renal tumors with poor vascularity; and angiomyolipomas with minimal fat component. Ultrasound also may provide additional diagnostic information over CT in selected cases of RCCs with venous invasion. In addition to some diagnostic and therapeutic procedures that can benefit from US guidance, intraoperative US remains the only available tool that enables to ensure renal-parenchymal-sparing surgery.

Keywords Kidney neoplasms · Pseudotumors · Ultrasound · Color Doppler studies

Introduction

Imaging of renal tumors relies mainly on CT since it is the gold standard in detecting and characterizing renal masses and staging renal cell carcinomas (RCC). Although US cannot answer all the questions related to renal tumor imaging, it plays a key role in early diagnosis of RCC and may provide additional diagnostic information over CT in selected cases among renal masses that remain equivocal at CT and RCCs with venous invasion. Moreover, US is the only available intraoperative tool that may help remove a small tumor during renal-parenchymal-sparing surgery. Herein we describe the results of US in the diagnosis of renal tumors and discuss its current role in detecting and characterizing renal masses and in the preoperative assessment of renal tumors.

Detection of renal tumors

Early diagnosis of RCCs

One of the most relevant clinical benefits of US is the increased early detection of RCCs. Up to 83 % of asymptomatic renal tumors are incidentally detected at US [1]. At initial screening, the tumor is significantly smaller (5.5 cm) and with lower local tumor stage than those depicted in symptomatic patients (7.8 cm) [1].

In addition to some technical and anatomical factors that may alter US performance, the detectability of renal tumors depends mainly on the size, location, and echogenicity of the lesion. The main limitations of US in the detection of renal tumors are related to small isoechoic intraparenchymal tumors and tumors of polar

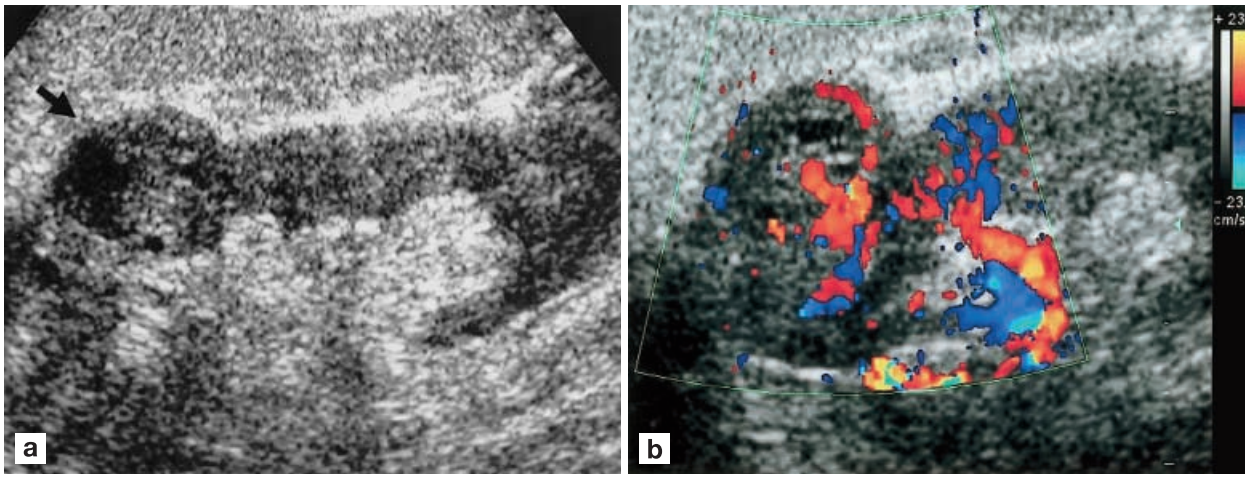


Fig. 1 a, b Small asymptomatic renal cell carcinoma (RCC). **a** Ultrasound shows isoechoic, slightly heterogeneous solid renal mass responsible for capsular bulging *(arrow)*. **b** Tumor vascularity at color Doppler exhibits a mixed penetrating and peripheral vascular distribution

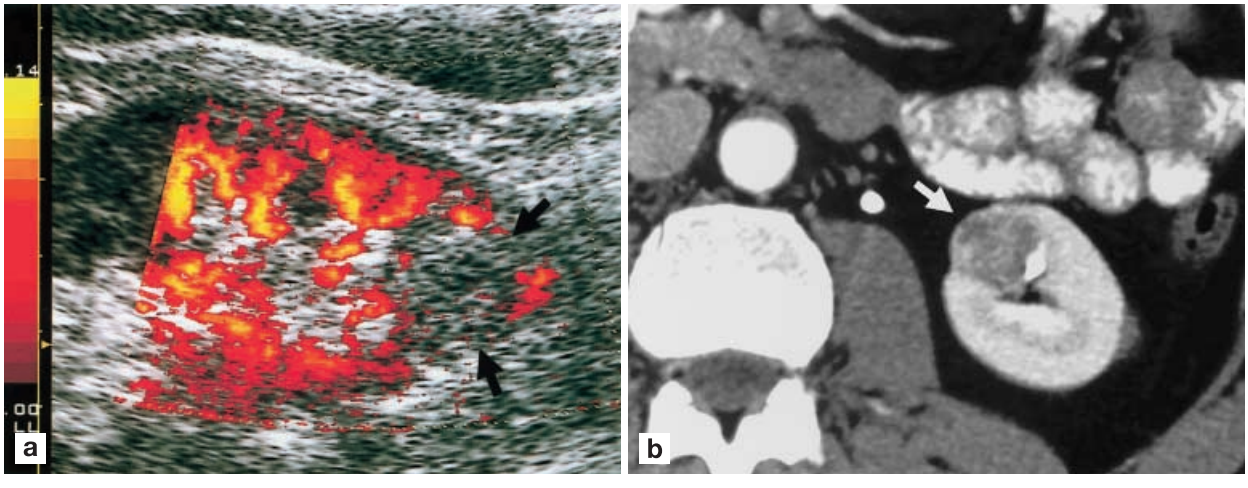
origin with extrarenal growth that may be obscured by bowel gas. Among small RCCs (3 cm or less), 23–46 % of solid tumors are iso- or hypoechoic compared with normal renal parenchyma (Fig. 1) [2, 3, 4]. On the other hand, the majority of small benign tumors are hyperechoic (94 % of small angiomyolipomas) and easily depicted at US; therefore, despite the increased detection of small hyperechoic renal carcinomas, the wide majority of renal tumors that are overlooked at US are small RCCs.

The use of color Doppler, with either conventional velocity or power mode, seems not to increase significantly the detection rate of small tumors; however, an increased confidence can be obtained in the diagnosis of small isoechoic intraparenchymal tumors by depicting a color-coded rim due to renal blood vessels that arise outside the lesion and surround it (Fig. 2). Such a finding is better seen on power Doppler US images.

Technical improvements

Recent technical improvements of gray-scale imaging are deemed to increase US performance in the detection of small renal tumors. Harmonic B-mode tissue imaging is now a widely implemented modality that provides a better contrast resolution and less artifacts on gray-scale images. In addition to its better capabilities in characterizing cystic renal masses, this modality may help depict small slightly hypo- or hyperechoic

Fig. 2 a, b Small isoechoic intraparenchymal RCC. **a** Power Doppler US shows hypovascular round shaped lesion *(arrows)* surrounded by normal renal vessels. **b** Contrast-enhanced CT demonstrates small solid renal tumor within the lower pole of the left kidney



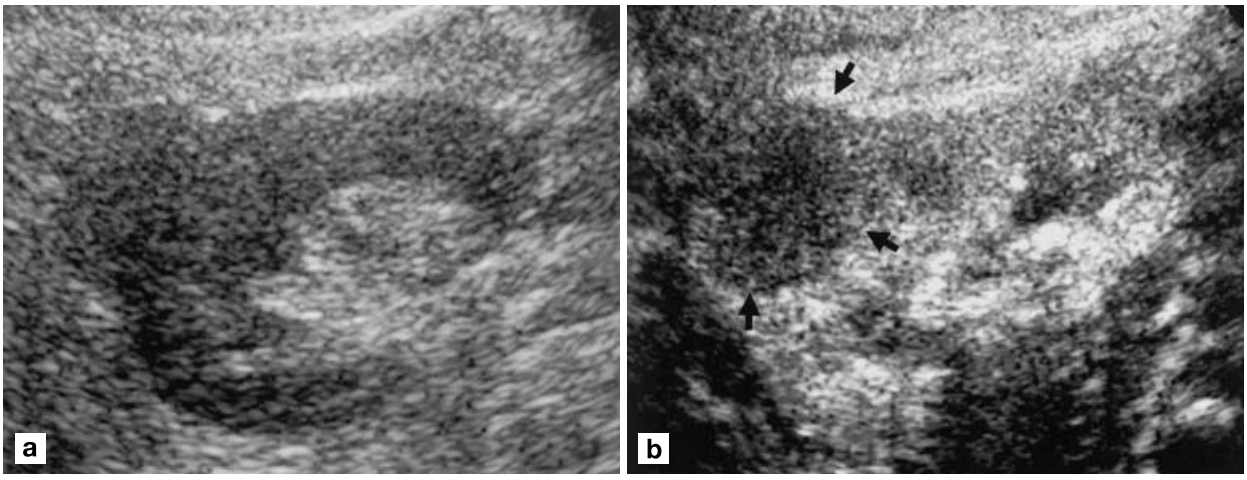


Fig. 3 **a** Pre- and **b** post-contrast US using pulse inversion imaging of a small isoechoic RCC (transverse scan). Contrast-enhancement of the normal renal cortex enables better delineation of the tumor (**b**, *arrows*)

solid masses. It also provides a better delineation or kidney margins and therefore increases confidence in diagnosing small subcapsular isoechoic tumors responsible for a capsular bulging.

The use of US contrast agents (USCA) enables to obtain a significant cortical signal enhancement after intravenous administration on both color Doppler and gray-scale images obtained with dedicated imaging sequences. The detection of small renal masses, especially those that exhibit isoechoic pattern, can be improved since the normal renal vascular architecture is altered.

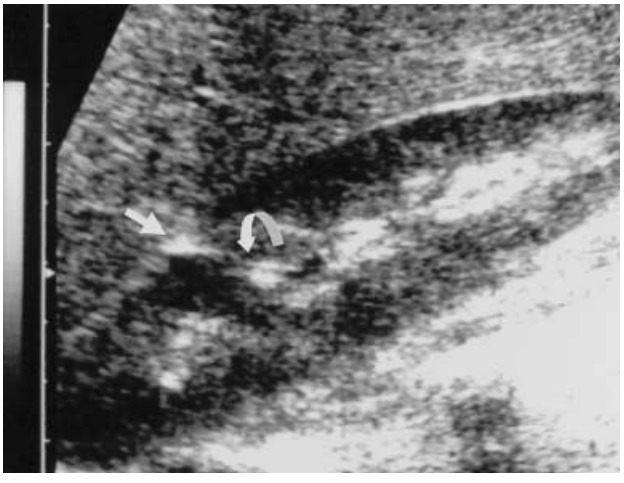


Fig. 4 Junctional parenchymal defect in a right kidney mimicking small hyperechoic subcapsular renal tumor *(straight arrow)*. Typically, a hyperechoic intraparenchymal line *(curved arrow)* connect the defect to renal sinus

At peak enhancement, small masses appear as round-shaped cortical defects underlined by the massive blood flow enhancement obtained from the normal surrounding vessels on postcontrast color Doppler images [5]. The same effect can be achieved with B-mode non-linear imaging. Small hypovascular renal masses exhibit a hypoechoic round-shaped mass surrounded by normal hyperechoic enhanced parenchyma on early postcontrast images (Fig. 3).

Characterizing solid renal masses

The goals of imaging in characterizing solid renal tumors are: (a) to differentiate renal tumors from normal variants or pseudotumors that may mimic a neoplasm; and (b) to differentiate benign from malignant renal tumors, especially angiomyolipoma from non-fatty renal tumors that should be removed.

Gray-scale US features exhibited by solid renal tumors do not provide definitive tissue characterization since a considerable overlap in echogenicity among renal tumors has been reported [2, 3, 4, 6, 7, 8]; however, several features have been advocated for differential diagnosis of solid tumors. Although not pathognomonic, some of the reported findings that correlate with the gross appearance of the tumor at histopathologic examination may help differentiate malignant from benign tumors.

Color Doppler US can add some information to that obtained at gray-scale US which can be useful for differential diagnosis of solid tumors. A recent power-Doppler-based classification has been reported by Jinzaki and coworkers [3].

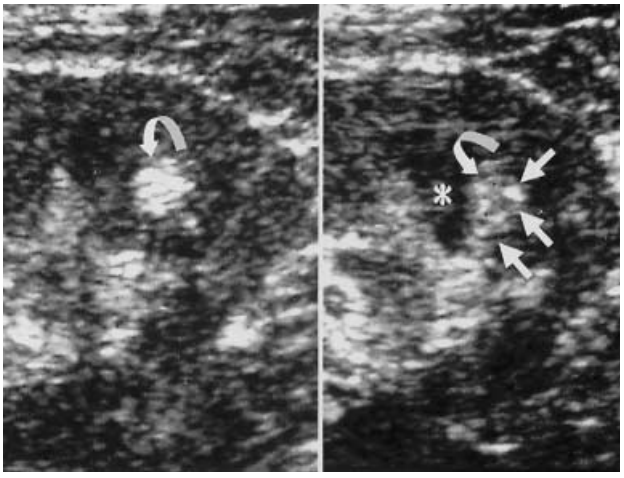


Fig. 5 False small hyperechoic renal tumor (*left, curved arrow*) due to renal sinus tissue extending up to the corticomedullary junction. Oblique scan *(right)* obtained in the plane of the longitudinal axis of the pyramid *(star)* demonstrates the connection between the corticomedullary junction and the renal sinus *(straight arrows)*

Pseudotumors

False hyperechoic tumors

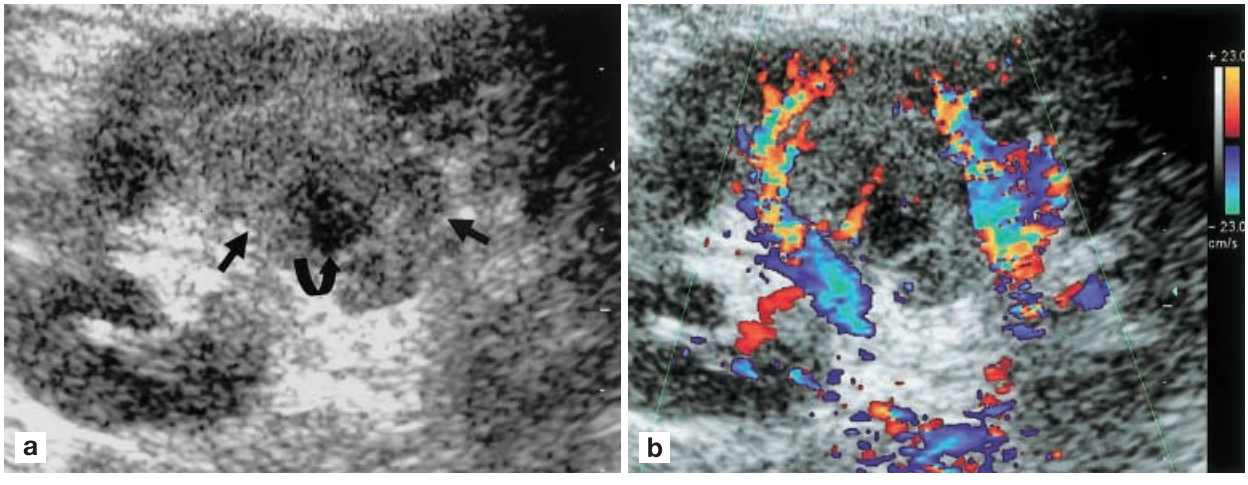
Some cortical defects containing fat may mimic a small subcapsular hyperechoic tumor at US. Such a finding can be related to a normal variant also known as the junctional parenchymal defect [9] or to a postoperative defect packed with retroperitoneal fat [10]. Criteria that may help avoid unnecessary work-up in both conditions are, respectively, the presence of a junctional parenchymal hyperechoic line associated with the parenchymal notch (Fig. 4) and a history of partial renal resection.

On the other hand, the renal sinus fat may create pitfalls in diagnosing a hyperechoic parenchymal tumor. Some fatty tissue arising from the renal sinus may be located at the corticomedullary junction and can mimic a round-shaped hyperechoic mass within the deep cortex (Fig. 5). Conversely, the intrasinusal growth of an AML may prevent tumor identification while mimicking sinus lipomatosis.

Lobar dysmorphisms and fetal lobations

Lobar dysmorphisms are well-known variants that may simulate renal tumor with sinus growth. Typical gray-scale US features include: a well-defined mass arising from the deep renal parenchyma; and an isoechoic homogeneous pattern compared with renal cortex, associated with the presence of a hypoechoic Malpighi's pyramid in case of junctional lobar dysmorphism (Fig. 6) [9]. Color Doppler US may increase confidence in diagnosing such variant by demonstrating a normal vasculature which consists of normal segmental and interlobar blood vessels that arise outside the lesion and surround it before they reach the neighboring corticomedullary junction (Fig. 6b). Arcuate branches can also be seen within the mass especially in cases of junctional dysmorphism (Fig. 6b). The diagnosis of pseudotumoral fetal lobation also can benefit from the color Doppler US demonstration of a normal cortical vascular distribution compared with surrounding renal parenchyma [3].

Fig. 6 a, b Junctional lobar dysmorphism. **a** Lobar portion of renal parenchyma with renal sinus development consists of renal cortex *(straight arrows)* and medulla *(curved arrow)*. **b** Color Doppler US shows normal interlobar and arcuate branch vascular distribution



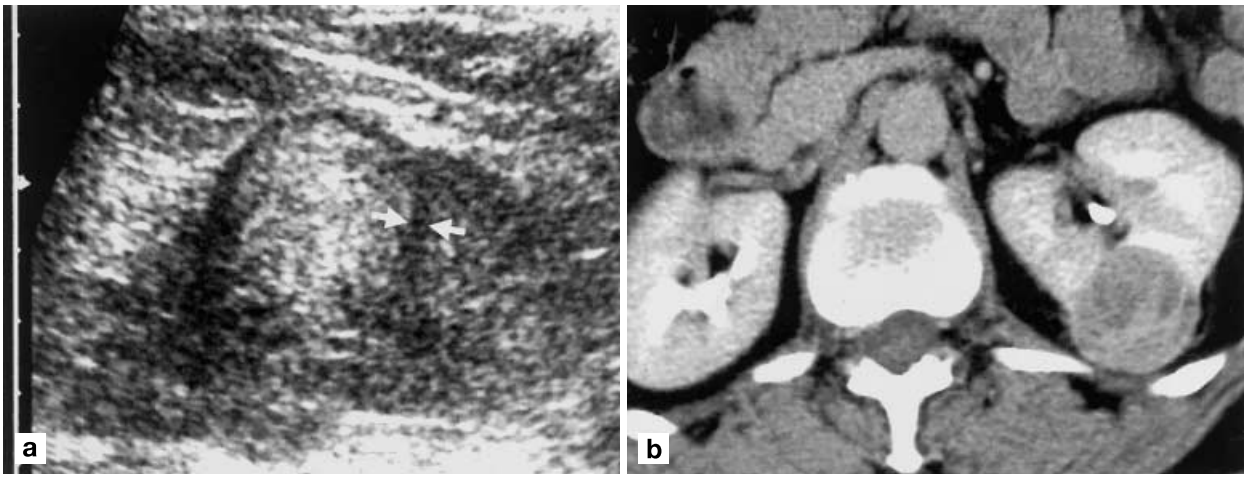


Fig. 7a, b Small hyperechoic RCC. **a** Ultrasound shows hyperechoic tumor with hypoechoic rim *(arrows)* which suggests malignancy. **b** A CT demonstration of a small tumor likely to be an RCC (histologically proved)

Small renal neoplasms

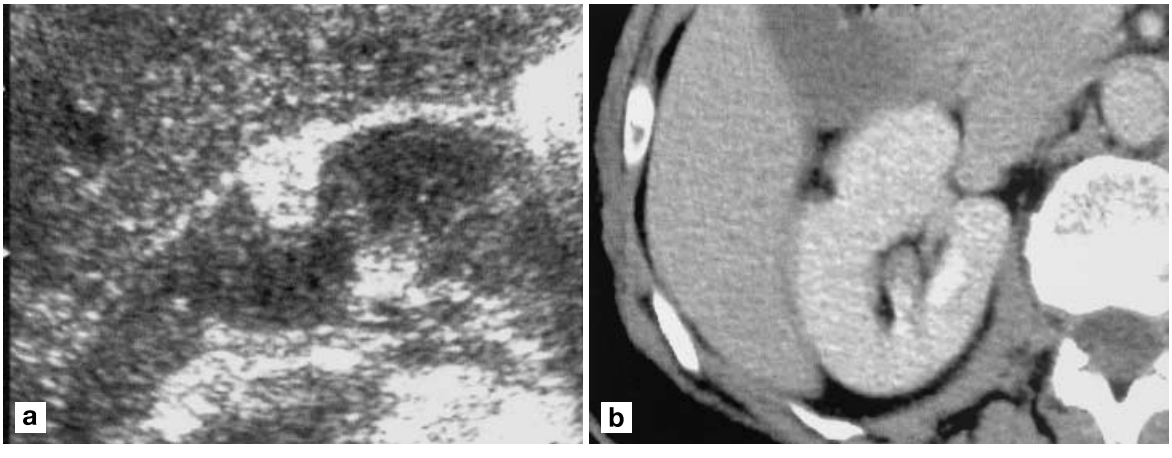
Small RCC

Approximately 30 % of small RCCs appear as markedly hyperechoic masses and may mimic AML [2]. Criteria such as the presence of an anechoic rim or small intratumoral cysts can suggest RCC at gray-scale US (Fig. 7) [6]. However, the usefulness of these findings for differential diagnosis is not yet established since there is a considerable variability in their detection rate among investigators, from 8 to 84 % and 12 to 31 %, respectively [3, 4, 6, 8]. The vascular distribution at power Doppler US could add some information to that at gray-scale US for diagnosis of RCC. The recent classification reported in the work of Jinzaki et al. consists of five patterns depending on the vascular distribution at power Doppler US [3]: pattern 0, no signal; pattern 1, intratumoral and focal signals; pattern 2, penetrating vessels; pattern 3, peripheral vascular distribution; and pattern 4, mixed, penetrating, and peripheral (Fig. 1b). Among the 64 reported small renal neoplasms, no RCCs exhibited patterns 0, 1, or 2, whereas all the 26 RCCs and only 20 % of the AMLs were associated with patterns 3 or 4. Although not specific enough, such a power Doppler pattern may suggest malignancy particularly when it is combined with gray-scale criteria.

Small benign tumors

Findings that suggest a small (< 3 cm) AML are (Fig. 8) [3, 8, 11]: a markedly hyperechoic lesion (iso- or hyperechoic compared with renal sinus); a homogeneous pat-

Fig. 8a, b Small angiomyolipoma. **a** Ultrasound shows a small markedly hyperechoic renal tumor with sharp margins and a homogeneous pattern. **b** A CT scan demonstrates obvious fat attenuation values within the lesion



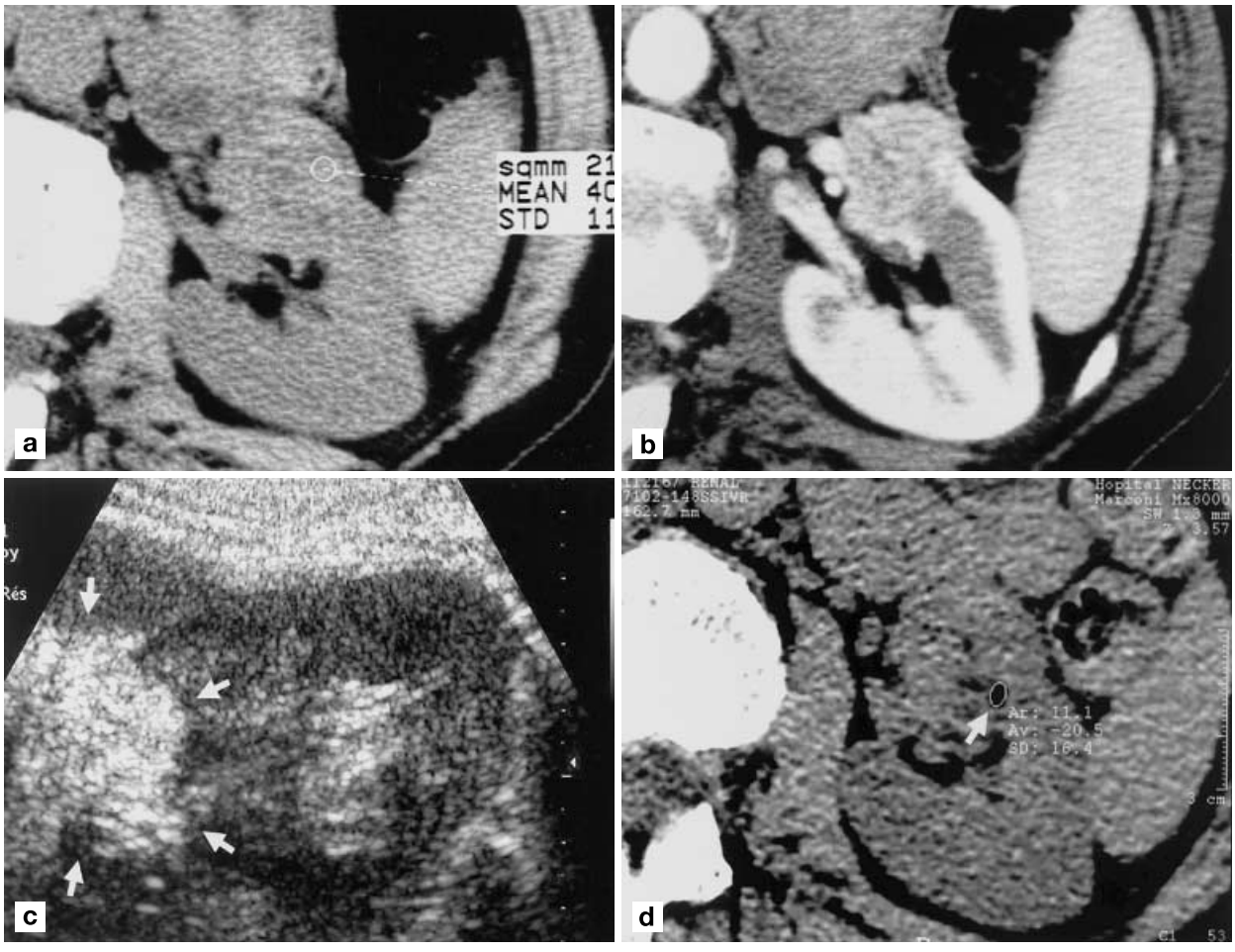


Fig. 9 a–d Atypical angiomyolipoma with minimal fat component. **a** Pre- and **b** postcontrast CT using a standard protocol (5-mm slice thickness) failed to demonstrate intratumoral fat. **c** Ultrasound showed suggestive hyperechoic pattern *(arrows)* that prompted repeat CT examination using thinner collimation. **d** Unenhanced CT scan using 3-mm slice thickness clearly demonstrates a tiny intratumoral island of fat tissue which prevents surgery

tern with sharp margins; shadowing, seen in 21–33 % of AMLs; intratumoral focal or penetrating vascular flow signal at power Doppler corresponding to patterns 1 and 2, respectively, from Jinzaki et al.'s classification [3].

Contrary to previous reports, echogenicity of AML seems not to correlate with the amount of intratumoral fat [11]; however, in a series of six AMLs with minimal fat, Jinzaki and coworkers found homogeneous isoechogenicity on sonograms in all cases [7]. Although a markedly hyperechoic homogeneous lesion is highly suggestive of AML, it is not pathognomonic and therefore requires CT confirmation. The demonstration of a renal tumor with such a suggestive US pattern should prompt careful CT examination or repeat examination, using a dedicated CT scanning protocol including precontrast thin (3-mm) sections (Fig. 9).

On the other hand, small AMLs with atypical US appearance include slightly hyperechoic (not as echogenic as renal sinus fat) and iso- or hypoechoic lesions compared with renal parenchyma which account for 29 and 6 %, respectively [3].

No reliable pattern at US has been reported to differentiate oncocytomas from RCCs. Although, tumor homogeneity has been advocated to suggest small oncocytoma, it has no interest for differential diagnosis because of a considerable overlap among small renal tumors including RCCs.

Large renal tumors

Although several features at gray-scale US may help differentiate benign from malignant renal neoplasms, CT is always mandatory to better characterize the tumor.

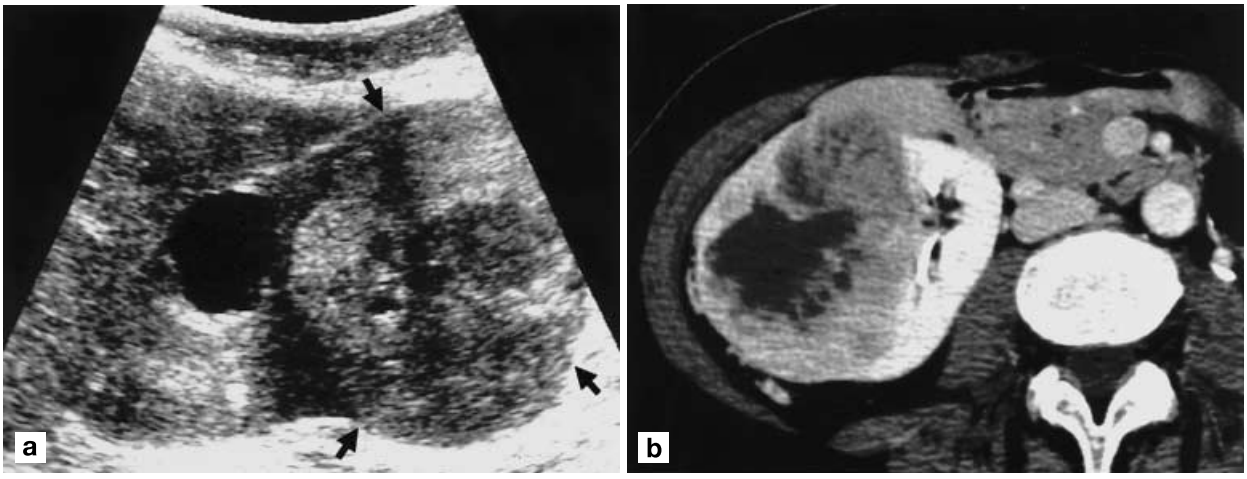


Fig. 10 Large RCC. **a** Ultrasound shows a large heterogeneous solid renal tumor *(arrows)* within the lower pole of the right kidney. **b** Contrast-enhanced CT demonstration of a typical large necrotic RCC

Large RCC

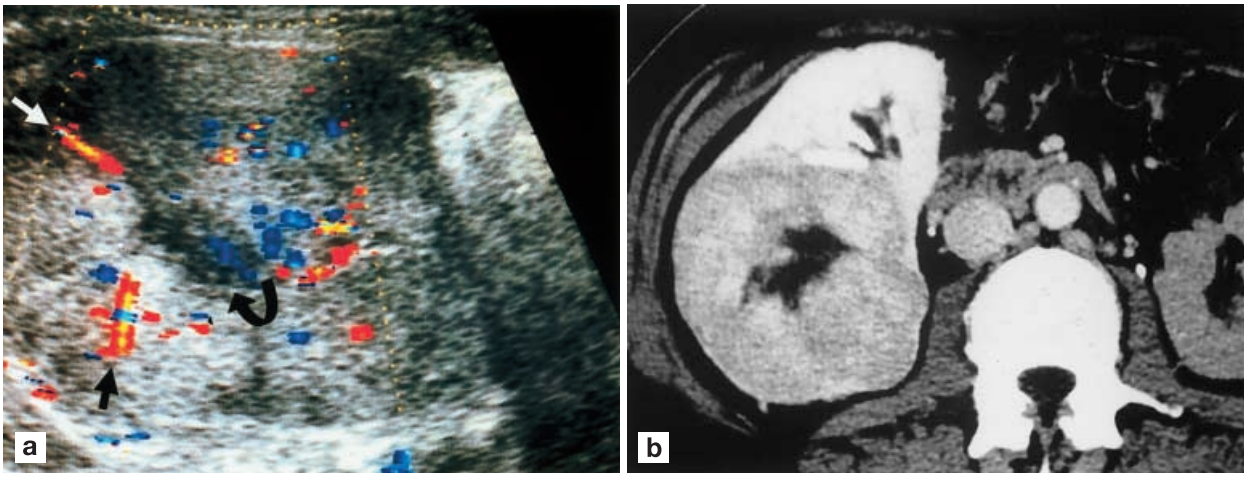
Large RCCs typically show heterogeneous US pattern due to intratumoral hypoechoic necrotic areas (Fig. 10), sometimes associated with scattered calcifications. At Doppler US, the presence of intratumoral arteriovenous shunting also suggest RCC. Such finding is at best characterized by spectral analysis obtained from vessels exhibiting high velocity signal on color Doppler image; however, this finding does not contribute definitive diagnostic criteria for RCC, since AMLs may exhibit the same pattern. On the other hand, the association between a large renal tumor and finding that suggests a venous tumor invasion strongly suggests malignancy and likely an RCC irrespective of the gray-scale appearance of the lesion.

Large benign tumors

Some suggestive patterns that have been described at CT in the diagnosis of oncocytomas can also be seen at US but with a lower detection rate and lower confidence. The central scar seen in large oncocytomas produce a stellate hypoechoic area at US (Fig. 11) [12]. A spoke-wheel distribution of tumor vessels also can be demonstrated at color Doppler with or without the association of a central hypoechoic scar (Fig. 11). Both criteria are only seen in large oncocytomas.

Large AMLs often show a suggestive hyperechoic appearance that may suggest the diagnosis at US;

Fig. 11a, b Large renal oncocytoma with suggestive pattern. **a** Contrast-enhanced CT shows a large renal tumor with suggestive intratumoral central stellate scare. **b** Color Doppler US shows hypoechoic central area *(curved arrow)* associated with a spoke-wheel distribution of tumor vessels *(straight arrows)*



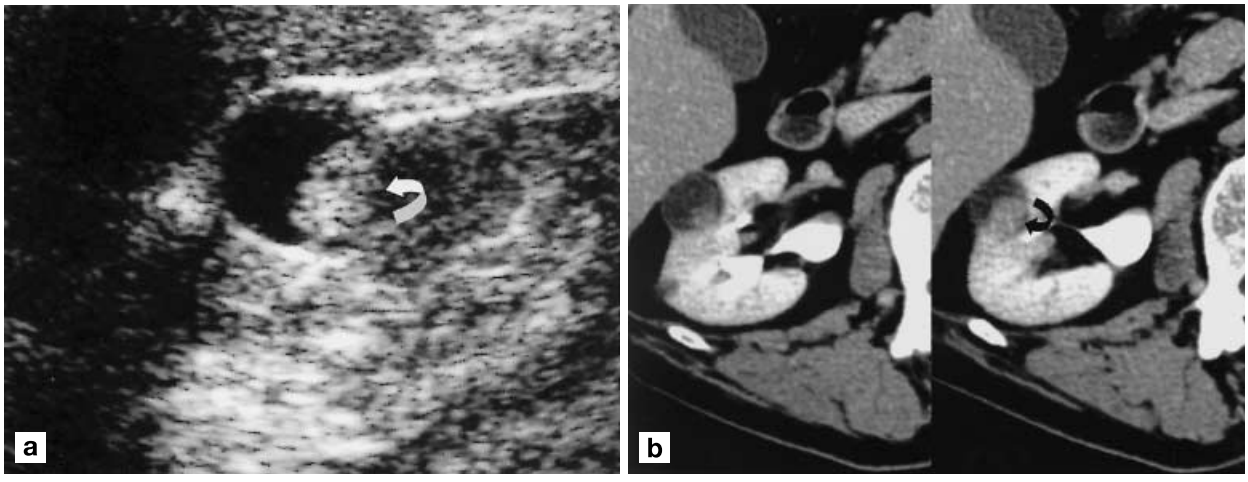


Fig. 12 a, b Cystic RCC. **a** Ultrasound shows a cystic renal mass with solid mural nodule *(curved arrow)*. **b** A CT confirmation of a typical cystic RCC with contrast-enhanced tumor tissue component *(curved arrow)*

however, a heterogeneous pattern also can be observed, especially due to hemorrhagic changes within the tumor. In addition, the hyperechoic tumor component can be obscured by perirenal fat tissue of similar US appearance in subcapsular AMLs with extrarenal growth.

Intratumoral false aneurysm is an unusual complication that may occur within a hemorrhagic AML [13]. It shows a hypoechoic round-shaped mass located within the tumor that filled with color signal on color Doppler image. Such a vascular lesion within a hemorrhagic renal tumor has only been described in AML [13]. It should prompt appropriate treatment with respect to the size of the AML because of the increased risk of bleeding recurrence.

US tissue characterization

Ultrasound tissue characterization based on either US-frequency-dependent attenuation [14] or relative gray-scale values measurements (compared with renal cortex) [15] have been recently evaluated in the diagnosis of solid renal tumors. Both tissue echo quantification techniques yield promising diagnostic aid in differentiating hyperechoic RCCs from AMLs.

Characterizing cystic renal masses

The Bosniak classification of cystic masses is based on CT findings [16]; however, it can be applied in certain cases of cystic masses at gray-scale US especially to rule out a cystic tumor when the lesion fulfills the criteria of a type-2 lesion (minimally complicated cyst): presenting with a single or two thin septations or a tiny calcification in a anechoic fluid-filled lesion, without peripheral thick wall (i.e., visible wall), on a technically adequate US examination. All other complex cystic masses should be viewed as suspicious and require CT or MR imaging with contrast medium administration. Nonlinear US modalities (harmonic and pulse-inversion imaging) have recently improved the capability of gray-scale US to characterize complex cystic lesions. The US criteria that strongly suggest a cystic or pseudocystic renal neoplasm include: a thick irregular peripheral wall; the presence of echoic mural nodule(s) (Fig. 12); the presence of multiple thick septae; a heterogeneous thick content; and the demonstration of vascular flow signal within the solid component of the lesion at color Doppler US.

At CT, category 3 (indeterminate cystic masses) often poses difficult diagnostic problems with cystic neoplasms, whereas categories 2 and 4 are without a doubt benign minimally complicated cysts and cystic/necrotic RCCs, respectively. Gray-scale US can provide useful additional information that may help differentiate benign complex cyst from some atypical renal tumors that belong to category 3.

Category 3 complex cysts, which result mostly from intracystic hemorrhage or infection, include cysts with regular thick wall and/or septations, with or without wall postcontrast enhancement. High attenuation values within a cyst suggest benign hemorrhage when the mass is of small size, with CT numbers higher than 50 HU, homogeneous, sharply marginated, either on pre- and postcontrast scans with no change after contrast administration (lack of enhancement). Hyperdense RCCs are rare conditions that can mimic such hyperattenuating complex cysts, but usually the tumor vascularity is obviously demonstrated on postcontrast CT images. Small hypovascularized tumors (mostly tubulopapillary

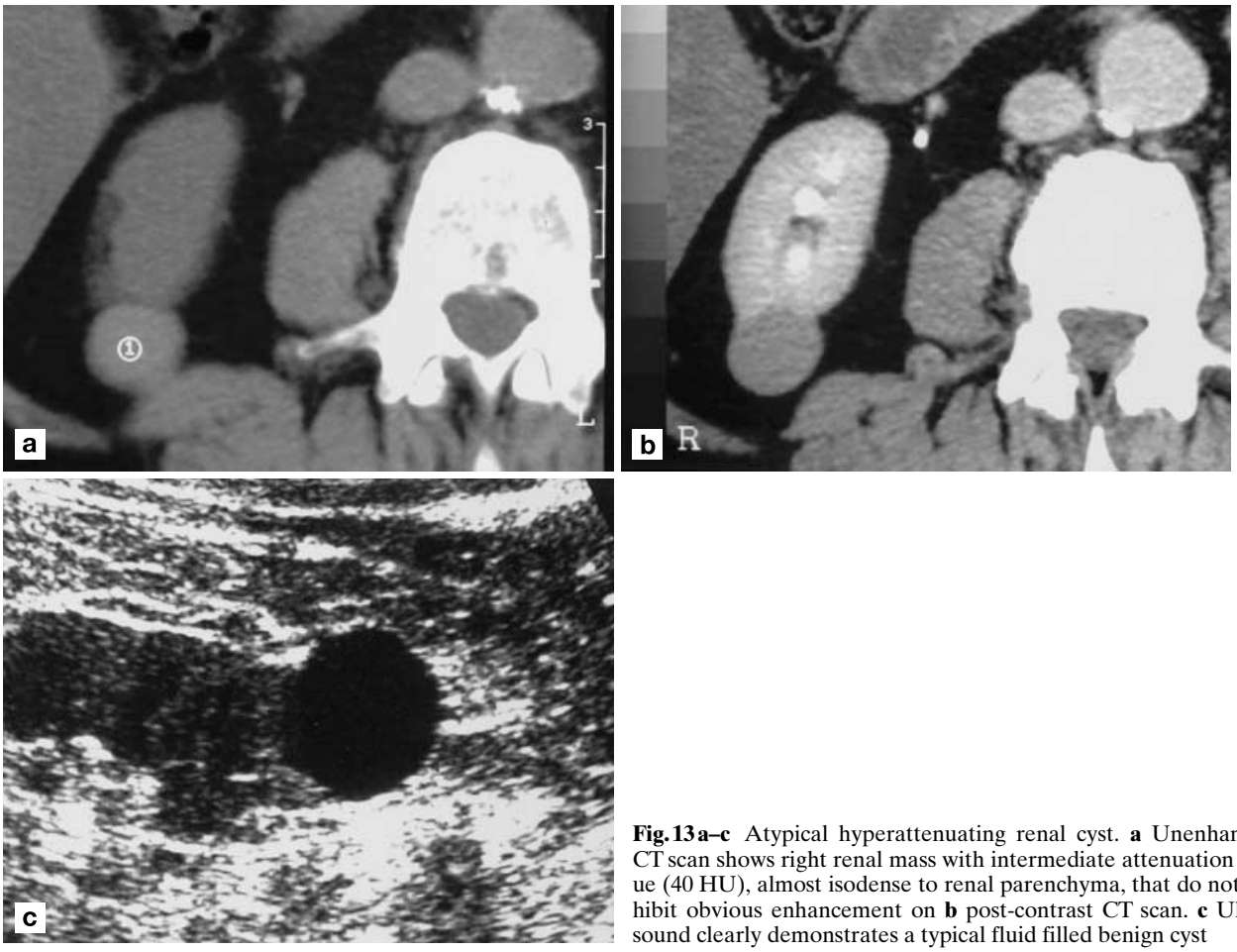


Fig. 13a–c Atypical hyperattenuating renal cyst. **a** Unenhanced CT scan shows right renal mass with intermediate attenuation value (40 HU), almost isodense to renal parenchyma, that do not exhibit obvious enhancement on **b** post-contrast CT scan. **c** Ultrasound clearly demonstrates a typical fluid filled benign cyst

RCCs) also may mimic a spontaneously hyperattenuating cyst owing to the fact that postcontrast enhancement can remain undetectable or doubtful. In addition, the artifactual increase in attenuation values of renal cysts on contrast-enhanced CT images [17] may contribute to equivocal CT findings. Therefore, an isodense (> 20, < 50 HU) renal mass which does not exhibit substantial postcontrast enhancement should be viewed as a possible hypovascularized tumor (especially when CT scanning technique is inadequate, i.e., without delayed cuts). This finding should prompt US examination since hyperdense cysts are typically anechoic in approximately 30–50 % of cases (Fig. 13). Atypical isodense complex cysts at CT with such US appearance do not require any further work-up.

Renal cell carcinomas with massive necrosis also can exhibit a category-3 pattern with thick regular enhancing wall. Such pseudocystic RCCs often exhibit a homogeneous isodense non-enhancing content quite similar to the fluid content of a complex cyst at CT. Ultrasound is often helpful in characterizing the tumor content which shows a heterogeneous echoic appearance consistent with necrosis often associated with a thicker and more irregular wall compared with CT description (Fig. 14).

US-guided procedures

Ultrasound guidance has several advantages over CT especially in renal applications: It provides a real-time follow-up of the procedure; kidney and renal lesions can be targeted while moving with respiratory motion; it can be performed using a dedicated US mobile unit; it can be utilized intraoperatively or combined with another imaging technique (X-Ray, CT, angiography).

Procedures that can benefit from US guidance are diagnostic and therapeutic. Ultrasound-guided needle biopsy of renal tumors is indicated in renal masses that suggest metastases or lymphoma and do not require surgery. Regarding the diagnosis of small oncocytoma, larger studies with more patients are still needed to assess the diagnostic efficacy of percutaneous biopsies.

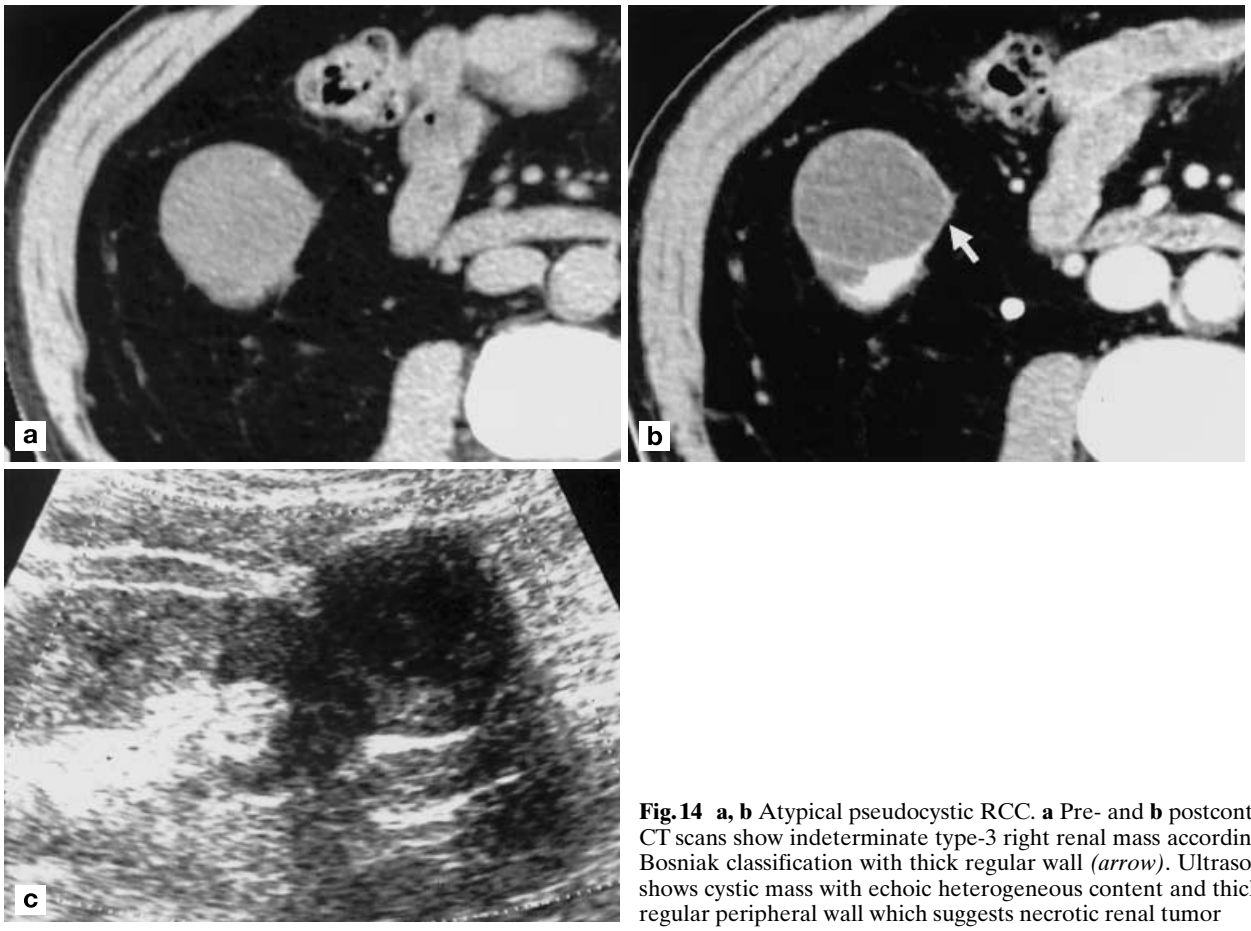


Fig. 14 **a, b** Atypical pseudocystic RCC. **a** Pre- and **b** postcontrast CT scans show indeterminate type-3 right renal mass according to Bosniak classification with thick regular wall *(arrow)*. Ultrasound shows cystic mass with echoic heterogeneous content and thick irregular peripheral wall which suggests necrotic renal tumor

From a therapeutic point of view, renal-parenchymal-sparing surgery and nonsurgical modalities can benefit from US guidance.

Intraoperative US remains the only available modality that may help remove a small renal tumor deeply located within the renal cortex or sinus (Fig. 15). It may identify additional tumors, after visible lesions have been removed, in up to 25 % of patients suffering from hereditary renal cancer (von Hippel Lindau's disease, hereditary papillary renal carcinomas) [18].

Finally, the development of percutaneous treatment using radio-frequency interstitial tissue ablation technique likely will benefit from US guidance and color Doppler US intraoperative evaluation of tumor vascularity.

Staging of RCCs

Ultrasound may provide useful additional information over CT in staging RCCs especially in the assessment of venous invasion. An accurate preoperative evaluation of a T3b renal cancer is crucial for patient management. The cranial extent of a tumor thrombus from the involved renal vein is often poorly evaluated at CT because of the inhomogeneous contrast filling of the inferior vena cava (IVC) on early and intermediate (30–120 s) postcontrast scans. Although delayed cuts show homogeneous enhancement of the IVC lumen, in most cases, they do not meet with a sufficient contrast level to identify accurately the enhanced tumor thrombus; therefore, an additional step in assessing the venous involvement is often required. Although MRI has become the gold standard for this purpose, US can be performed first since it is highly accurate in assessing IVC involvement providing that the examination is technically adequate [19, 20]. The tumor thrombus is seen as a solid echoic mass lying within the venous lumen, often responsible for a venous enlargement and more or less surrounded by color flow (Fig. 16). The upper limit of the tumor thrombus within the intrahepatic IVC should be accurately localized with respect to the hepatic veins and right atrium.

The presence of neovascularity is often identified and indicates tumor thrombus (Fig. 16); however, an associated bland thrombus, often located cranially and/

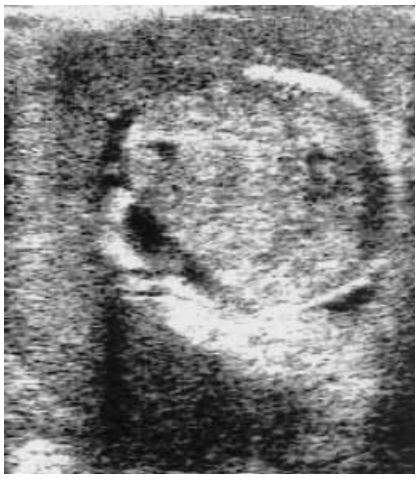


Fig. 15 Intraoperative US (transverse scan) of a small RCC located within the renal sinus

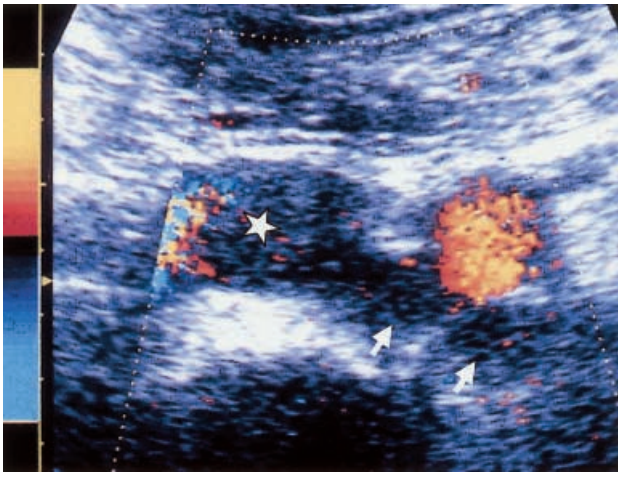


Fig. 17 Renal cell carcinoma with retro-aortic left renal vein invasion. Color Doppler US shows enlarged echoic left retro-aorta left renal vein *(arrows)* with inferior vena cava involvement *(star)*

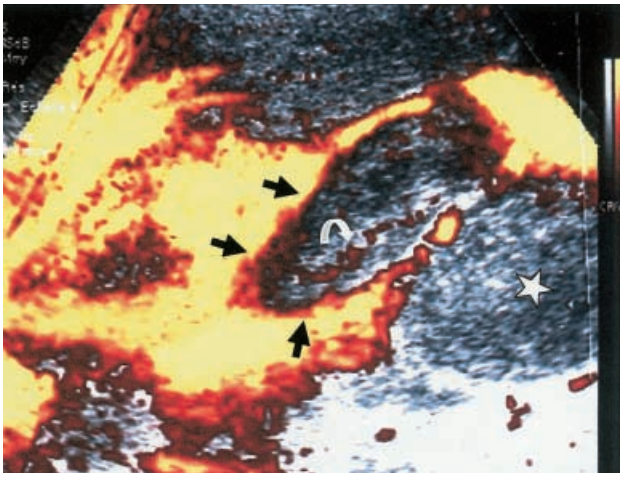


Fig. 16 Renal cell carcinoma with inferior vena cava invasion. Power Doppler US (longitudinal scan) of the inferior vena cava shows tumor thrombus *(straight arrows)* with color flow signal related to tumor vascularity *(curved arrow)*. Enlarged node is also seen posterior to the vena cava *(star)*

or below the level of the renal veins, is difficult to differentiate from tumor tissue.

The patient should also be screened with caution for an invaded retro-aortic left renal vein especially in cases of left RCCs with thrombosed infrarenal IVC or when the main hilar pre-aortic renal vein is not seen (Fig. 17). Such a variation in the renal vein in conjunction with venous tumor invasion may be responsible for a false-negative result at CT because of the lack of normal infrarenal venous system enhancement on early postcontrast images.

The use of US contrast agents may improve tumor thrombus assessment in difficult cases by demonstrating flow contrast enhancement within the patent IVC distal to the thrombus. In addition, it has the potential to better characterize the tumor vascularity and therefore may help differentiate tumor from bland thrombus.

Conclusion

Despite the limitations of US in providing a complete evaluation of renal tumors before treatment planning, initial screening, characterization of renal masses, and staging of RCCs can benefit from some recent advances of the technique. Routine abdominal US plays a key role in early diagnosis of renal tumors. In light of some new reported diagnostic criteria, combined gray-scale and color Doppler US may strongly suggest the histopathologic nature of a renal tumor with respect to the size, the US attenuation characteristics, and the vascular distribution of the lesion. Ultrasound also contributes additional diagnostic information for differential diagnosis of some renal masses, and staging of RCCs, that remain equivocal at CT. Finally, intraoperative US remains the only available tool that enables to ensure renal-parenchymal-sparing surgery.

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