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Pitfalls and Sources of Error of Color Duplex Sonography in Screening for Renovascular Hypertension

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Abstract

Background and Aims: To discuss sources of error and pitfalls of color duplex sonography (CDUS) in screening for renovascular hypertension (RVH).

Methods: We retrospectively reviewed 47 patients with positive CDUS in patients with suspected RVH from May 1, 2007 to February 28, 2009. Manifestations of RVH on CDUS were analyzed. The results of main renal artery stenosis on CDUS were confirmed with that of magnetic resonance angiography (MRA), computed tomographic angiography (CTA), or digital subtraction angiography (DSA). Pitfalls and sources of error of CDUS in screening for RVH were identified. RVH was classified into three groups: 1) main renal artery stenosis (RAS); 2) intrarenal artery stenosis; and 3) intrarenal arteriovenous fistula (AVF).

Results: Two cases of false positive and two cases of false negative main RAS on CDUS were corrected by MRA or DSA. Three cases with intrarenal artery stenosis and four cases with intrarenal AVF were not visualized at the initial CDUS but detected on repeat studies. Peak systolic velocity > 2 m/s at the stenotic artery was the most sensitive parameter for detecting RAS in either main renal artery or intrarenal artery. Acceleration time > 0.07 m/s in the intrarenal artery was seen in only 10 cases (10 /20, 50%) with hemodynamically significant main RAS (>60% arterial lumen reduction).

Conclusions: Some pitfalls and sources of error of CDUS can be corrected and minimized with proper scanning and interpretation. Intrarenal RAS and AVF should be investigated with optimized Doppler settings. CDUS, with its advantages outweighing its limitations, should be considered a first line study in screening for RVH by experienced ultrasound professionals.

Keywords: Arteriovenous Fistula, Color Duplex Sonography, Hypertension, Renal Artery Stenosis.

Introduction

Renovascular disease is considered the most common cause of potentially curable secondary hypertension and is found in 1-5% of the general hypertensive population (1). Common causes of renovascular hypertension (RVH) include renal artery stenosis (RAS) resulting from lesions of atherosclerosis, fibromuscular dysplasia, or Takayasu's arteritis in the main renal artery (2-13), intrarenal branch artery, or both. Intrarenal artery stenosis in one large angiographic series was found to occur in 11 % of patients (14, 15). Prevalence of RAS among patients referred to a vascular laboratory can be as high as 22% (16). Arteriovenous fistula (AVF) is a complication of kidney biopsy, which may also lead

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to RVH (17-20).

It is important to diagnose RVH so that correction of the abnormality (stenosis or AVF) of renal vessels can minimize damage to renal parenchymal function. Furthermore, efficient control of blood pressure is critical for preventing life-threatening complications of hypertension such as aneurysms, cardiac ischemia, and cerebral vascular incidents.

Imaging techniques commonly used for the diagnosis of RVH are magnetic resonance angiography (MRA), computed tomographic angiography (CTA), digital subtraction angiography (DSA), and color duplex sonography (CDUS). CDUS is a moderately accurate screening test for renal artery stenosis (2). However, it is underutilized mostly due to unfamiliarity with the techniques and the inherent difficulty of performing the examination (3).

The aim of this study was to analyze pitfalls and sources of error in using CDUS to detect renal vascular abnormalities with CDUS in order to improve the accuracy of CDUS in screening for RVH.

Materials and Methods

From May 1, 2007 to February 28, 2009, 47 patients [27 men and 20 women, age range 21 - 90 years (mean age 54.8 years)] with suspicious RVH underwent CDUS. All patients had refractory hypertension on triple drug regimen, recent onset or aggravation of hypertension without (12 cases) or with (35 cases) abnormal renal function (defined as serum creatinine > 1.1 mg/dl). Hypertension was defined as a systolic blood pressure ≥ 140 mm Hg and a diastolic blood pressure ≥ 99 mm Hg. All patients were referred by nephrologists, internists, vascular surgeons or cardiologists. Results and characteristics of CDUS in the cases with main RAS were confirmed with MRA, CTA or DSA by reviewing images in the PACS system in the Department of Radiology.

Institutional review board approval was obtained for this study (IRB Protocol #0811010096). Since this study was a retrospective review, a waiver of written consent from patients was granted.

CDUS

The patient was placed in the supine or decubitus position in order to obtain a Doppler angle less than 60°. We used a 2.5 MHz – 4.5 MHz curved linear array transducer or 2-4 MHZ sector probe (Sequoia 512, Siemens medical solutions, Mountain View, CA or Logiq 9, General Electric, Milwaukee, WI) to perform CDUS. Gray scale imaging was used to evaluate the size and echotexture of the kidney. Atherosclerosis in the abdominal aorta and renal arteries was routinely observed (Figure 1a). Color flow imaging was employed in searching for blood flow abnormalities in renal vessels and for detecting accessory renal arteries (Figure 1b). Spectral Doppler sampling was started from the ostial portion and then traced along entire renal artery ending at the intrarenal artery (segmental or interlobar artery). The appearance of focal turbulence on color flow images helped to guide spectral Doppler sampling of the flow velocity. Hemodynamic evaluation by Doppler spectral analysis included peak systolic velocity (PSV) of the renal artery, PSV ratio of stenotic renal artery to the aorta at renal artery level, and acceleration time of the intrarenal artery (artery distal to the stenosis).

Higher pulse repetition frequency (PRF) was applied to avoid Doppler aliasing at arterial stenoses and AVF's. Lower PRF was used to detect slow flow in the intrarenal vessels and assess perfusion of the kidney. To achieve an accurate flow assessment, a small color Doppler box was maintained with an appropriate depth for maximizing the number of frames per minute (frame rate) and a pulse frequency repetition adequate for the structure to be analyzed (6). Moreover, we observed that the use of a small color Doppler box to concentrate Doppler energy on a magnified region improved visualization of abnormalities in small vessels. A large color Doppler box was employed to search for global abnormalities of the kidney and for

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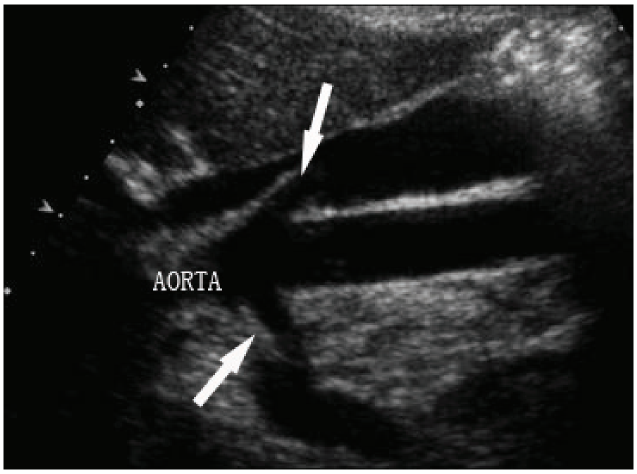

Figure 1a. Longitudinal view of normal renal arteries (arrows) and the abdominal aorta on a zoomed gray scale image

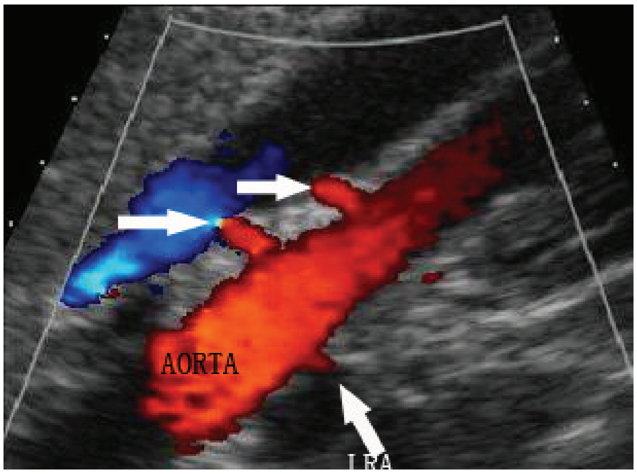

Figure 1b. Normal appearance of the right renal artery, right accessory real artery, single left renal artery (arrows), and abdominal aorta on longitudinal view of color flow image. LRA, left renal artery.

comparing one portion of a kidney to another (7).

Measurements of Spectra: using built-in software in the ultrasound scanner.

PSV: the highest point in systole (m/S).

Renal / aorta ratio: ratio of PSV at stenotic renal artery / PSV at abdominal aorta at renal artery level.

Acceleration time: the slope from the beginning of systole to the early systolic peak (Figure 1c).

Diagnostic criteria:

Hemodynamically significant main renal artery stenosis (>60% arterial lumen reduction):

Direct evaluation: Main renal artery

PSV > 2.0 m/s (16, 21)

PSV ratio of renal artery / aorta >3.5 (21)

Indirect evaluation: Intrarenal arteries (distal to the stenotic artery)

Acceleration time > 0.07 m/s

Intrarenal artery stenosis:

PSV of an intrarenal artery > 2.0 m/s

Intrarenal AVF:

Mixed arteriovenous waveform on spectral Doppler and increased velocity as evident by focal turbulence on color flow imaging and high PSV on spectral

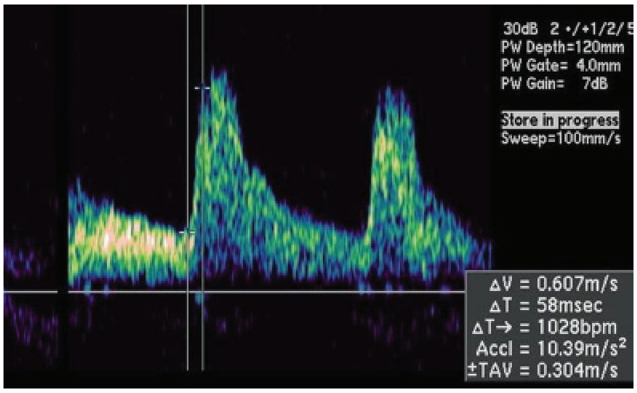

Figure 1c. Normal acceleration time (58msec), the slope from the beginning of the systole to the early systolic peak, of the intrarenal artery on spectral Doppler

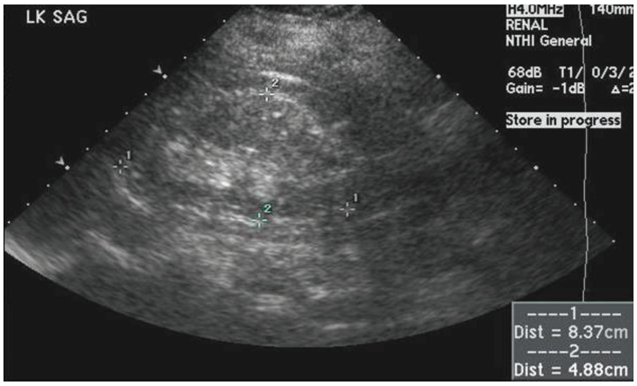

Figure 2a. The size of the left kidney is small (8.37 cm in lenth) and echogenicity of the kidney is increased in a patient with left renal artery stenosis. LK, left kidney; SAG, saggital view of the left kidney.

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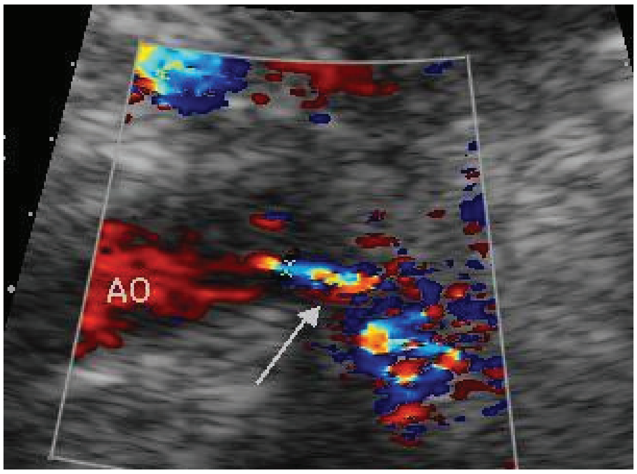

Figure 2b. Turbulent flow at left proximal renal artery (arrow) on transverse color flow image of the abdominal aorta at the level of renal artery origin. AO, abdominal aorta.

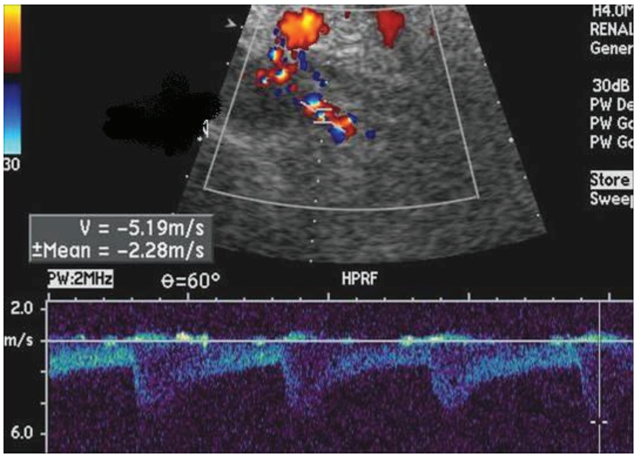

Figure 2c. Increased peak systolic velocity (5.19 m/s) demonstrated at the stenotic left renal artery on spectral Doppler. LRA, left renal artery; PROX, proximal.

Doppler (20).A steal phenomenon is considered if there is poor perfusion and diminished flow in the remainder of renal parenchyma with high flow velocity at the AVF (19).

Results

Main renal artery stenosis

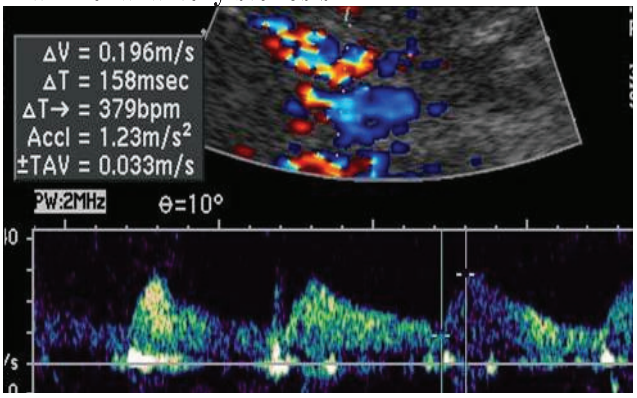

Figure 2d. Significantly slow acceleration time (158msec) as parvus tardus spectral waveform measured at the intrarenal artery distal to the stenosis

PSV > 2.0 m/s at a stenotic main renal artery was observed in 20 cases (20/22) with hemodynamically significant RAS (defined as arterial lumen reduction > 60%). Two cases (2/20) with abnormal acceleration time of the intrarenal artery and limited visualization of the main renal artery were interpreted as suspected main RAS. Studies of CDUS were followed by DSA (one case) and MRA (one case) that demonstrated no stenosis in the main renal artery. There were two cases of false negative RAS due to technical difficulty in optimizing visualization of the stensois at the main renal artery of the kidney (1/2) and lack of appearance of parvus tardus at the intrarenal artery (1/2).

Parvus-tardus, the waveform on spectral Doppler at the intrarenal artery distal to the stenosis appeared in 50 % of cases (10/20) with main RAS (Figures 2a-2f). It did not present (Figures 3a-3f) in 50 % of patients (10/20) with hemodynamically significant main RAS.

CDUS was performed on a patient with history of abdominal aorta aneurysm and hypertension. A left middle renal artery dissection with a hemodynamically significant stenosis (PSV 5.0 m/s) was initially visualized on CDUS. A left renal artery dissection was confirmed by contrast-enhanced computed tomography (Figure 4).

Intrarenal artery stenosis

There were three cases (3/7) of intrarenal RAS not visualized on initial CDUS. These patients were called back for additional imaging and intrarenal RAS

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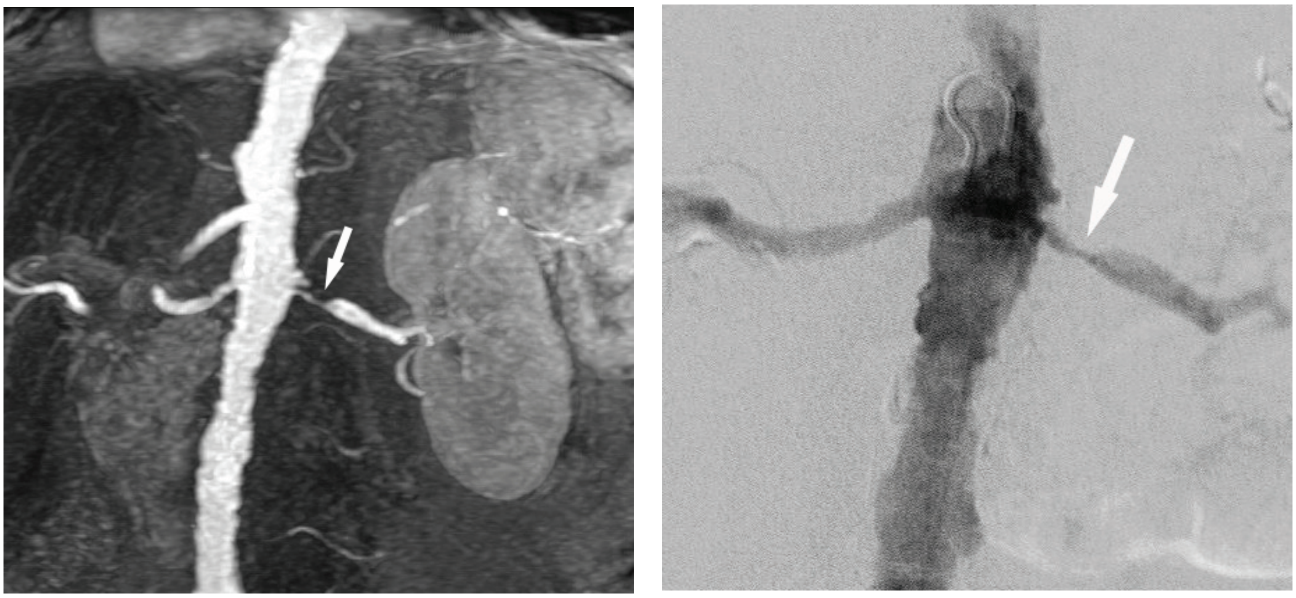

Figure 2e, 2f. >80% stenosis (arrow) of the left proximal renal artery is demonstrated on MRA (2e) and DSA (2f)

(Figure 5) was found on repeat scanning by more experienced ultrasound technologists.

Intrarenal arteriovenous fistula (AVF)

There were twenty patients with abnormal renal function who underwent percutaneous kidney biopsy. Seventeen of the twenty patients had abnormal renal function and 5 cases were accompanied by hematuria. AVF (Figure 6) with "steal" phenomenon was visualized in 5 cases. There were 4 cases (4/20) of negative AVF at initial scanning that were subsequently detected on repeat CDUS.

Discussion

CDUS is an ideal modality in screening for RVH because of the following advantages: it is a non-invasive, radiation-free, modality with portability, high accuracy, low cost, and no contraindications due to renal failure or contrast allergy. It is specifically considered the first line study when MRA or CTA is not desired or contraindicated. However, there are pitfalls of CDUS that can lead to inadequate results or diagnostic errors in screening for RVH.

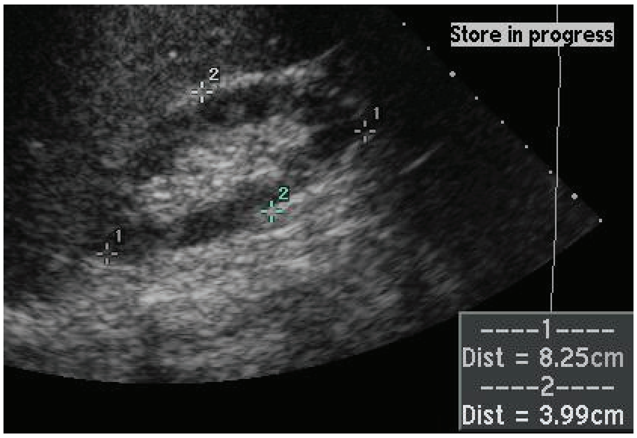

Figure 3a. The right kidney is echogenic and small in size (8.25cm in largest dimension) on longitudinal view of gray scale image

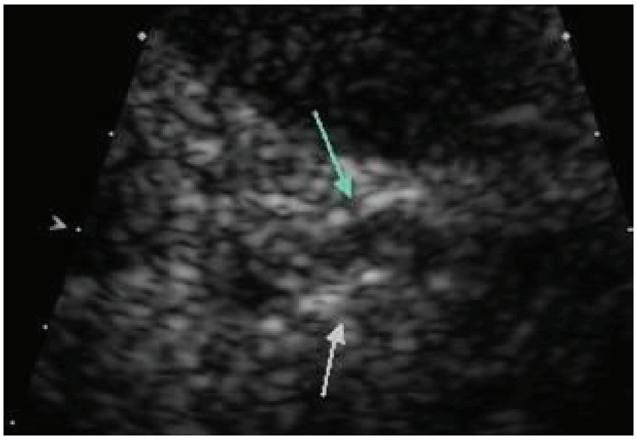

Figure 3b. Atherosclerotic plaques with calcification causing luminal narrowing in the right renal artery (arrow) on gray scale image

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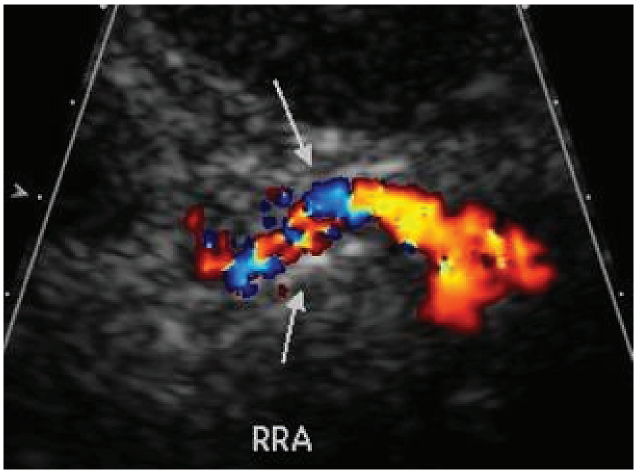

Figure 3c. Remarkably turbulent flow at the stenosis of the right proximal renal artery on longitudinal view of color flow image

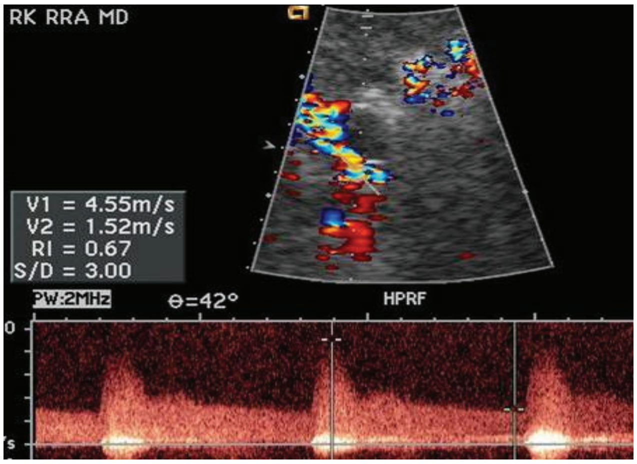

Figure 3d. Spectral Doppler demonstrated high peak systolic velocity (6.27 m/s) at the right renal artery with hemodynamically significant stenosis

Common pitfalls of CDUS in screening for main RAS are failure in visualizing the entire renal artery and missing the highest PSV at a stenosis during spectral Doppler tracing. These errors occur because of 1) patient-related factors, e.g., obesity, bowel gas, shortness of breath or poor tolerance of the exam, 2) technical factors, e.g., variation in operator experience and suboptimal angle or 3) anatomic factors, e.g., multiple renal arteries or multi-site stenoses. It is important to consider that DSA, MRA and CTA may also not be able to detect all cases in polar renal arteries (22).

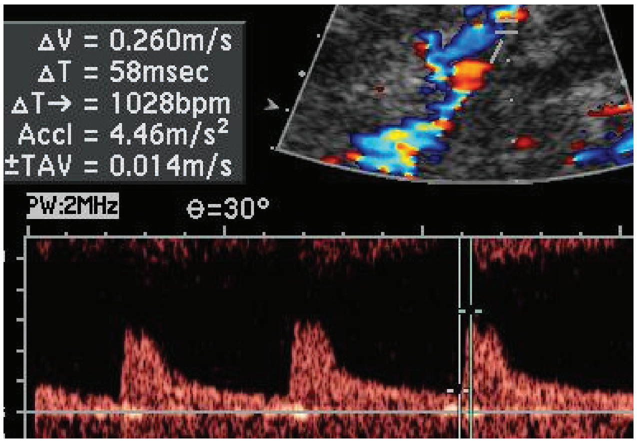

Figure 3e. Normal acceleration time (58msec) at the intrarenal segmental artery distal to the stenosis on spectral Doppler

When using both direct and indirect indications of RAS with Doppler parameters, we had the same results as Karplus (2). Specifically, the single measurement PSV had the highest performance characteristics for the diagnosis of main RAS. In our study, PSV > 2.0 m/s at stenotic renal artery was demonstrated in all 20 cases with hemodynamically significant main RAS confirmed by MRA, CTA, or DSA. However, an indirect indication, Acceleration time > 0.07 m/s with parvus tardus wave form in the intrarenal artery, was evident in only ten cases (10/20) with hemodynamically significant RAS. As Bude and Rubin reported (23), the mechanism of developing a parvus-tardus waveform distal to the stenosis is complex, which may not be evident in patients with chronic renal parenchymal disease or patients with poor end organ vessel compliance. Therefore, we consider the appearance of parvus tardus as a reference parameter in the diagnosis of RAS.

Sources of error in evaluation of abnormalities of the intrarenal artery include: 1) incorrect machine settings, e.g., low PRF on color Doppler setting overlaps small focal AVF or intrarenal RAS, and high PRF may suppress color Doppler to fill in a small AVF, 2) the error in measuring acceleration time may occur with incorrect sweep setting while recording

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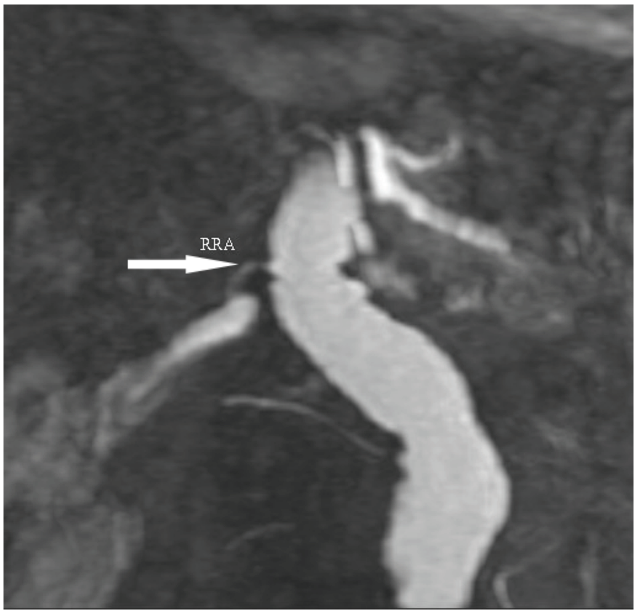

Figure 3f. MRA confirmed the stenosis at the right proximal renal artery

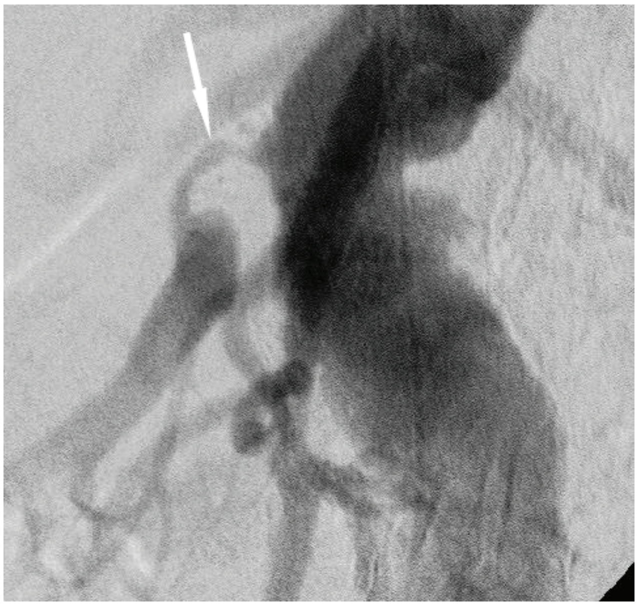

Figure 3g. Right renal artery stenosis on DSA

spectral Doppler. A sweep setting at 100 mm/s is only used when the upstroke on spectral waveform is not recognizable due to a fast heart rate (> 100 bpm). False parvus tardus may be present if a sweep of 100 mm/s is set on the patient with slow heart rate (< 60 bpm), as seen in two cases with false positive RAS in our study, and 3) visualization of a focal turbulence on intrarenal color Doppler image may result from high flow velocity at a stenotic artery or turbulent flow at an AVF, which is easily differentiated with spectral Doppler.

Intrarenal RAS is not common. False diagnosis can occur if color Doppler is set improperly. Since it is difficult to optimize the stenosis at small arterial branches (< 2-3 mm in diameter) in the kidney on MRA or CTA (21), CDUS may act as a compensatory

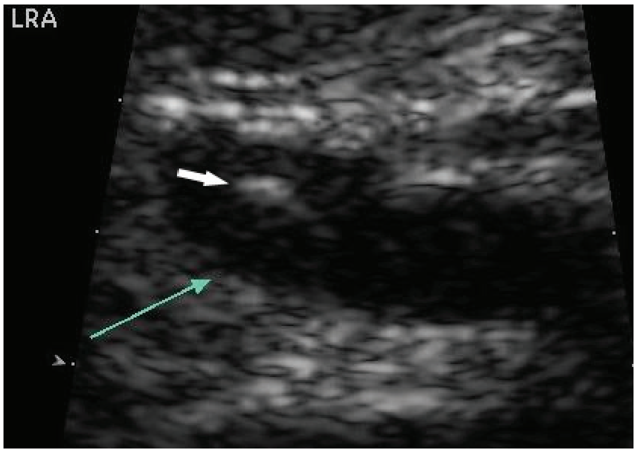

Figure 4a. A left middle renal artery on dissection (arrow) with flap (arrow head) is seen on the longitudinal view of a gray scale image. LRA, left renal artery.

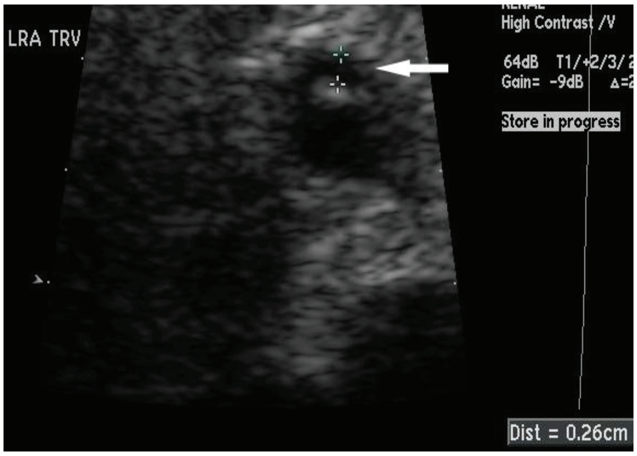

Figure 4b. A left middle renal artery dissection is present on transverse section of a gray scale image. A narrowed lumen (between calibers) measures 0.26cm. LRA, left renal artery; TRV, transverse section.

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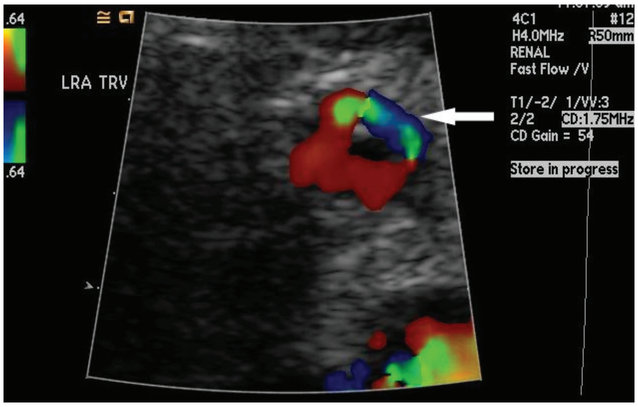


Figure 4c. Transverse section of the left renal artery with double lumen on color Doppler imaging. LRA, left renal artery; TRV, transverse section.

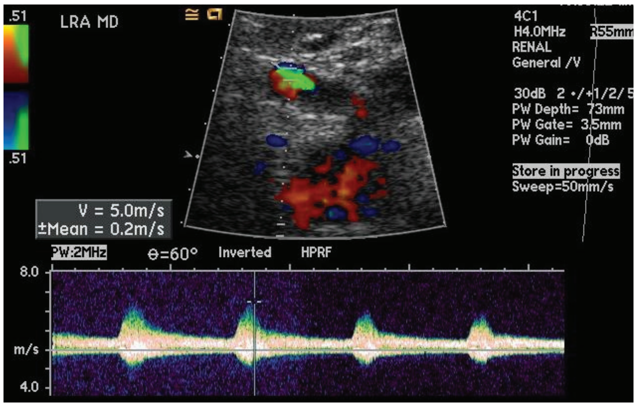
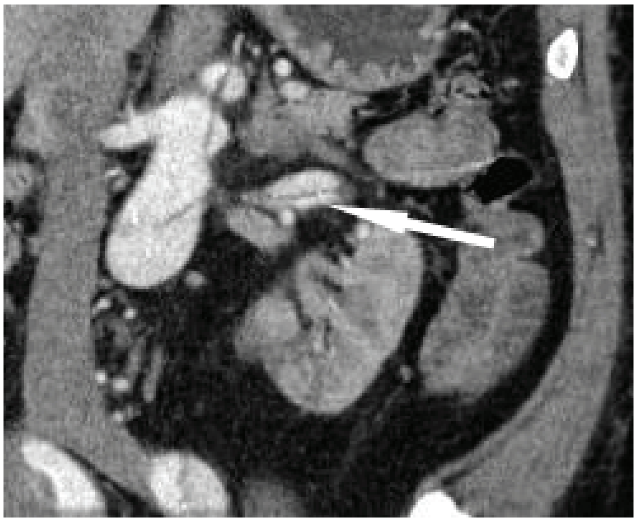
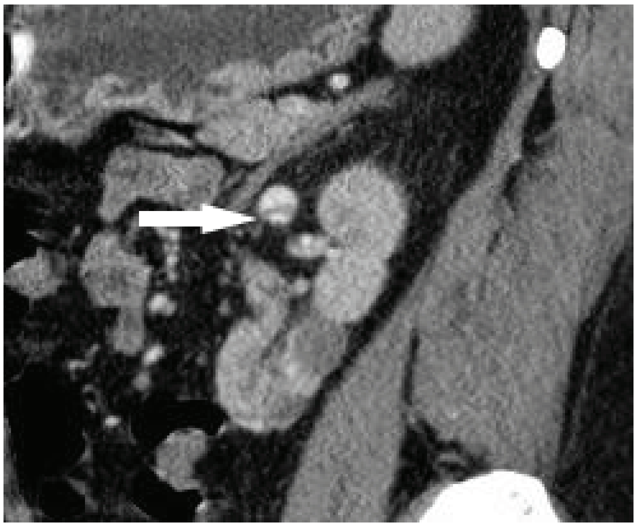


Figure 4d. Increased peak systolic velocity (5.0 m/s) at the left renal artery dissection is demonstrated on spectral Doppler



(4e)



(4f)

Figure 4e, 4f. The left renal artery dissection is confirmed on long axis images (4d) and short axis (4f) on a coronal section of contrast enhanced computed tomography

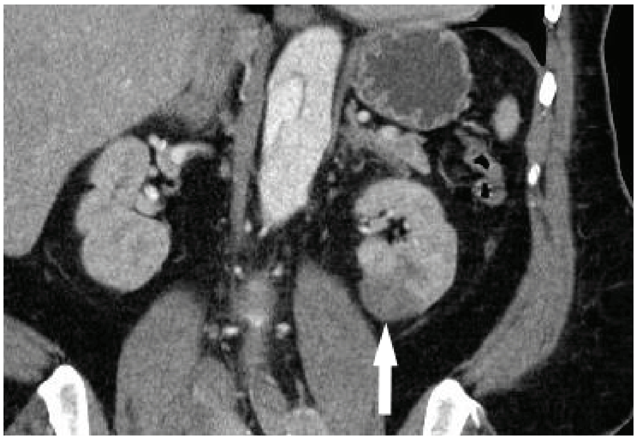


Figure 4g. Infarction (arrow) of the lower pole of the left kidney is also seen on contrast enhanced computed tomography

imaging technique to CTA and MRA in evaluating the intrarenal artery at the interlobar level. The use of small color Doppler box on a zoomed area is helpful in visualizing intrarenal artery branches (Figure 5c).

Many intrarenal AVF's can resolve spontaneously. A large AVF could produce a "steal" resulting in blood going preferentially through the arteriovenous communication instead of the entire renal parenchyma. If the resultant ischemic area is large enough, renal failure can occur. Correcting an arterial-venous shunt causing ischemia may necessitate emergency or scheduled surgical resection (18), or catheter embolization of the AVF, depending upon the size of AVF and renal

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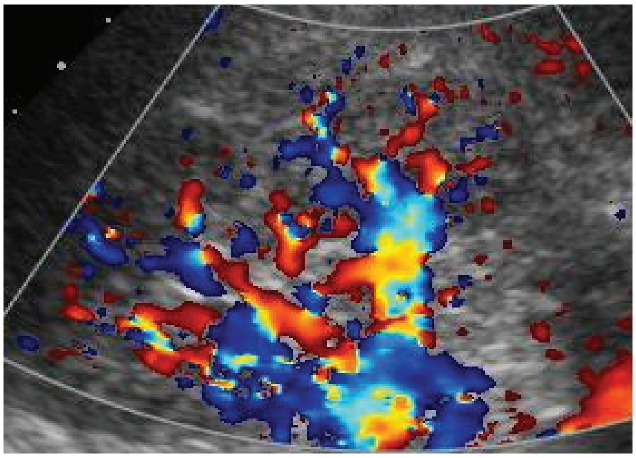

Figure 5a. There is no abnormality present in the entire transplanted kidney on longitudinal view of color flow image with low PRF setting

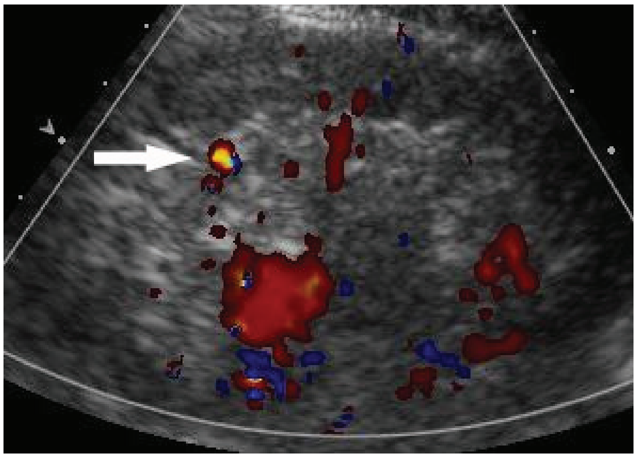

Figure 5b. A small area with turbulent flow at upper pole of the kidney appeared after decreased color Doppler priority setting

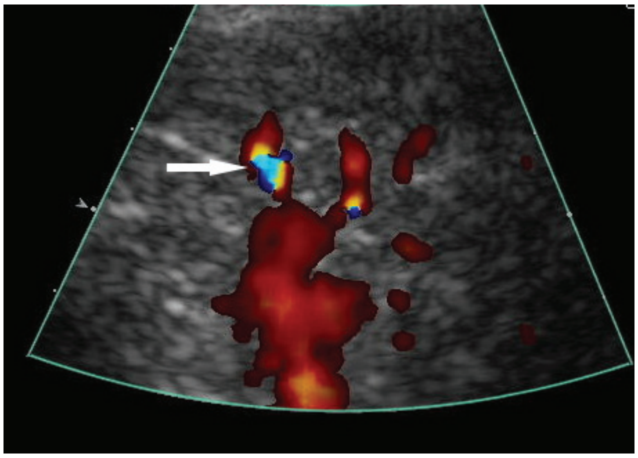

Figure 5c. Focal turbulence (arrow) at the junction of segmental artery and interlobar artery was clearly visualized on zoomed color flow image

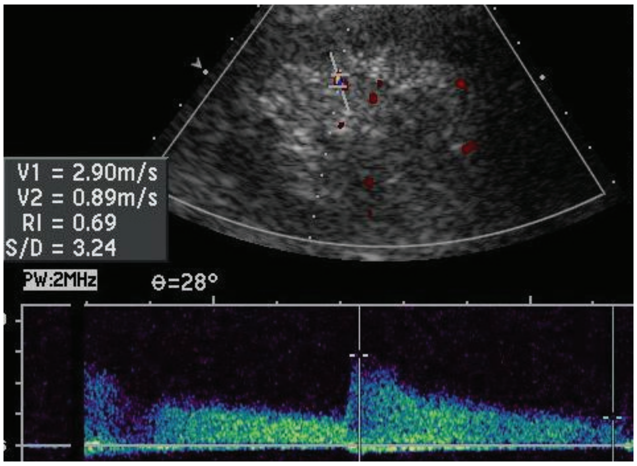

Figure 5d. An increased peak systolic velocity (2.9 m/s) at the intrarenal artery indicates an intrarenal artery stenosis

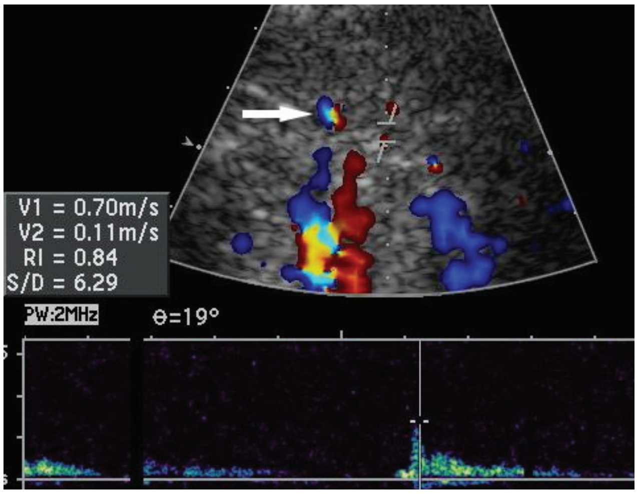

Figure 5e. Normal peak systolic velocity (0.70 m/s) sampled at the intrarenal artery without stenosis on spectral Doppler

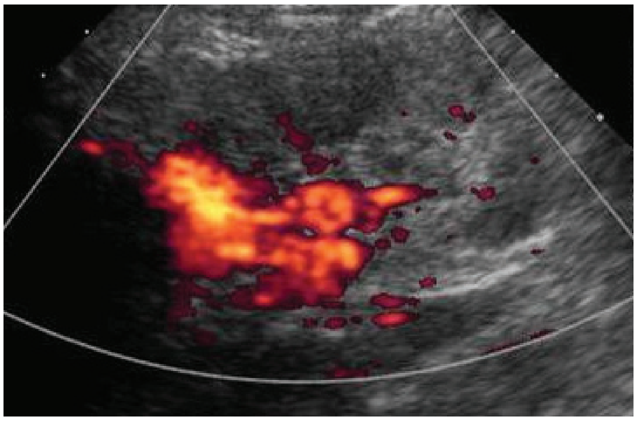

Figure 6a. Left native kidney sonogram was performed a week after kidney biopsy due to hypertension and hematuria. There was increased flow in the upper pole on power Doppler imaging

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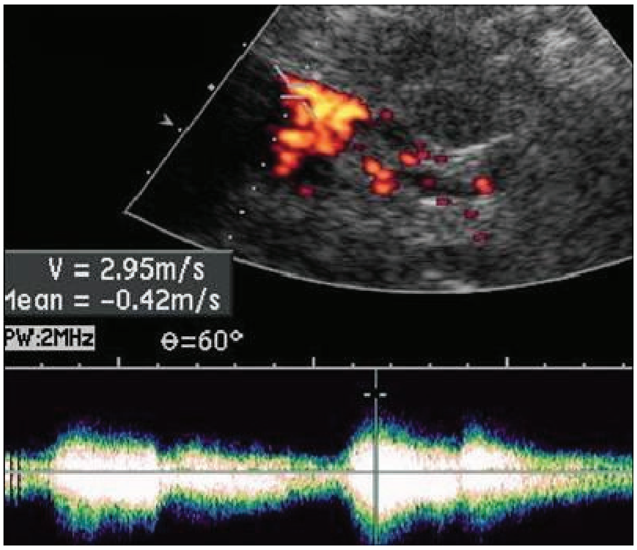

Figure 6b. Increased peak systolic velocity (2.95 m/s) and mixed arteriovenous flow is demonstrated on spectral Doppler indicating an arteriovenous fistula

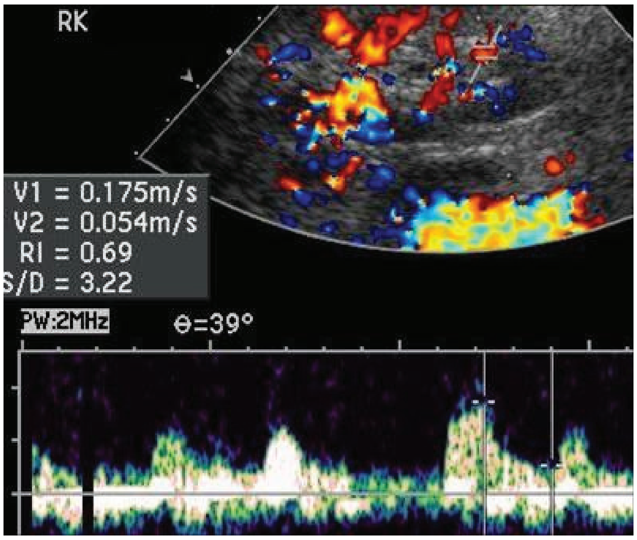

Figure 6c. Significantly diminished flow (0.175m/s) is demonstrated in the remaining renal parenchyma. A steel phenomenon is suspected

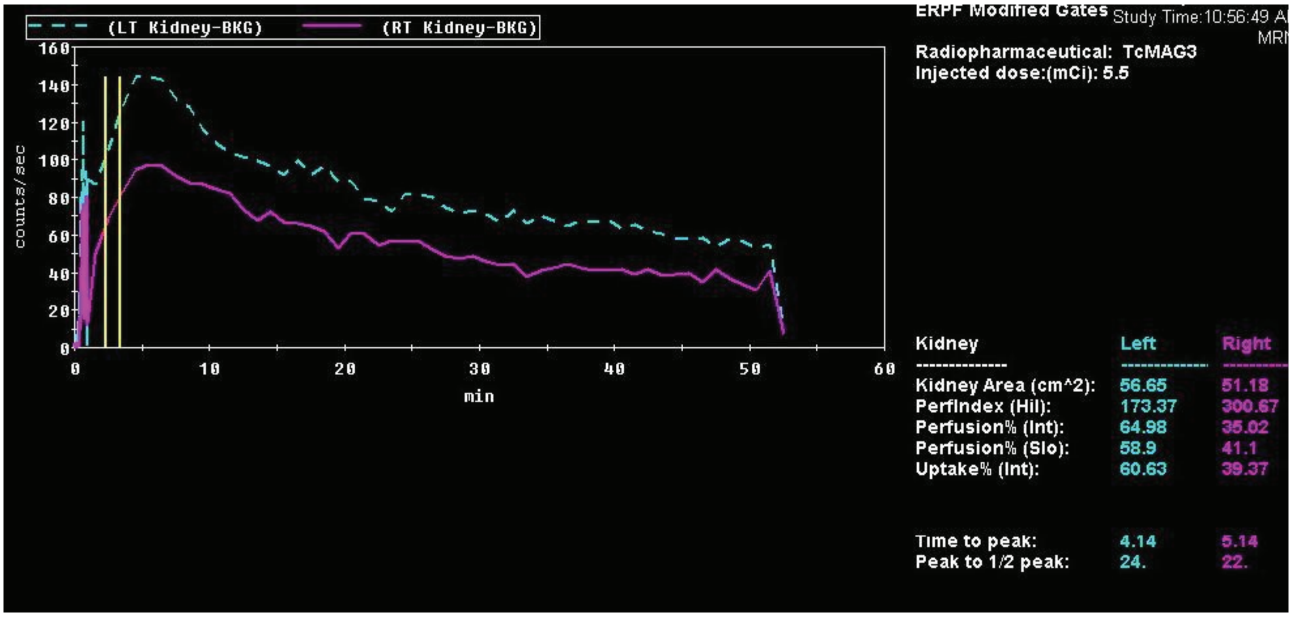

Figure 6d. Decreased renal function (right kidney) caused by AVF steel is confirmed on nephrography

function. Scanning carefully and proper color flow settings are important in detecting an intrarenal AVF that may be the cause of renal failure and hypertension.

MRA or CTA may be added as confirmation in cases with undetermined RVH on CDUS. DSA is still considered the gold standard in the diagnosis of main RAS. DSA is generally used at the time of therapeutic intervention for correction of RAS or embolization of AVF (20, 22).

The limitation of this study is inter-observer variation of scanning technologists. Other limitations include inter-observer variation of interpreting radiologists and variability due to the use of different machines (e.g., Sequoia and Logiq 9).

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Conclusions

Color duplex sonography serves a vital role in the diagnosis of RVH. There are pitfalls of CDUS in screening for RVH, which can be overcome by using appropriate techniques. Some technical errors of CDUS can be corrected. The accuracy of CDUS in detecting renovascular abnormalities may be improved with comprehensive training in both scanning technique and image interpretation.

Conflict of Interest

None declared.

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