Sonography in Renovascular Hypertension

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Objective. To familiarize practitioners with different sonographic manifestations of renal artery compromise and the sonographic techniques for renal artery imaging. ***Methods.*** Approximately 1500 examinations evaluating for renal artery disease are performed in our vascular laboratory every year. Most of the patients have the symptoms of hypertension (possibly related to renovascular etiology) and renal insufficiency. From our cumulative experience, the optimal scanning techniques are defined for each renal artery, for extrarenal versus intrarenal vascular evaluation, and for patients with different body habitus. We have also tabulated our technical success rate. Cases with sonographic evidence of renal artery compromise are identified. The validity, sensitivity, and specificity of different parameters are examined. ***Results.*** We achieve an approximately 75% to 80% success rate in obtaining technically adequate studies. We have not found the tardus-parvus waveform evaluation to be as valuable as direct interrogation of the renal artery. ***Conclusions.*** Duplex/color Doppler sonography serves a vital role in the diagnosis of renal artery stenosis and occlusion; it has an excellent correlation with contrast-enhanced angiography. It is also used for intraoperative or postrevascularization surveillance to show evidence of recurring stenosis, thrombosis, and other complications. ***Key words:*** Doppler sonography; renal arteries; renovascular hypertension.

Abbreviations
ESP, early systolic peak; IMA, inferior mesenteric artery; IVC, inferior vena cava; PSV, peak systolic velocity; RA, renal artery; RAS, renal artery stenosis; RI, resistive index

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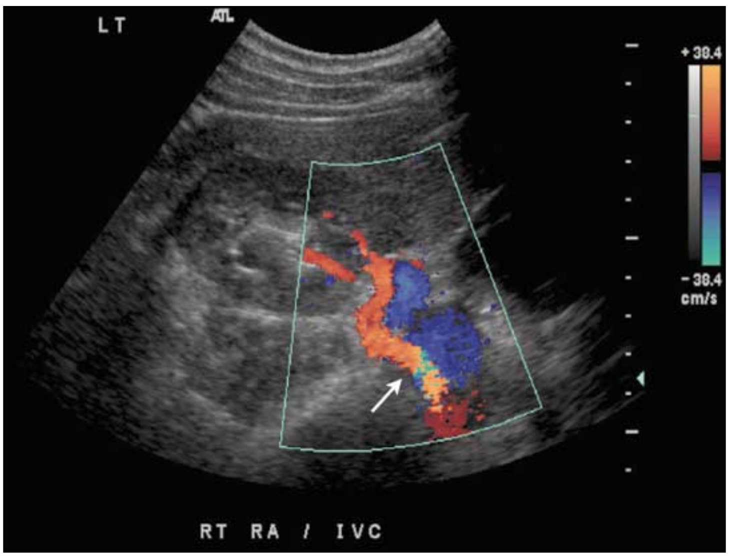
Duplex/color Doppler sonography is an excellent means of evaluating renal artery (RA) disease, which is not an infrequent cause of hypertension and end-stage renal disease. It has high sensitivity and specificity, when compared with contrast-enhanced angiography, in the diagnosis of RA stenosis on the basis of Doppler samples obtained from extrarenal arteries (using measurements of peak systolic velocity [PSV] and renal-aortic ratio). Specificity is further increased combined with intrarenal waveform analysis. Duplex/color Doppler sonography of RAs is a noninvasive, extremely safe modality, but it is underused, mostly because of unfamiliarity with the techniques and the inherent difficulty of performing the examination. This article describes in detail sonographic techniques for optimal RA imaging and a spectrum of sonographic manifestations of RA stenosis. Furthermore, the role of sonography in patient selection for revascularization, as well as intraoperative and postoperative surveillance, will be discussed.

Renal Artery Scanning: Techniques and Normal Anatomy

The 2 main approaches for imaging the RAs are through the anterior abdominal wall and the flank. Which approach is used depends on the specific portion of the renal vasculature being investigated. In most cases the anterior approach is used to evaluate the main RAs. The flank approach (Fig. 1) may be used to image both the intrarenal vasculature and the main RAs. Each of these windows has limitations, which are dependent on individual body habitus and several other variables, such as the ability of patients to hold their breath. To be successful, the anterior approach must be undertaken with the patient fasting, or the left RA will be difficult or impossible to image. Additionally, when scanning any given patient, the ability to image the left RA may vary with time, presumably because of changes in overlying bowel gas. An additional scan or one performed after a brief walk may yield results that are remarkably improved when compared with the original. The opposite may happen as well, so if images are of good quality, document them when you can.

Figure 1. Color image of the right RA (arrow), scanned via a flank approach. Note that this vantage point uses the liver and kidney to create a sonographic window and optimizes the Doppler angle. The beam is pointed almost directly in the line of flow of the RA.



Right Renal Artery

The right RA originates from the anterolateral aspect of the aorta and immediately turns posteriorly to course beneath the inferior vena cava (IVC). These areas, in our experience, are often difficult to image from the typical transverse anterior abdominal window (Fig. 2). The proximal right RA is not only deep in the abdomen but also lies perpendicular to the Doppler beam in the usual transverse scan plane. The right RA may also be difficult to separate from the overlying IVC in this plane. We have improved our success rate in identifying the right RA by using a modified flank approach in which scanning is done through the anterolateral abdomen. The transducer is usually placed somewhat lower than it is when the liver is used as a window to image the kidney, and the beam is passed through the kidney itself. From this low, anterolateral vantage point, RA flow is in a direction that is parallel to the Doppler beam, optimizing signal reception. The patient usually needs to be placed in the opposite lateral decubitus position.

Left Renal Artery

The left RA tends to originate from the posterolateral surface of the aorta and courses posteriorly over the psoas. Even in obese patients, the ostium can usually be found when the transabdominal window is used (Fig. 3), if sufficient transducer pressure is applied. An aid to locating the left RA is to first identify the left renal vein, which is usually larger and easier to find than its arterial counterpart. Once the vein is identified, the artery will often be apparent as a smaller vessel directly behind it, coursing in the opposite direction. One should also be aware of the possibility of multiple RAs and scan along the aorta above and below the main artery looking for an additional vessel. The impression that the main RA enters the kidney eccentrically is a hint that a second artery may be present (Fig. 4, A and B). A pitfall that should be avoided is mistaking the origin of the inferior mesenteric artery (IMA) for that of the left RA. Although following the vessel into the kidney is definitive, this is not always possible. The IMA, however, tends to have a high-resistance spectral waveform, which is quite different from the normal low-resistance pattern of the RA. The IMA also originates much lower along the aorta than the left RA, unless the latter arises from an atypical location. A second approach to imaging the left RA is a variation of the flank approach described for the right RA above. In this situation, the patient is placed in the right lateral decubitus position, and with scanning through the kidney, the main RA is followed back toward the aorta. The decubitus position is essential, because the kidney often falls toward the midline and acts as its own window.

Other Approaches

Another method of identifying the main RAs, particularly the areas of the ostia (where most stenoses occur in older patients), has been termed the "banana peel" view (Fig. 5). In this situation, again, the patient is turned to the opposite decubitus position from the vessel being examined. The decubitus position is particularly effective in obese patients with soft abdomens, because the pannus falls toward the table. This leaves behind a hollow anterior to the paraspinus muscle, which is excellent for placement of the transducer and minimizes depth between the probe and the RA. For the banana peel view, the transducer is oriented longitudinally. The aorta is located, and the transducer is moved in an anterior-to-posterior direction until the RA is identified arising from it, coursing toward the transducer. Looking at the RAs and the aorta as a whole, some have likened this appearance to a half-peeled banana with its skin curved alongside. On the right, an additional aid in locating the RA is to image the IVC and to look posterior to it until a vessel crossing perpendicularly and of the opposite color is found. This must be the right RA, because no other large vessel lies posterior to the IVC.

Intrarenal Vessels

The intrarenal vessels are usually imaged by a flank approach; again the patient should be placed in a lateral decubitus position. Color Doppler imaging, with or without power, usually provides an elegant display of the renal vessels to almost the surface of the kidney in most patients.

The main RA and vein can be visualized entering the kidney in the area of the hilus, and several orders of branching vessels can be followed distally. The main RA divides into anterior and posterior divisions. The latter continues to the posterior surface of the kidney to supply the posterior segment, whereas the former divides into segmental arteries for the remainder of the kidney. The segmental arteries further bifurcate into lobar and then interlobar arteries, which travel directly toward the transducer in the columns of Bertin between the medullary pyramids. The interlobar arteries then give rise to arcuate arteries, which traverse the corticomedullary junction and give off the interlobular arteries.

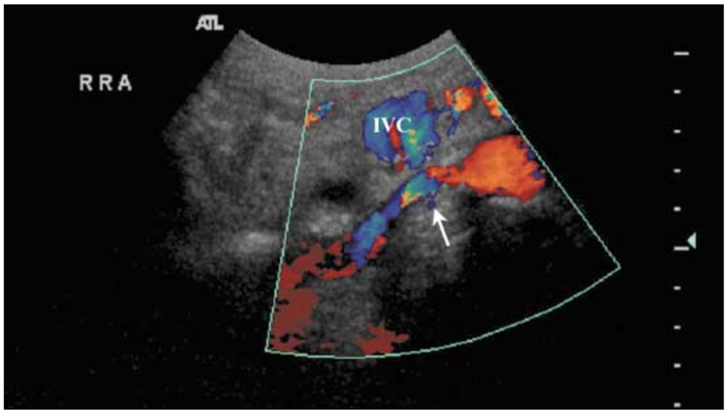


Figure 2. Color image of the right RA (arrow), via a transverse anterior abdominal approach, showing its posterior course relative to the IVC. Flow in the area immediately beyond the ostium is pointed toward the transducer and shown in red; the remainder of the vessel is shown in blue as flow away from the transducer.

Figure 3. Color Doppler image of the left RA (long arrow) and vein (short arrow) via a transverse anterior abdominal approach.

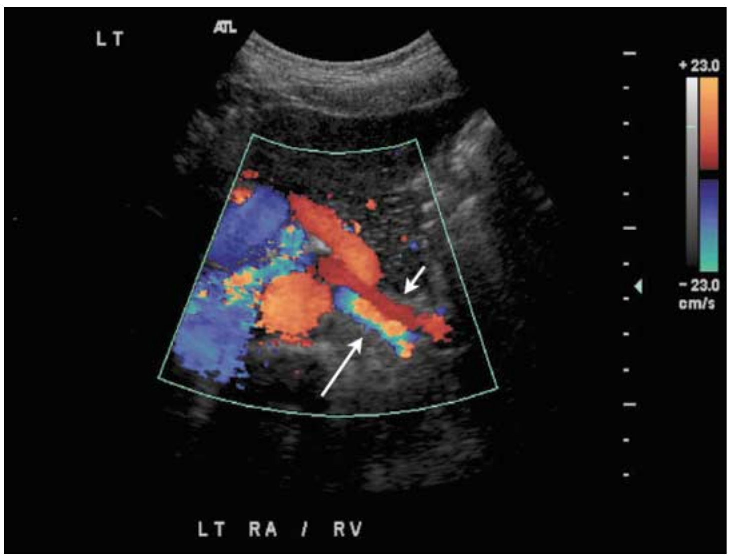
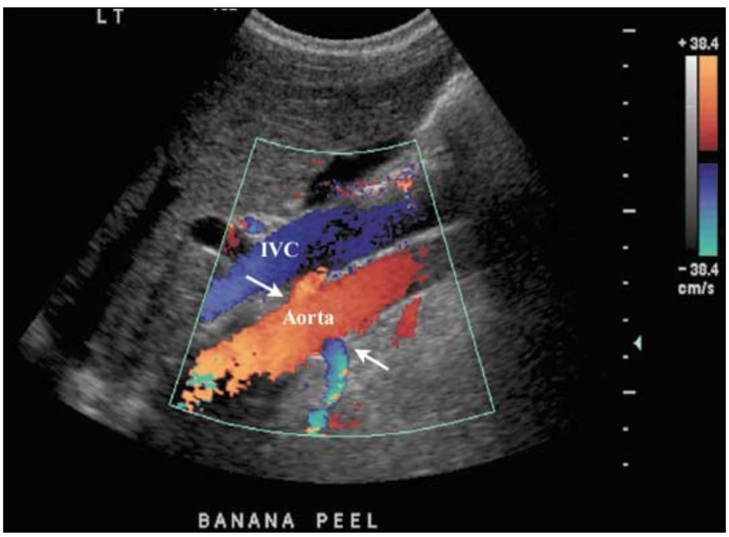


Figure 4. Dual RAs. A single RA was initially identified (**A**), but its entrance into the renal hilum was noted to be eccentric. Scanning inferiorly along the aorta, a second RA was found (**B**) and eventually connected to the lower portion of the left kidney.

One should be aware that Doppler displays are strictly a function of angle, and the color assignment for veins and arteries (blue versus red) will be the opposite when considering the closer half of the kidney versus the half that is farther away from the transducer. Spectral patterns in the normal kidney invariably have low resistance, with mean resistive indices (RIs) between 0.58 and 0.64.[1] Most authorities consider normal less than 0.70. In kidneys with intrinsic parenchymal disease, high resistance patterns may be seen. These may be reflected back into the main RA. Most authorities currently think that the best signals for evaluation come from the large segmental or interlobar arteries as they course directly toward the transducer. In this location, signals are the strongest and most reproducible. Weak signals from peripheral (arcuate arteries) should be avoided.

Figure 5. Color image of the ostium (arrows) in both RAs arising off the aorta, scanned with the banana peel technique. In this maneuver, the Doppler beam angle is optimized and close to zero.



Diagnosis of Renal Artery Stenosis

Main Renal Artery Imaging

Renal artery stenosis (RAS) is a relatively common and potentially correctable cause of hypertension and end-stage renal disease. Numerous articles have evaluated duplex/color Doppler sonography as a method for screening patients thought to have RAS. In many of these studies, the diagnostic Doppler samples were obtained from the extrarenal artery in the area of the stenosis.[2–6] Both PSV and the renal-aortic ratio (main RA PSV compared with aortic velocity) have been used as diagnostic parameters. Although there is some variation, most authorities have recommended 180 or 200 cm/s as the cutoff for normal PSV and a renal-aortic ratio of 3.5 as abnormal. A study by House et al,[7] however, found that lowering the renal-aortic ratio to 3.0 considerably improved their sensitivity with minimal adverse effects on specificity. In one of the original studies of Doppler imaging and RAS, Kohler et al[2] found sensitivity of 84%, specificity of 97%, and overall agreement with angiography of 93%. A study by Olin et al,[4] in which duplex sonography in a large number of patients was compared with angiography, produced excellent results, with sensitivity and specificity of 98%. Positive and negative predictive values were 0.99 and 0.97, respectively.

Two other studies[5,6] produced very poor results when attempting to evaluate the main RAs for stenotic lesions with duplex/color Doppler sonography. Desberg et al[5] reported 0% sensitivity, largely due to a high number of technically inadequate studies. Berland et al also had similar problems with technically inadequate studies and resultant poor sensitivity. For reasons that are not clear, 100 cm/s was used as the threshold for normal velocity in both studies, thereby producing a high number of false-positive results and specificity of 37%. Controversy has focused on the ability to depict the main RA and to obtain a technically adequate scan. Obviously, if one cannot depict the artery, velocity measurements cannot be made. Although there seem to be great differences in the ability to scan the main RA from laboratory to laboratory, even those who have produced excellent results agree that the sonographic evaluation of the extrarenal arteries is difficult and time-consuming. The evaluation can be further complicated by bilaterality of the disease (Fig. 6, A–E) and unusual patient anatomic characteristics such as an aberrant origin of the RA (Fig. 7, A–C). Extreme tortuosity of the abdominal aorta can also alter the RA orientations (Fig. 8, A and B) so that the RAs originate anteriorly and posteriorly off the aorta rather than in their typical lateral course.

Intrarenal Doppler Waveform Analysis

An alternative method of identifying RAS indirectly by using intrarenal waveforms stems from an observation by Handa et al[8] that systolic upstroke is abnormal distal to a hemodynamically important stenosis. This phenomenon has been called the "tardus-parvus" effect (Fig. 9, A and B), borrowing from the term used earlier to describe the delayed (tardus) and dampened (parvus) upstroke in the peripheral pulse distal to a stenosis of the aortic valve. Several articles have shown excellent results with this indirect technique[9,10] and a slowing of the systolic upstroke or the acceleration index (normal, >300 cm/s^2), an increase in acceleration time (normal, <70 milliseconds), and loss of the early systolic peak (ESP) appear to be the most useful parameters. Although some would rely on these measurements, many proponents of this technique think that simply looking at the waveform shape and observing the presence or absence of an ESP is sufficient to differentiate normal from abnormal (Fig. 10, A and B).

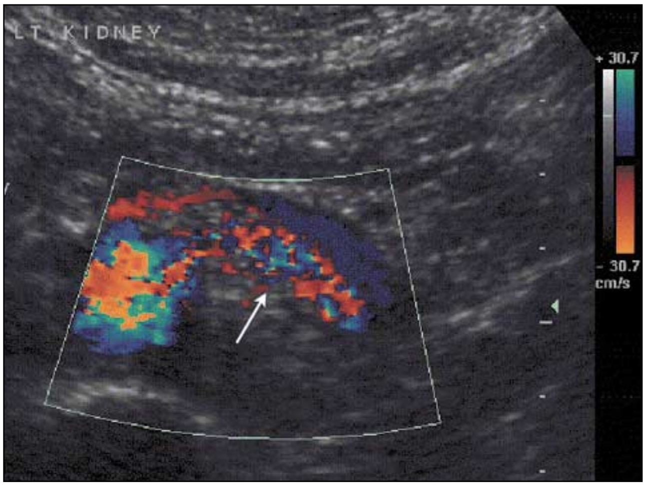
Intrarenal Doppler examination is relatively easy to perform in patients without abnormalities. Obtaining diagnostic-quality spectral signals, however, can be challenging in patients with decreased blood flow to the kidney from any cause and in those patients having difficulty holding their breath. As mentioned above, to evaluate waveforms adequately, large, strong spectral signals must be obtained. To get the largest spectral images possible, one should decrease the velocity scale until the waveform fills almost the entire field and increase sweep speed. Potentially greater problems with the tardus-parvus technique than the ability of obtaining technically adequate studies are its lack of sensitivity[11,12] and the intrinsic variability of Doppler waveforms in the population without abnormalities.[13] Spectral abnormalities may be subtle and differentiating normal from abnormal waveforms is not always straightforward. Other problems with using the tardus-parvus technique are that the degree of stenosis necessary to consistently cause downstream changes is unknown (proponents often claim that a stenosis must be at least 60% to produce a positive result) and that variations in sensitivity and specificity are possible in certain populations. Regardless of which technique is used, one must scan a clinically selected population if good results are to be obtained.[14] Not only will scanning all patients with hypertension be prohibitively expensive and time-consuming and produce a very low yield of positive results, but it will also frustrate technologists and physicians.

Practical Considerations

Most accrediting organizations recommend the use of both intrarenal and extrarenal scanning. Our population comprises almost entirely older patients, and most have long-standing atherosclerotic lesions with poorly compliant vessels. As such, we have not found the tardus-parvus waveform evaluation to be as valuable as the direct interrogation of the RA. However, we routinely sample intrarenal waveforms (upper and lower poles of each kidney) to avoid missing a patient with severe RAS who has a limited extrarenal scan. With meticulous scanning and several of the techniques outlined above, we have been able to improve our ability to image the main RAs in most cases and rely heavily on sonography in the evaluation of RAS. Similar to the results produced in the study by House et al,[7] we achieve an approximately 75% to 80% success rate in obtaining technically adequate studies.

Sonographic Contrast Agent Study

We have recently evaluated the potential of a sonographic contrast agent to improve visualization of the main RAs and have been very encouraged by the results.[15] With contrast enhancement, the number of patients without abnormalities who were confidently identified as such increased considerably because of the



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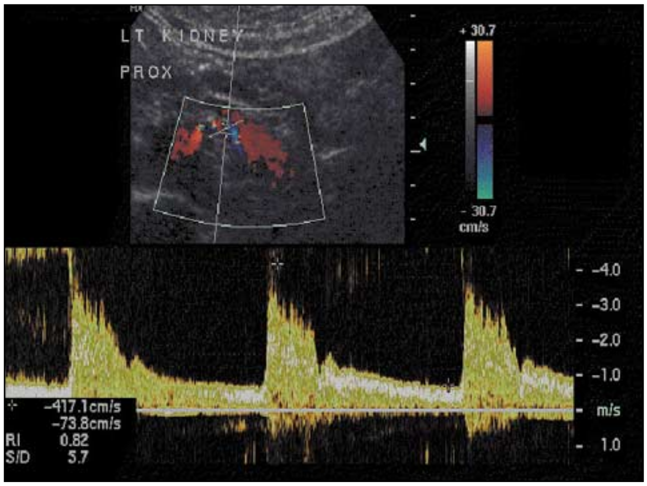

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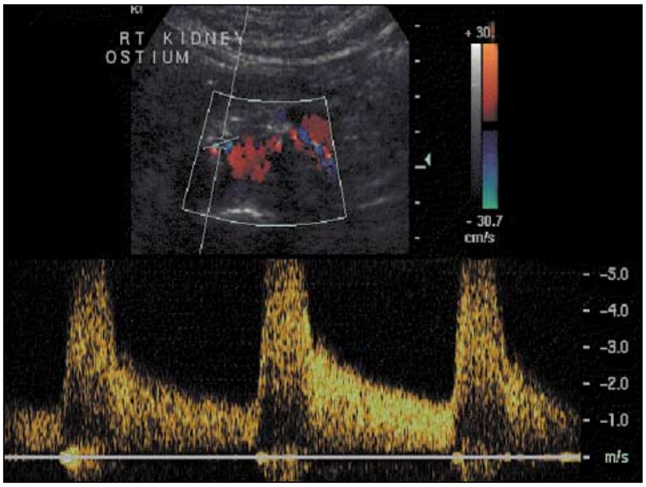

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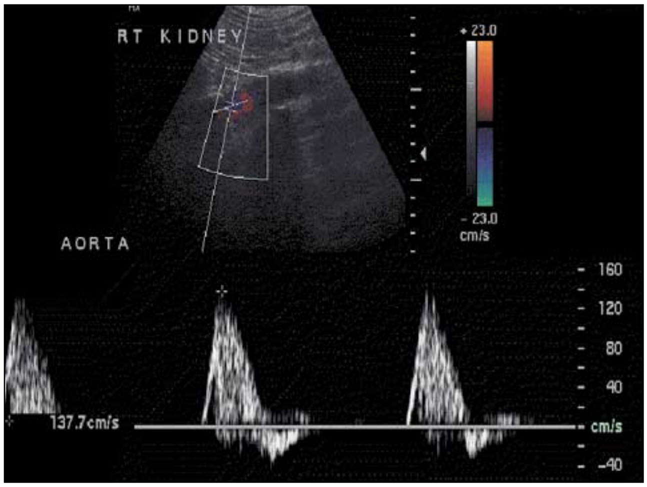

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Figure 6. A, Notable color flow aliasing (arrow) is shown immediately beyond the left RA ostium as a result of high velocity and turbulence at this segment of presumed stenosis. **B**, Corresponding duplex Doppler image shows markedly increased velocity (>400 cm/s). **C**, Doppler image of the right renal ostium also shows high velocity (>500 cm/s). **D**, The aortic velocity is 138 cm/s. The renal-aortic ratio is clearly abnormal on the right and borderline on the left (between 3.0 and 3.5). The renal artery PSV is clearly abnormal bilaterally. **E**, Abdominal aortogram shows high-grade, bilateral renal ostial stenoses. The patient underwent surgical correction of both lesions.

ability to better define the main RAs (Fig. 11, A and B). The number of patients who had RAS successfully identified by sonography was increased by 25%. Scan time decreased, and the number of dual RAs identified more than doubled.

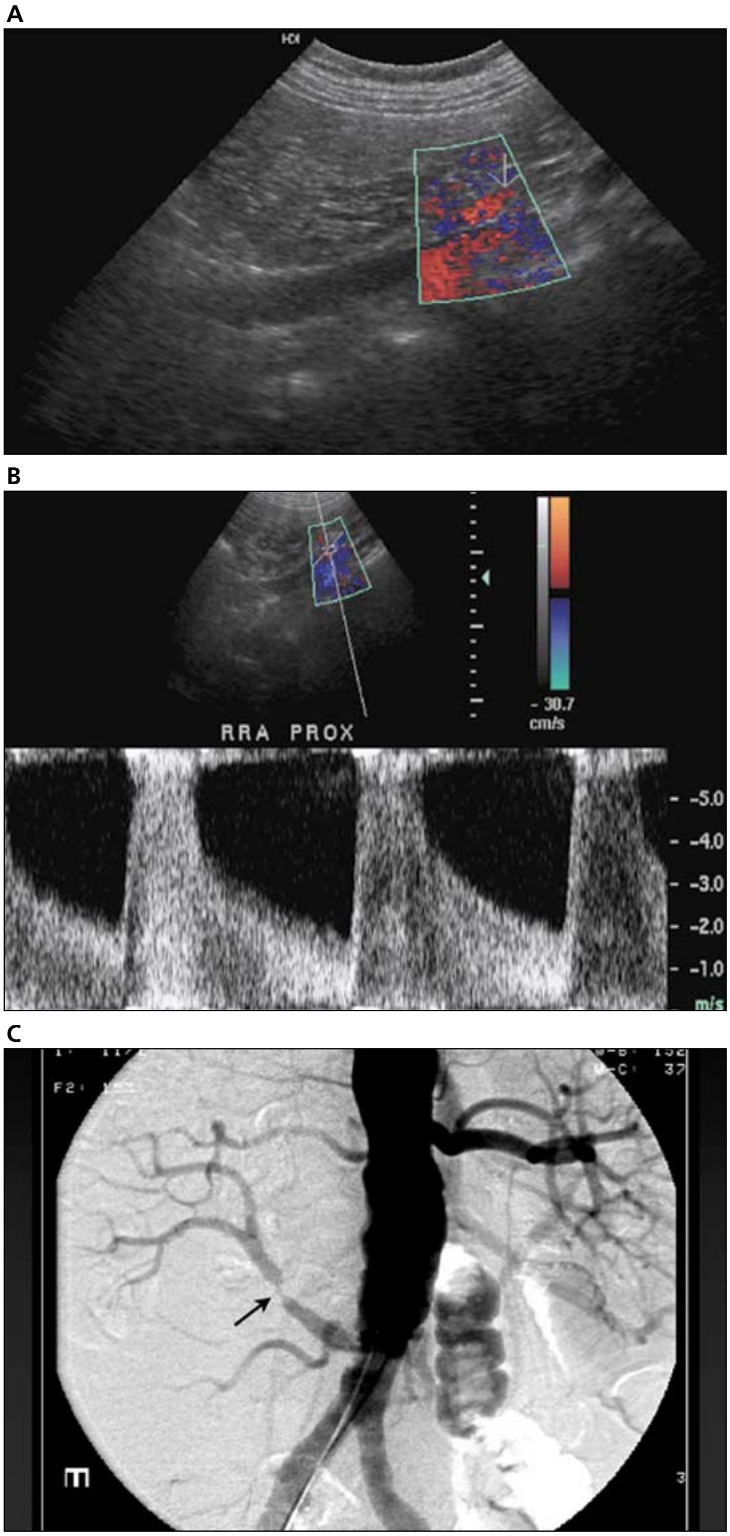
Evaluation After Revascularization of the Renal Artery

Another use for Doppler sonography in RAS is for intraoperative evaluation of the vessel after endarterectomy. Unlike the carotid artery, in which surgical results are excellent in most large centers, renal endarterectomy carries a relatively high complication rate. Loss of the kidney due to RA occlusion or recurrent hypertension from residual stenosis is said to occur in as many as 10% of patients. Color/duplex Doppler sonography can be used in the operating room, and thrombosis, residual stenosis, or an intimal flap can be corrected before closing the abdomen (Fig. 12, A–C). Dougherty et al[16] relied on an abnormal renal-aortic ratio (>3.5) for the identification of stenoses and were able to reduce their complication rate considerably. We use a combination of PSV (>200), the renal aortic ratio, and the real-time appearance of visible plaques in the operating room and agree that this evaluation should be a routine part of the surgery for all patients undergoing renal endarterectomy. Furthermore, Duplex sonography can be used for detection of recurrent stenosis in RAs with stents, again using a combination of PSV and the renal aortic ratio. High sensitivity (near 100%) and specificity (75%–90%) were reported by Bakker et al[17] and House et al[18] independently.

Preintervention Evaluation of the Renal Artery

A note should be made about the success of procedures such as surgery and endovascular intervention in lowering blood pressure or improving renal function in patients identified as having RAS. Surgery is a highly invasive procedure and carries significant risks in healthy patients, let alone those with multisystem disease. Refined techniques developed recently have made percutaneous stent placement and angioplasty effective and safer alternatives to

Figure 7. A, The right RA (arrow) was found to follow an unusual inferior course and originated quite low along the abdominal aorta, just above its bifurcation. The artery is shown adjacent to mid-lower IVC. **B**, Notable velocity elevation is shown in the midsegment of the right RA. **C**, Abdominal aortogram showing the inferior origin of the right RA, with high-grade stenosis in its midsegment (arrow).



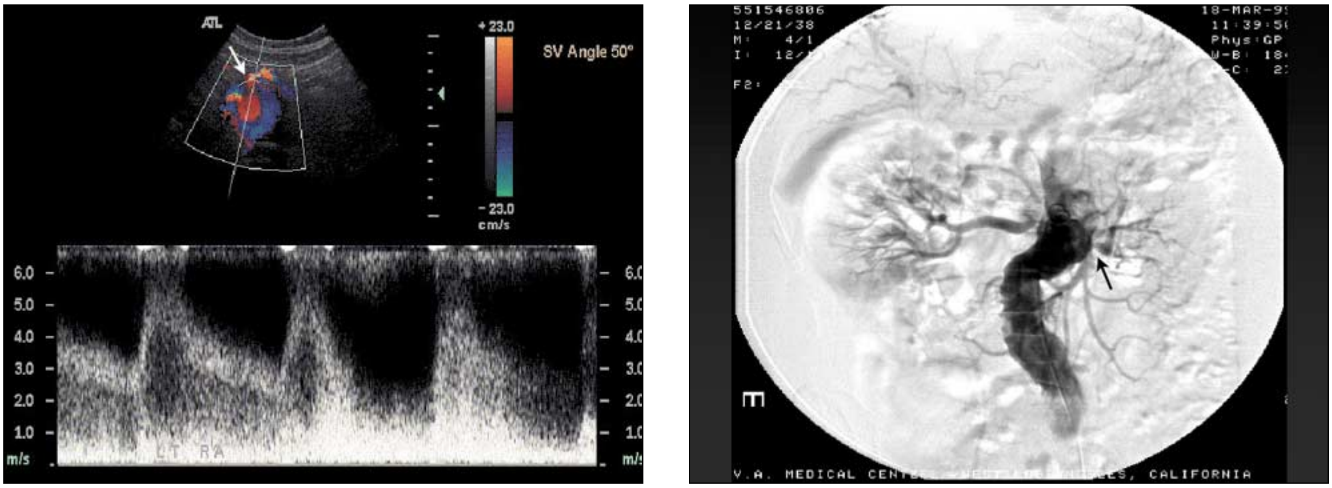


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Figure 8. A, Spectral Doppler image of the left renal ostium showing marked velocity elevation compatible with RA stenosis. As a result of aortic tortuosity, the left RA (arrow) is found originating anteriorly off the aorta. The right RA arose almost directly posteriorly (not shown). **B**, Abdominal aortogram confirming the sonographic findings. Note the marked tortuosity of the aorta and the unusual angulation of RAs requiring oblique imaging to display the ostial areas. The arrow points to the left renal ostial stenosis. Note that the right RA origin is also narrowed.

surgical treatment (reported technical success rate of 98% versus 77% and 12-month patency rate of 66%–80% versus 34%–83% for primary stent placement and primary angioplasty, respectively).[19,20] However, percutaneous correction also has its share of mortality and morbidity. Furthermore, it is well known that a considerable number of patients have no improvement despite the removal of a stenotic lesion. This considered, it would be of value to preoperatively determine which patients would benefit from a corrective procedure and which would not. A recent study by Radermacher et al[21] determined that if a patient had an RI of greater than 0.80 preoperatively, the chance of improvement of either renal function or hypertension was poor. There was a notable improvement in outcome with correction of the stenotic lesion when patients had RIs of less than 0.80. It is well known that patients with a variety of chronic renal diseases have increased RIs. In the case of those with RA stenosis, irreversible damage is postulated to be due to the effect of long-standing hypertension. Doppler sonography, therefore, can be used to differentiate those with intrinsic renal disease who would likely not respond from those who would and to avoid potential complications of a procedure that will yield no benefit. That said, it is likely that all patients being considered for intervention to correct RAS should be evaluated with Doppler sonography. This would apply regardless of whether Doppler sonography is considered the optimum method for diagnosis of the lesion itself.

Conclusions

Duplex/color Doppler sonography is a valuable tool in early diagnosis of RA disease, detection of recurrent stenosis and occlusion, and identification of optimal candidates for interventions. Meticulous techniques are important for accomplishing successful examinations.

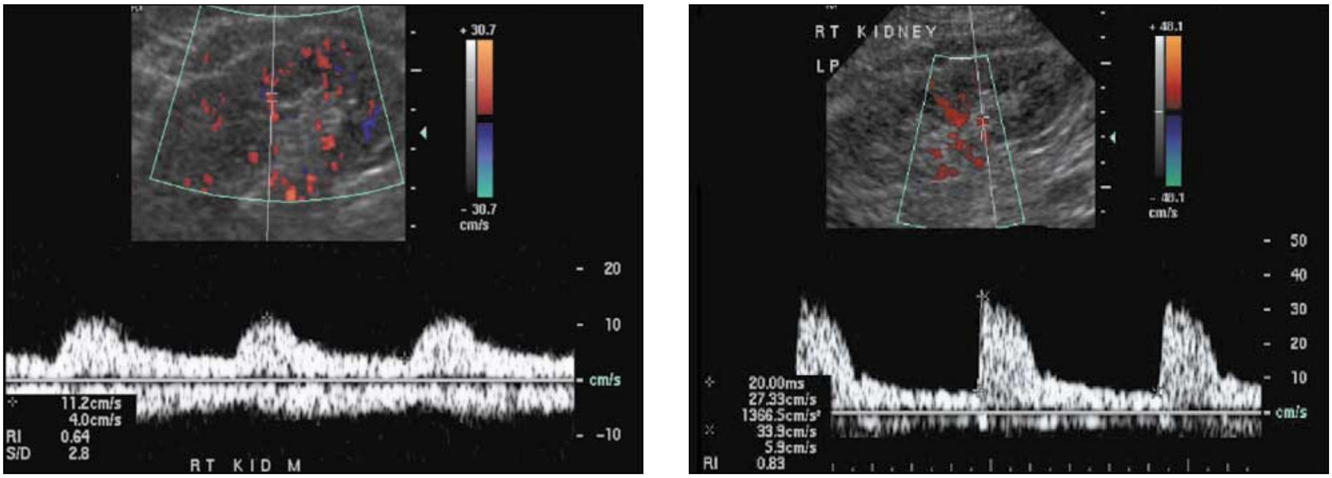

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Figure 9. A, Tardus-parvus waveforms in a patient with RA stenosis (same patient as in Fig 8). Note the delayed and dampened upstroke, yielding a rounded appearance to the waveform. **B**, Doppler spectra from the same patient, immediately after angioplasty, show a normal appearance. Note the return of a rapid systolic upstroke and a well-defined ESP.

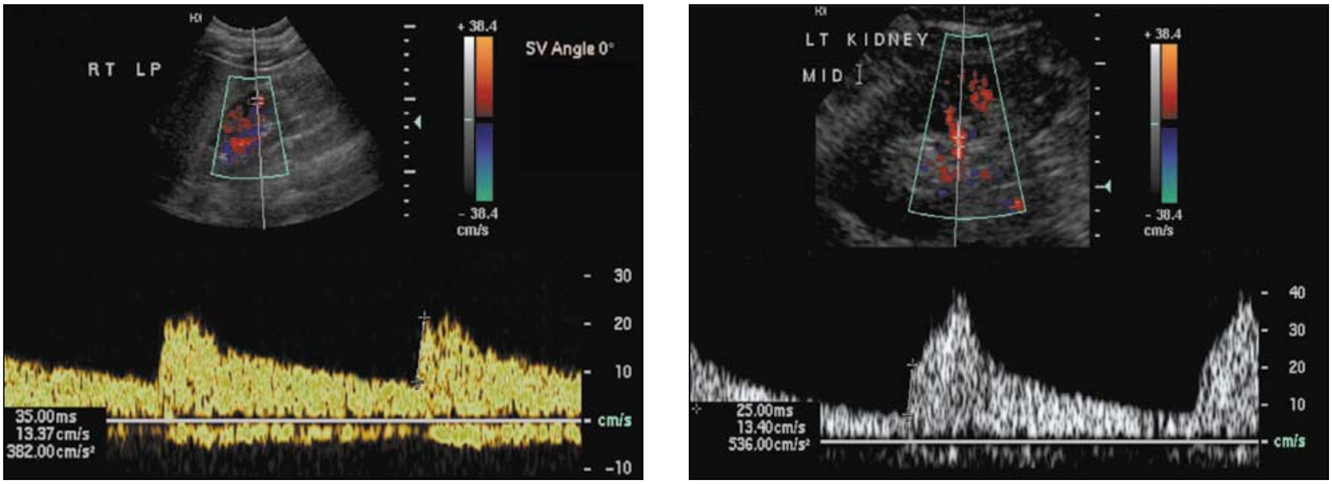

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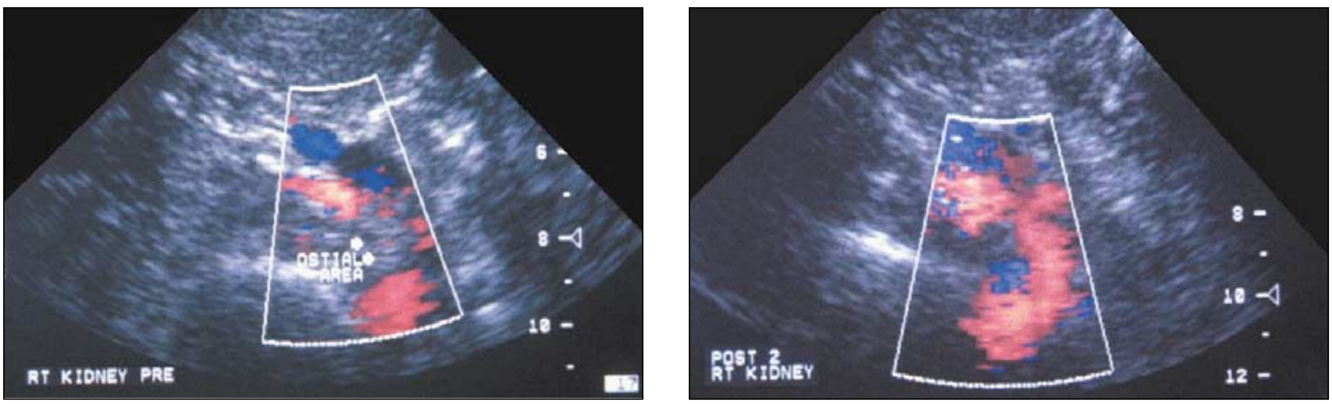
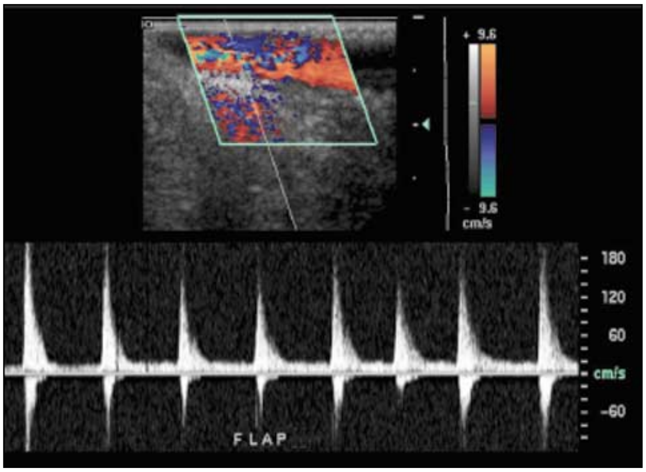
Figure 10. A, Normal intraparenchymal waveforms show a rapid systolic rise and a well-defined ESP. The acceleration time and index are both normal. **B**, This image from another patient without RA stenosis shows a more confusing waveform. There is no well-defined ESP, but the initial portion of the systolic rise is normal. Doppler indices should be taken from the initial portion of the waveform, not the highest point of the velocity spectrum.



A B

Figure 11. Sonographic contrast agent study. **A**, The evaluation of the main RAs can be difficult secondary to body habitus or overlying bowel gas, as shown here. In this patient, the proximal and ostial portions of the main RAs can be particularly challenging to depict. **B**, An intravenous sonographic contrast agent improves visualization of the renal ostium considerably in this same patient. The entire RA is now visible.



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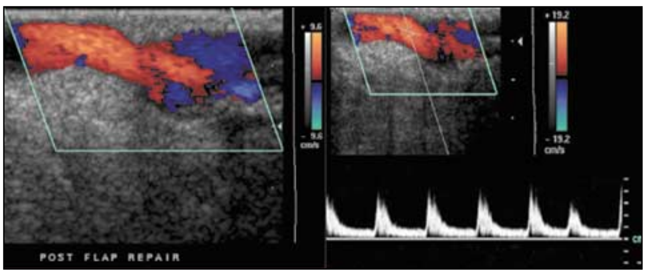

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Figure 12. Intraoperative sonography. **A**, A strikingly abnormal Doppler waveform is shown at the anastomotic site of a renal bypass graft. **B**, An intimal flap (arrow) is shown on this gray scale image of the corresponding region, later surgically repaired. **C**, After repair, color and spectral Doppler images show normal findings.

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