How ~~Not~~ to Miss or Mischaracterize a Renal Cell Carcinoma: Protocols, Pearls, and Pitfalls

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OBJECTIVE. MDCT protocol optimization for renal cell carcinoma requires attention to several data acquisition, reconstruction, and display parameters. Specifically, multiple acquisitions with varying coverage, careful timing of each contrast-enhanced phase, and use of 2D and 3D multiplanar displays are required. This article reviews these parameters, supplemented by experience-based pearls and pitfalls.

CONCLUSION. Proper data acquisition and utilization of postprocessing tools are essential to avoid missed diagnoses or misinterpretation when imaging renal cell carcinoma.

The MDCT data acquisition protocols for known or suspected renal cell carcinoma have been defined by numerous published investigations [1–6] and are well understood. However, protocol optimization requires attention to several data acquisition, reconstruction, and display parameters. Specifically, multiple acquisitions with varying coverage, careful timing of each contrast-enhanced phase, and use of 2D and 3D multiplanar displays are required. The purpose of this pictorial essay is to review these various parameters, supplemented by experience-based pearls and pitfalls. Case presentations using axial images, 2D multiplanar reconstructions, and 3D renderings are used to show how proper data acquisition and utilization of these postprocessing tools are essential to avert missed diagnoses or misinterpretation.

MDCT of Renal Cell Carcinoma: Protocol Optimization

Proper Timing of Acquisition Phases

When a patient is imaged to characterize a known or suspected renal mass, an unenhanced acquisition is combined with two or more contrast-enhanced studies (corticomedullary, nephrographic, or excretory) (Fig. 1 and Table 1). Through research, the optimal timing has been defined by comparing contrast-enhanced acquisitions with respect to lesion conspicuity and detectability [1–6].

The corticomedullary phase is an arterial phase acquisition that we usually perform 25–30 seconds after initiation of contrast administration (typical injection rate, 3–4 mL/s). During the corticomedullary phase, the renal cortex and arterial structures reach peak enhancement, and the cortex and medulla are maximally differentiated. The corticomedullary phase is particularly important for urologists planning partial nephrectomy surgery because it provides a vascular map.

The subsequent acquisition (nephrographic phase) is timed to image the kidney during a period of uniform cortical and medullary enhancement. Whether the degree of cortical enhancement is greater or less than that on the corticomedullary phase depends on the timing of each phase. Birnbaum et al. [2] reported that when the corticomedullary phase was performed at 30–33 seconds and the nephrographic phase was performed at 120 seconds, the renal cortex progressively increased in enhancement. However, in an investigation by Cohan et al. [1] that used a 40-second delay for corticomedullary phase and a mean of 163 seconds for nephrographic phase, the renal cortex decreased from 147 to 117 HU, on average.

To define the onset of nephrographic phase, Birnbaum et al. [6] performed a helical CT study, with 100–150 mL of contrast material infused at 2–3 mL/s. By use of bolus tracking, renal enhancement was measured between 40 and 127 seconds after contrast infusion. The mean nephrographic phase onset was 89 seconds (range, 60–136 seconds). As injection duration increased, the onset was progressively delayed; increasing the duration from 33 to 75 seconds modified the nephrographic phase onset from 75 to 103 seconds. Other

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factors that affect the onset include patient age (the age range in Birnbaum's study was 55–66 years). We acquire the nephrographic phase between 60 and 80 seconds.

In 1997, Szolar et al. [4] conducted an investigation to determine the phase that resulted in maximum conspicuity for small renal masses. Using helical CT with 120 mL of contrast material infused at 2.5 mL/s, the first contrast-enhanced acquisition was performed at 50 seconds, followed by a second phase that began 169–194 seconds after contrast infusion. Comparison of lesion conspicuity between the two phases revealed that maximum tumor-to-kidney contrast coincided with the nephrographic phase, during which 95% of lesions were equally or better visualized. A number of investigations have shown that the nephrographic phase is superior for renal cell carcinoma conspicuity and detection [1, 4, 5] (Fig. 2). Szolar et al. [4] reported that the nephrographic phase unveiled 1.3 times more masses in cortex and 5.3 times more lesions in medulla, compared with the corticomedullary phase. In addition, Kopka et al. [5] showed that diagnostic confidence was highest during the nephrographic phase, and the combination of unenhanced, corticomedullary phase, and nephrographic phase images yielded the best rate of renal cell detection, characterization, and staging.

In some cases, tumor conspicuity is maximized during the corticomedullary phase [7] (Fig. 3). These include masses that enhance to a greater degree than the cortex and those lesions that extend into the medulla enabling contrast between medulla and mass. Of note, appearance varies according to histology. Although clear cell renal carcinoma typically is hypervascular and often heterogeneous on the corticomedullary phase acquisition (Fig. 4), chromophobe and papillary tumors enhance to a lesser degree on the early acquisition [8].

Imaging pearl—In general, the excretory phase is performed in combination with the corticomedullary or nephrographic phase, is acquired after a 5- to 8-minute delay, and results in opacification of the renal collecting system. The collecting system is best visualized using coronal multiplanar reformation and volume rendering to simulate a conventional excretory urography.

Imaging pitfalls—Proper timing of contrast-enhanced acquisitions is very important. In patients with cardiac disease, use of fixed delays can result in the corticomedullary phase corresponding to a very early arterial acquisition. Although this is useful to show tumor neovascularity (Fig. 5) and for visualization of the renal artery, the nephrographic phase acquisition in such a patient would also be acquired too early, before the medulla has fully enhanced and before maximum tumor-to-kidney contrast is achieved. As a result, both medullary and cortical lesions could be missed.

The obstructed kidney enhances later, such that the nephrographic phase and excretory phase will occur at a later time, in comparison with the contralateral side (Fig. 6). In the presence of a solid renal mass, the lesion may be most conspicuous during the normal excretory phase.

If a small renal mass is located within the medulla, it may not be identified during the corticomedullary phase acquisition because of the absence of medullary enhancement and because maximal tumor enhancement occurs during the nephrographic phase.

One additional pitfall noted by Szolar et al. [4] and Cohan et al. [1] is that the focal areas of unenhanced medulla can simulate a renal mass during the corticomedullary phase.

Without a good nephrographic phase acquisition (60–70 seconds), the extent of renal vein and inferior vena cava tumor thrombus can be missed.

Data Set Reconstruction

The rate at which small renal masses are being incidentally detected is increasing as a result of advancements in CT technology and increasing utilization. Lee et al. [9] have shown that patients with lesions smaller than 4 cm have better survival rates in comparison with rates reported for all renal cell carcinomas. Furthermore, preliminary data from a direct comparison of symptomatic patients and those with incidentally identified masses revealed that the incidentally discovered lesions were significantly smaller (mean diameter, 4.8 vs 8.1 cm) and were associated with more favorable histologic profile, lower recurrence rates, and improved survival rates [10]. Accordingly, detection of renal cell carcinoma at a small size is associated with improved patient outcomes, and these lesions

TABLE 1: 64-MDCT of the Kidney for Hematuria and Renal Mass Evaluation: Parameters for the Four Acquisition Phases

Parameter	Phase			
	Unenhanced	Corticomedullary[a]	Nephrographic[a]	Delayed[a]
Peak kilovoltage	120	120	120	120
Milliamperes per second[b]	250	250	250	250
Rotation time (s)	0.33	0.33	0.33	0.33
Detector thickness (mm)	0.6	0.6	0.6	0.6
Scan direction	Craniocaudal	Craniocaudal	Craniocaudal	Craniocaudal
Reconstruction section (mm)	3.0 (thick) and 0.75 (thin)	3.0 (thick) and 0.75 (thin)	3.0 (thick) and 0.75 (thin)	3.0 (thick) and 0.75 (thin)
Timing method	NA	Fixed, 25–30 s	Fixed, 60–80 s	Fixed, 7 min
Reconstruction interval (mm)	3 (thick) and 0.5 (thin)	3 (thick) and 0.5 (thin)	3 (thick) and 0.5 (thin)	3 (thick) and 0.5 (thin)
Kernel	B30f medium smooth	Thick, B30f medium smooth; thin, B20f smooth	Thick, B30f medium smooth; thin, B20f smooth	B30f medium smooth

Note—NA = not applicable.

[a]Standard IV contrast infusion protocol includes 100–120 mL of 350 mg I/mL concentration contrast material infused at 4 mL/s. In patients with renal insufficiency, 60–70 mL of 320 mg I/mL isosmolar contrast material is used, infused at 4 mL/s. Patient hydration preceding the examination is essential.

[b]All scan protocols are selected to minimize dose. Scanners now frequently have dose reduction software, which is especially valuable in patients undergoing multiple scans during different phases.

are often amenable to partial nephrectomy or radiofrequency ablation.

Protocol optimization for detection includes biphasic or triphasic acquisitions and careful adherence to timing, as shown above. However, data set reconstruction also affects both lesion detection and characterization. Jinzaki et al. [11] compared reconstruction protocols of 5 × 5 mm (section × interval) with those of 3 × 1.5 mm. Thinner overlapping reconstructions resulted in an increase in the percentage of small lesions detected, markedly improved ability to distinguish cystic from solid lesions among those measuring 5–10 mm, and decreased the percentage of indeterminate lesions.

Data Set Evaluation

In addition to multiple contrast-enhanced acquisitions, multiplanar display techniques are essential to unveil or improve confidence in identifying small masses that deform the renal contour more substantially or exclusively in the coronal plane. For 2D and 3D interpretation, each of our CT volumes is also reconstructed with 0.75-mm-thick sections at 0.5-mm intervals and is interactively interrogated by a radiologist using a combination of multiplanar reconstructions, maximum intensity projection, and volume rendering.

Imaging pearls—As shown by the representative cases (Figs. 5, 7, and 8), some small masses are better visualized in the coronal plane. By displaying the kidney coronally, as opposed to in the axial plane, both shape and enhancement of a mass may become more apparent. Contour deformation (Fig. 7) and differential enhancement of the mass (Fig. 8) become more convincing when compared with the entire kidney displayed in the coronal orientation.

Imaging pitfall—When performing interactive rendering, it is imperative to recognize that maximum-intensity-projection renderings may make solid renal masses appear less conspicuous, whereas volume rendering (based on voxel attenuation) maintains lesion contrast, especially on the nephrographic phase (Fig. 6).

In conclusion, through case presentation, we have reviewed how acquisition protocol and interpretative practice affect conspicuity of renal cell carcinoma on contrast-enhanced MDCT. Early diagnosis of smaller masses results in improved outcomes. As shown here, careful attention to technique and routine use of available postprocessing tools facilitate visualization of smaller masses.

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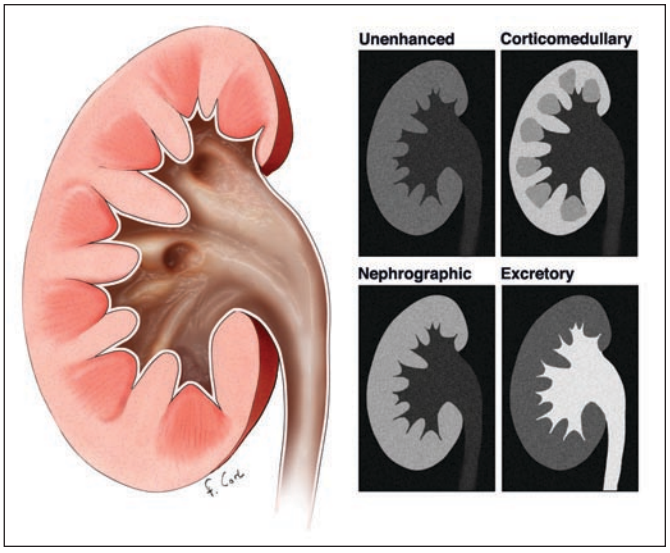


Fig. 1—Schematic of four acquisitions performed for renal CT shows differential enhancement that occurs during each phase. Illustration by Frank Corl.

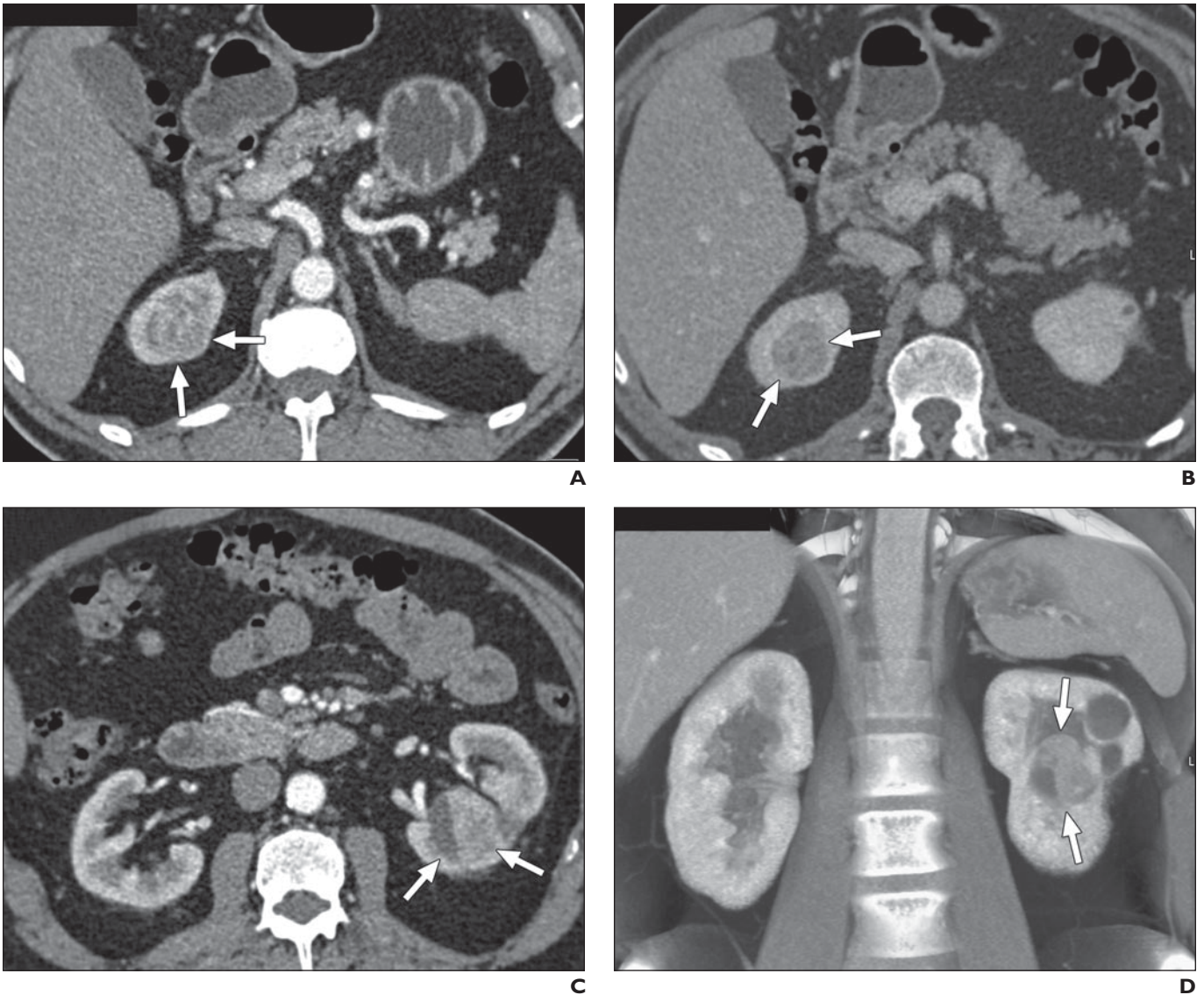
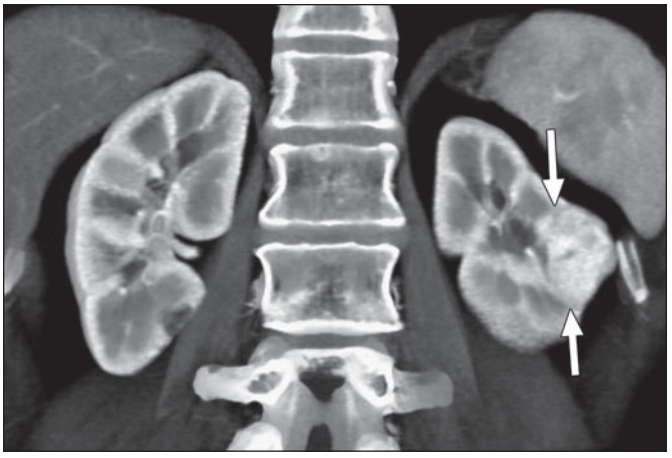
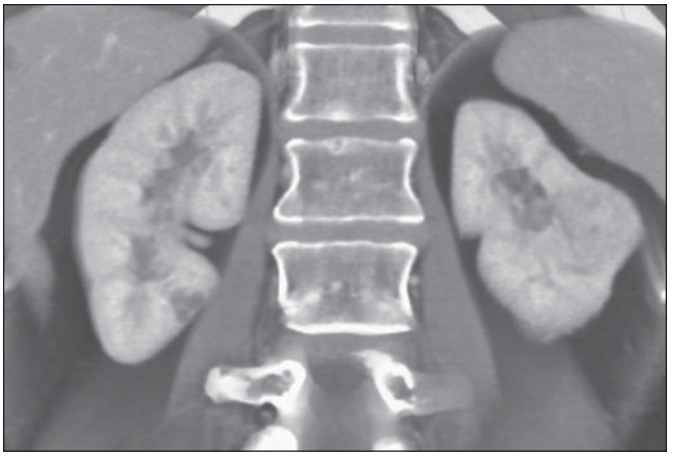


Fig. 2—61-year-old man with history of prostate cancer and bilateral kidney lesions.
A and **B,** Axial corticomedullary phase (**A**) and nephrographic phase (**B**) images show 2.5-cm clear cell carcinoma in right upper pole (*arrows*); owing to cortical location, maximum lesion conspicuity is during nephrographic phase.
C and **D,** Axial corticomedullary phase (**C**) and coronal nephrographic volume rendering (**D**) images depict second solid and cystic mass (*arrows*) in left kidney, which was also clear cell carcinoma.



A



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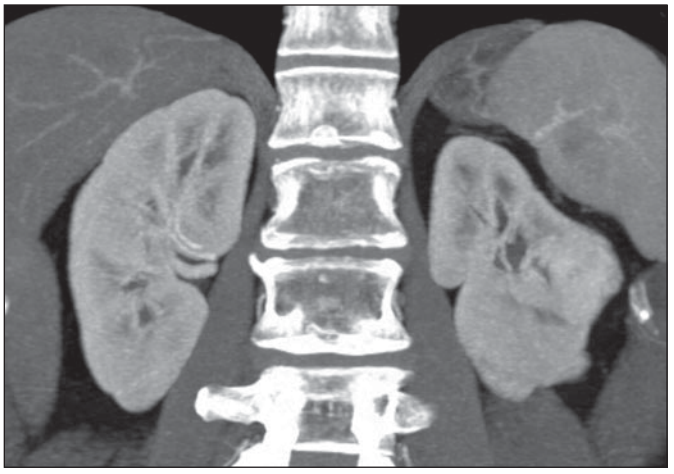


C

Fig. 3—57-year-old woman with incidentally discovered 4 × 3 cm solid renal mass.
A, On coronal volume-rendered image from corticomedullary phase, involvement of unenhanced medulla provides distinction of kidney from mass, which enhances similar to cortex. Volume rendering displays voxels according to original tissue attenuation, enabling identification of mildly heterogeneous, solid enhancing mass in left interpolar region (*arrows*).
B, On coronal volume-rendered image from nephrographic phase, lesion is still seen, but enhancement nearly matches renal parenchyma. This case also shows how rendering technique affects renal mass conspicuity.
C, With coronal maximum-intensity-projection rendering, tumor-to-kidney contrast is lost.

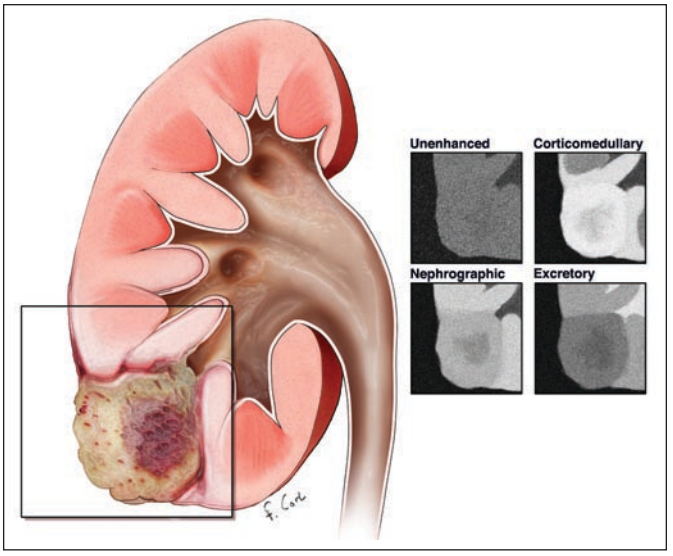


Fig. 4—Illustration of renal cell carcinoma. Because it is a vascular mass, lesion enhances similar to cortex during corticomedullary phase, with maximum tumor-to-kidney contrast usually occurring during nephrographic phase. Illustration by Frank Corl.

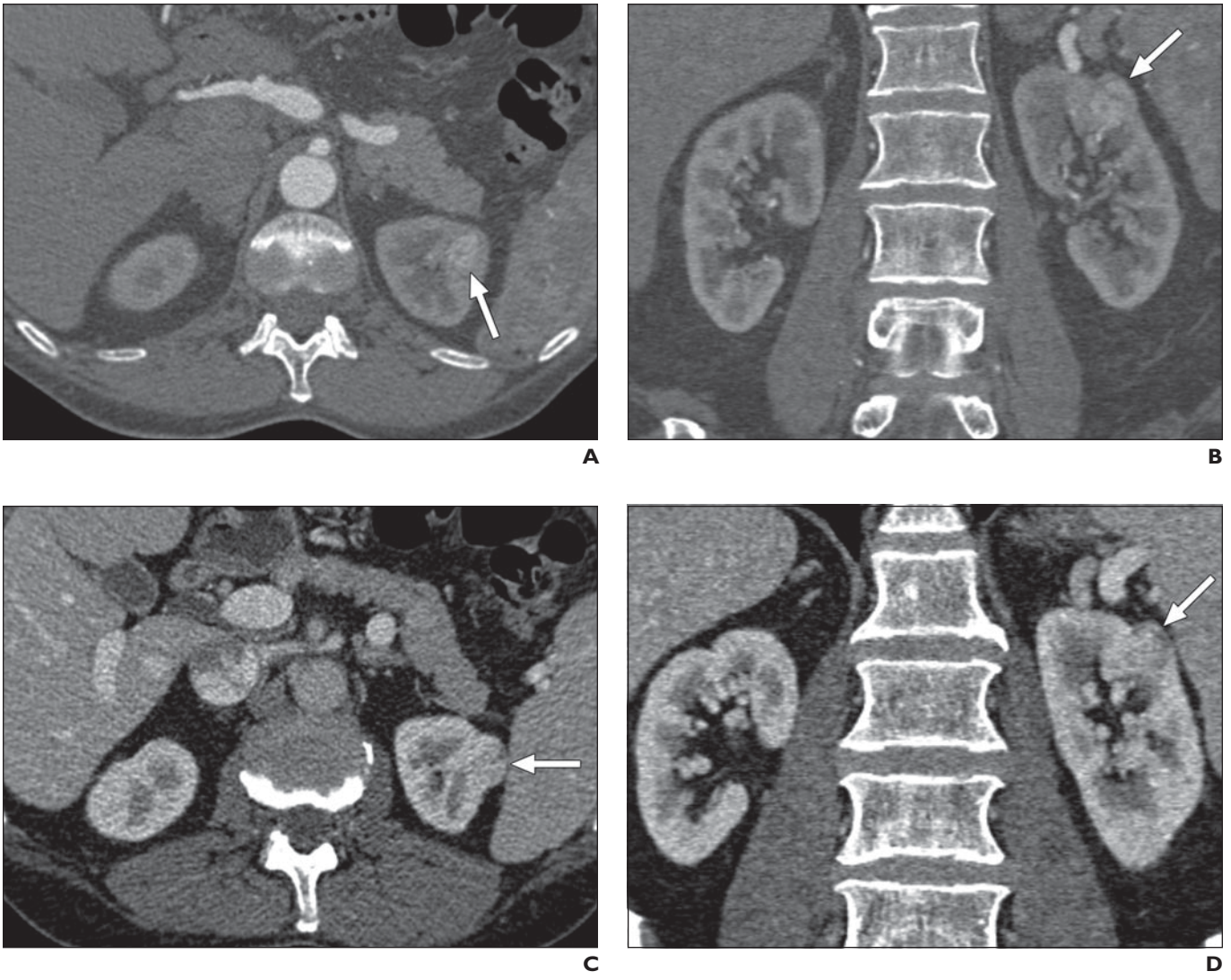
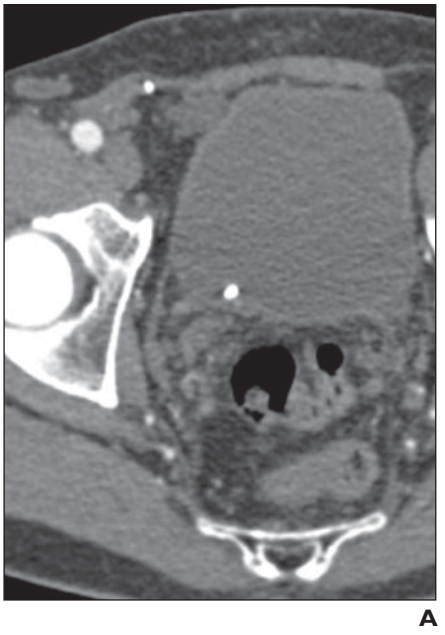
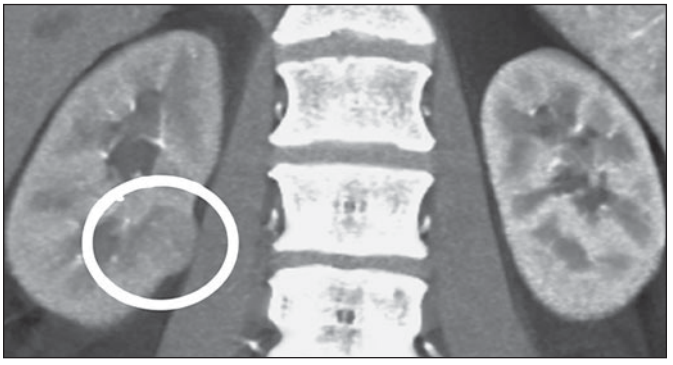


Fig. 5—68-year-old man with 1.5-cm clear cell renal carcinoma in left upper pole.
A–D, Hypervascular mass (*arrows*) is subtle on axial images. Because first acquisition corresponds to very early arterial phase, shown with axial image (**A**) and coronal multiplanar reformation (**B**), tumor neovascularity results in lesion enhancing to greater degree than renal cortex. This early timing of first acquisition also results in second phase being earlier than typical nephrographic phase, as seen in axial image (**C**) and coronal multiplanar reformation (**D**), where mass is inconspicuous because it enhances to similar degree as renal cortex.



A



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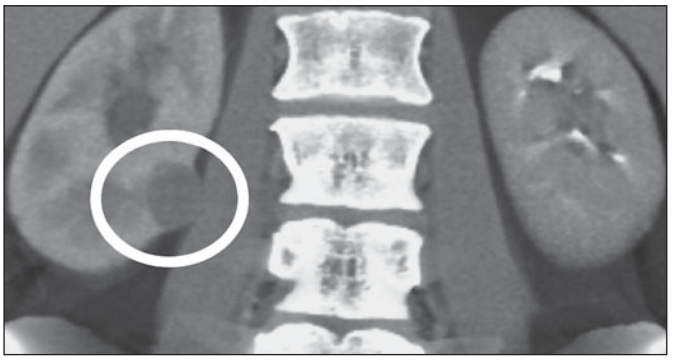
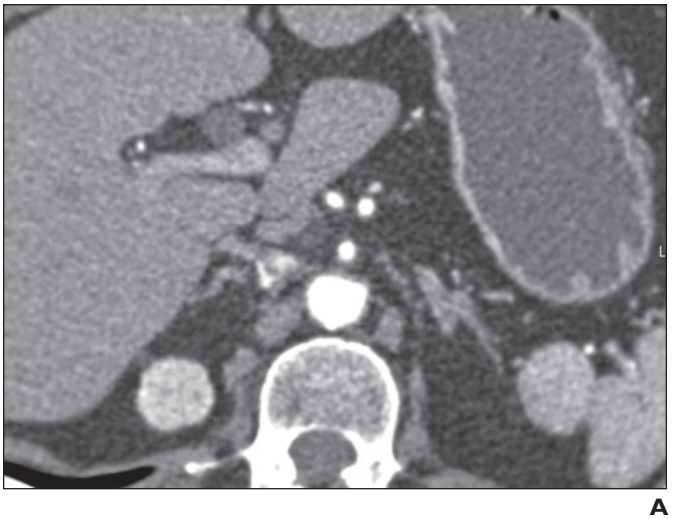
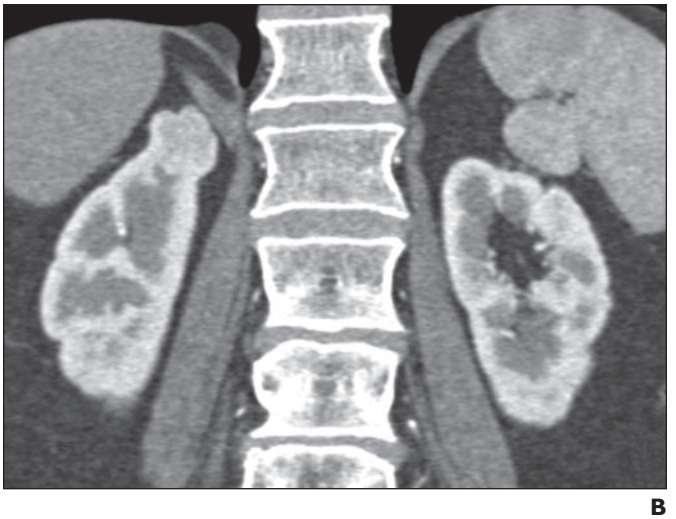


C

Fig. 6—49-year-old man with renal mass and obstructing calculus.
A, Axial image through pelvis shows obstructing calculus at right ureterovesical junction.
B, Corticomedullary coronal volume rendering shows diminished enhancement of right kidney, but solid mass (*circle*) is seen.
C, As shown on this coronal volume rendering, maximal lesion-to-kidney contrast in right kidney (*circle*) occurred during excretory phase acquisition, where obstructed right kidney appears to enhance in nephrographic phase pattern and does not excrete contrast material.



A



B

Fig. 7—79-year-old woman whose renal mass best appreciated with coronal display.
A, Axial corticomedullary phase acquisition shows what appears to be upper pole of right kidney.
B, Coronal multiplanar reformation in corticomedullary phase reveals lobulated exophytic solid mass consistent with renal cell carcinoma.

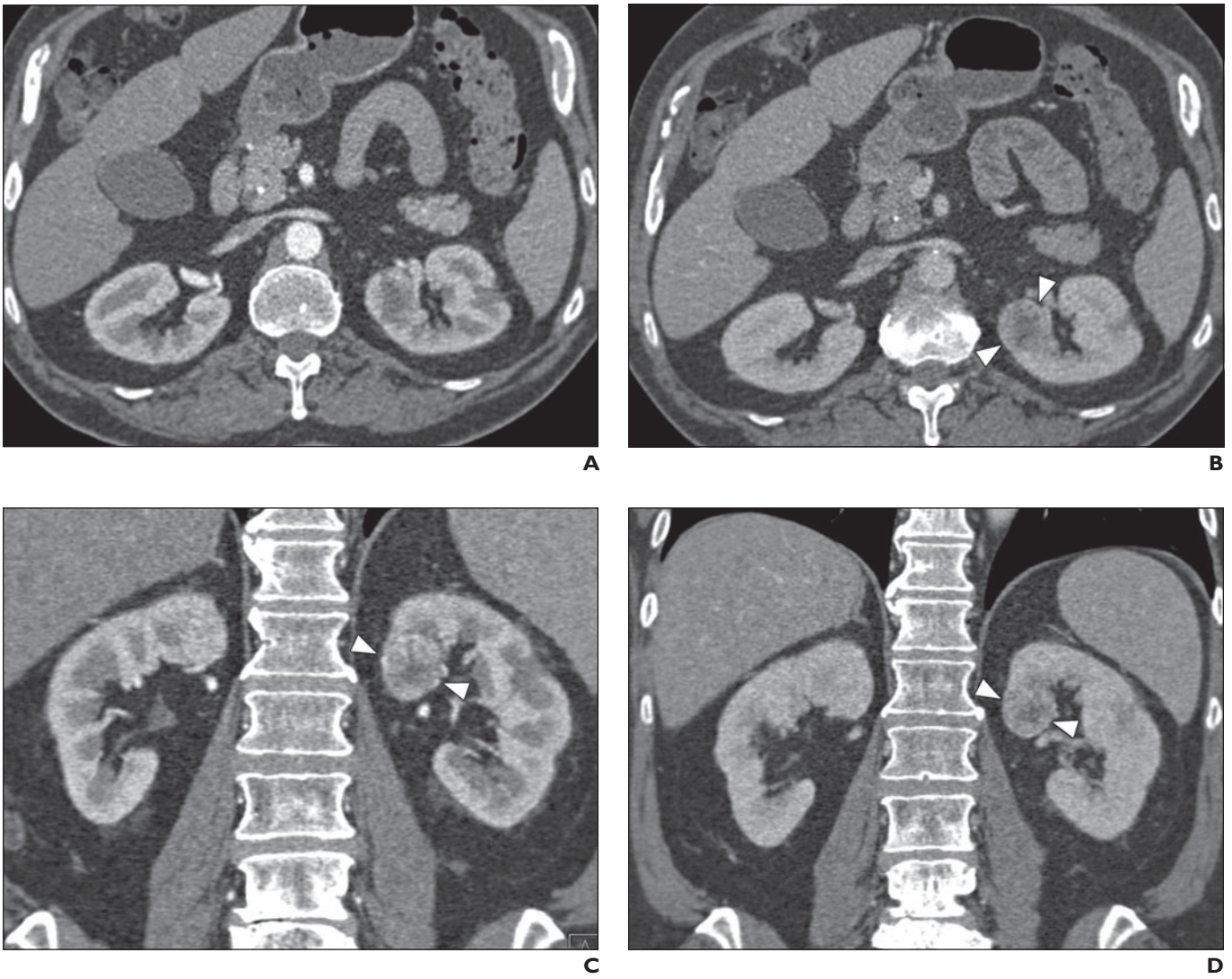
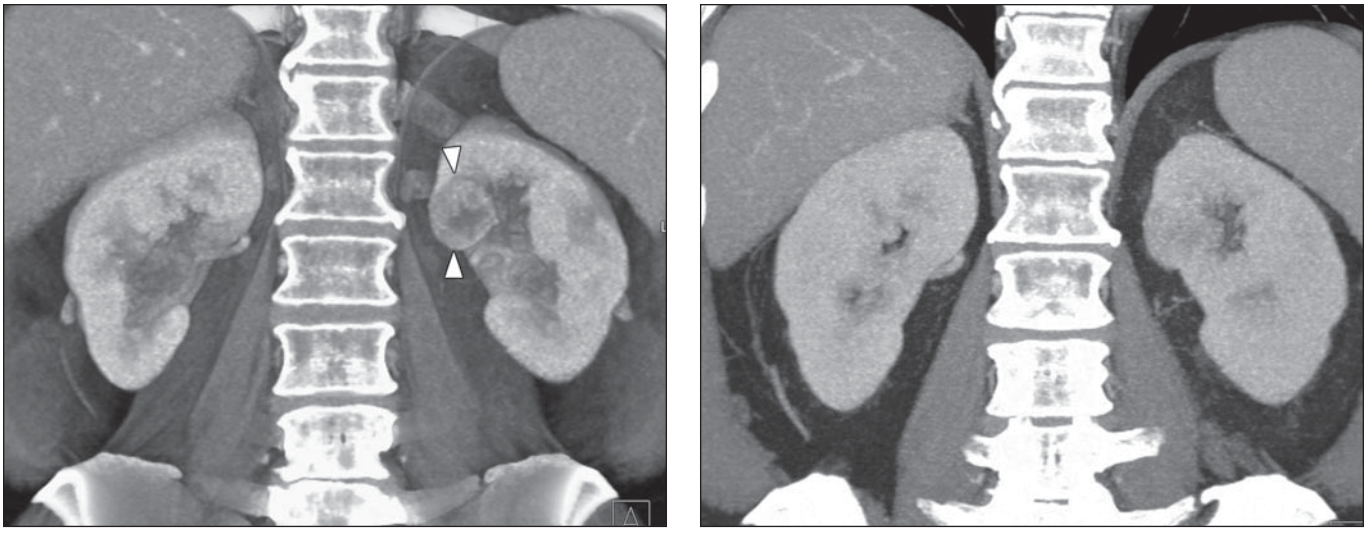


Fig. 8—64-year-old man with 3-cm clear cell renal carcinoma.
A, Mass in left kidney is barely perceptible on corticomedullary phase axial image, owing to small size and peripheral enhancement pattern that mimics renal cortex.
B–D, Combination of nephrographic phase axial images (**B**) and coronal multiplanar reformations in corticomedullary phase (**C**) and nephrographic phase (**D**) enable definitive identification of neoplasm (*arrowheads*).

(Fig. 8 continues on next page)



E F

Fig. 8 (continued)—64-year-old man with 3-cm clear cell renal carcinoma.
E and **F,** Using coronal 3D renderings, mass is much more conspicuous with volume rendering (**E**) than maximum intensity projection (**F**) because tumor-to-kidney contrast is not maintained with maximum intensity projection. In this case, coronal volume rendering shows lesion (*arrowheads*, **E**) better than multiplanar reformations, underscoring importance of using all available postprocessing tools.

FOR YOUR INFORMATION

The reader's attention is directed to part 2 accompanying this article, titled "Optimizing Detectability of Renal Pathology With MDCT: Protocols, Pearls, and Pitfalls," which begins on page 1001.