ULTRASOUND EVALUATION OF THE RENAL TRANSPLANT

INTRODUCTION

Renal transplantation has become a common surgical procedure for patients with end-stage kidney disease. The increased frequency of transplantation coupled with increased patient survival have made it necessary for radiologists in all practice settings to be familiar with the normal ultrasound appearance and the imaging findings of common complications associated with renal transplantation. In the setting of an abnormal physical examination or laboratory value indicating renal transplant dysfunction, imaging examinations are often requested to evaluate for morphologic and vascular abnormalities of the transplant. The portability, accessibility and non-invasive nature of ultrasound make it a critical component in the evaluation of a renal transplant. A thorough ultrasound evaluation and screening of the renal transplant hinge on the radiologist's ability to optimize the scanning parameters to achieve a diagnostic examination, delineate normal transplant anatomy, and recognize the common complications.

ULTRASOUND TECHNIQUE

In the majority of cases, the renal transplant is placed in the retroperitoneal space of the right iliac fossa. Vascular anastomoses are carried out in an end-to-side fashion between the transplanted renal vessels and the recipient's common or external iliac vessels (Figure 1). In the minority of cases, multiple vascular anastomoses or a jump graft are required. In such cases, correlation to the operative report or diagram is often essential in understanding the transplant anatomy. The transplanted ureter is implanted in the superior aspect of the bladder. Once the transplanted kidney is identified, images are acquired in the transverse and sagittal planes and the renal size is recorded. The adjacent soft tissues are scanned to identify any fluid collections. After color or Power Doppler is applied to assess global flow and to identify the renal pedicle, spectral Doppler analysis of the renal artery, renal vein, iliac vessels and anastomoses is initially carried out (Figures 2 and 3). The peak systolic and end diastolic velocities are recorded and the waveforms are evaluated. The intrarenal segmental or interlobar arteries are also evaluated with spectral Doppler analysis at the inferior, mid and superior aspects of the transplant (Figure 4).

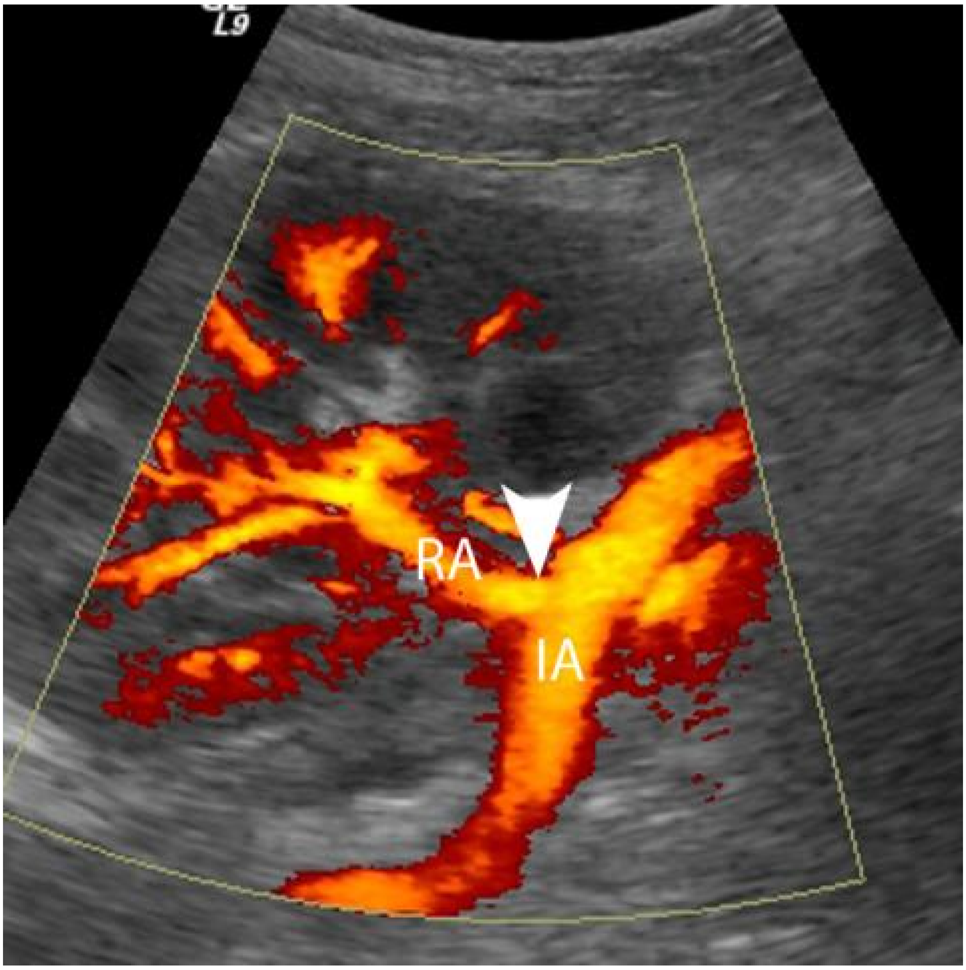

Figure 1. Normal renal transplant anatomy. Power Doppler image shows the renal transplant in the right iliac fossa. The end-to-side anastomosis (arrowhead) between the transplanted renal artery (RA) and the recipient's external iliac artery (IA) is well shown.

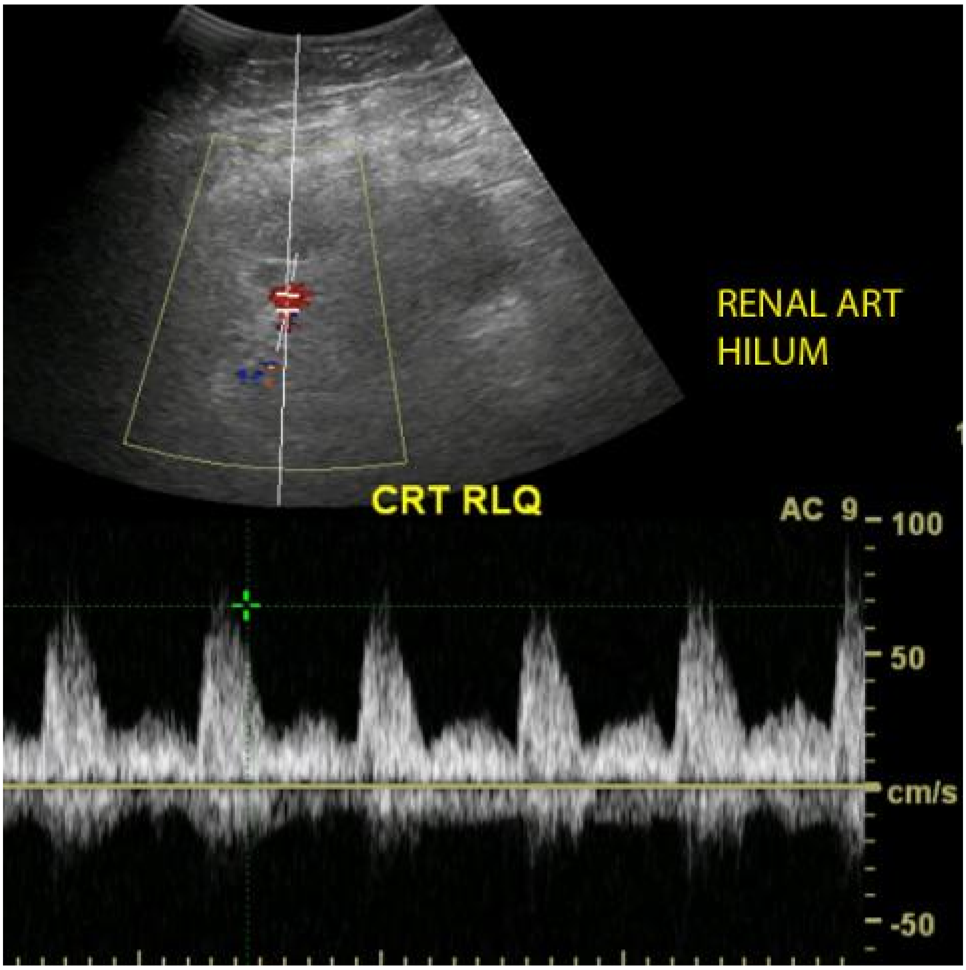

Figure 2. Normal renal artery shown on spectral Doppler ultrasound. There is a brisk systolic upstroke and antegrade diastolic flow in the normal renal artery waveform.

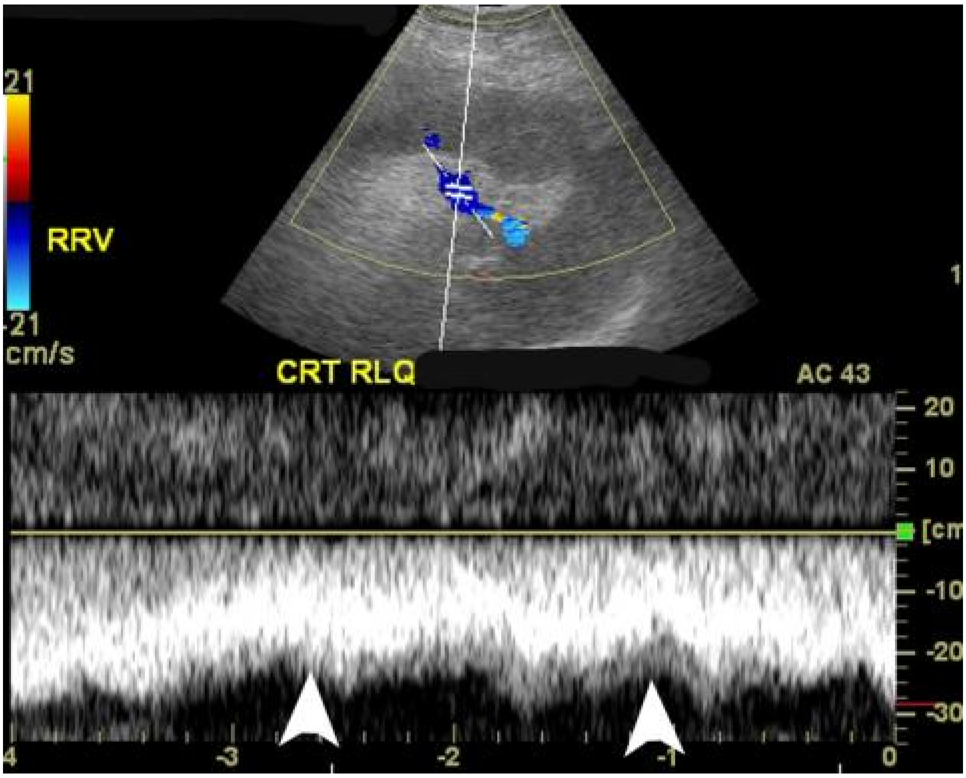

Figure 3. Normal renal vein shown on spectral Doppler ultrasound. The normal renal venous waveform (arrowheads) is continuous and monophasic.

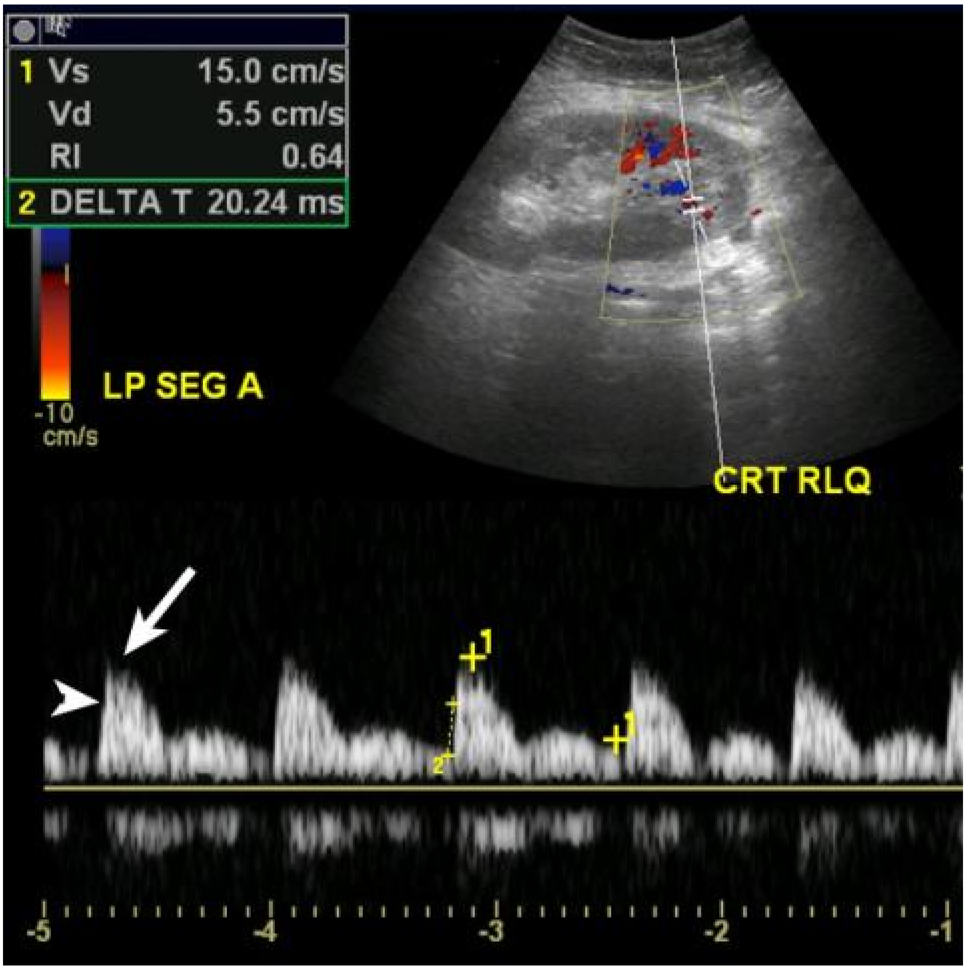

Figure 4. Normal segmental arterial waveform. Spectral Doppler image shows a brisk systolic upstroke (arrowhead), normal systolic notch (arrow) and normal resistive index.

Technique optimization consists of adjusting several scanning parameters and insonating a suitable region of interest that includes the entire renal transplant, ipsilateral iliac vessels and the surrounding tissues. The gray-scale evaluation is optimized through use of a higher frequency probe (Figure 5); the superficial position of most renal transplants allows use of a 7 MHz probe. Additionally, use of harmonic and compound imaging can be used to maximize tissue contrast in select situations. A key component of the Doppler portion of the examination is the degree of pressure applied by the probe. While it may be occasionally useful to apply gentle pressure to displace intervening bowel or fat, care must be taken to not compress the vasculature of the renal transplant; doing so will impede diastolic flow and falsely increase the resistive index, thereby leading to a potential erroneous interpretation. In order to properly assess the global parenchymal flow to the transplant, the Doppler gain should be set to the highest level without creating a noisy image. An improperly low initial Doppler gain will result in apparent hypoperfusion and may result in difficulty in identifying the intraparenchymal vessels for spectral Doppler evaluation. To accurately assess color flow and spectral velocity, care should be taken to ensure a proper angle of insonation; ideally, the angle should be less than 60 degrees. When beginning an examination, the Doppler filter should be set at the lowest possible setting and slowly increased. This approach will ensure that slow flow in a vessel is not masked by an improper filtration setting. Similarly, the pulse repetition frequency should begin at the lowest possible setting as well. The pulse repetition frequency can then be subsequently increased in the setting of aliasing so as to properly scale the velocity.

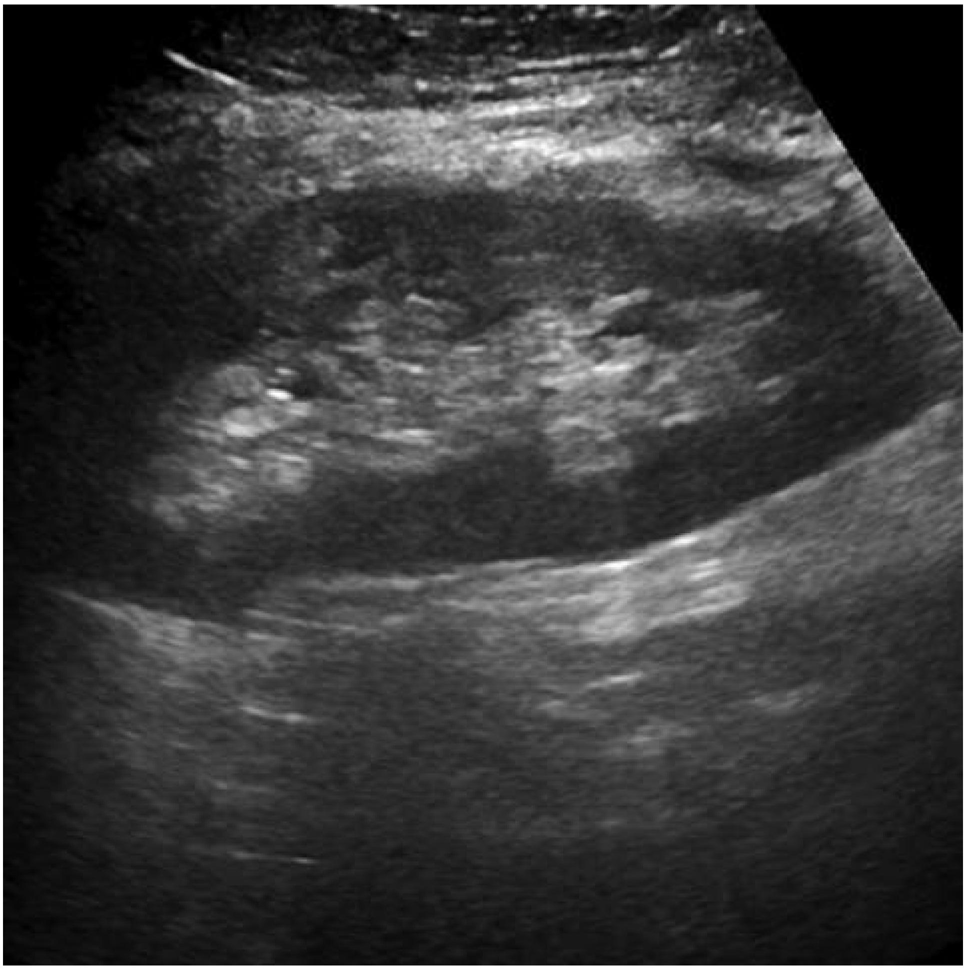

Figure 5. Normal renal transplant. Sagittal gray-scale image using a 7 MHz transducer shows that normal cortex is easily differentiated from the echogenic sinus fat.

Table 1

Summary of US parameters for renal transplant Doppler evaluation

Parameter	Initial setting	Comment
Gray-scale	7 MHz	Low frequency can obscure parenchymal detail
Transducer pressure	minimal	High pressure can compromise diastolic flow
Doppler gain	highest possible	Optimizes global flow assessment
Doppler filter	lowest possible	Maximizes detection of slow flow
Pulse repetition frequency	lowest possible	Increase slowly to adjust velocity scale in aliasing

US EVALUATION OF COMPLICATIONS OF RENAL TRANSPLANTATION

The various ultrasound findings associated with complications of renal transplantation are summarized in Table 2. Classically, the complications affecting the transplanted kidney can be categorized as anatomic, functional and vascular.

Table 2

Summary of abnormal renal transplant ultrasound findings

Ultrasound Finding	Differential Diagnosis
Increasing size of renal transplant	rejection, infection, venous thrombosis

Decreasing size of renal transplant	chronic ischemia, chronic rejection
High resistive index	acute tubular necrosis, obstruction, infection, severe rejection, extrinsic compression
Low resistive index	arterial stenosis, advanced aortic or iliac atherosclerosis, arteriovenous fistula
Hydronephrosis	obstruction (stone, clot), anastomotic stenosis/edema, neurogenic bladder, bladder outlet obstruction

ANATOMIC COMPLICATIONS

Anatomic complications are generally defined as physical problems with the renal transplant and its surrounding tissues and include post-operative fluid collections (seroma, hematoma, urinoma, abscess), hydronephrosis and parenchymal masses. The majority of post-operative fluid collections are due to hematomas and seromas (Figures 6 and 7). These fluid collections arise following manipulation of the tissues in the operative bed and subsequent oozing in the peri-operative period. Fluid collections which are crescent-shaped or have small volume and exert no mass effect upon the renal transplant are not clinically significant; such collections can be followed on serial ultrasound examinations and typically regress over a period of days to weeks. In cases of sufficiently large fluid collections, mass effect on the transplant can result in obstructive hydronephrosis, kinking of the vascular pedicle and compromised parenchymal perfusion which can ultimately lead to decreased function. At gray-scale examination, the fluid collection with mass effect compresses the renal parenchyma and collecting system, resulting in distortion of the normal ‘reniform’, elliptical shape of the transplant. At Color Doppler evaluation, parenchymal flow may be relatively decreased at the site of compression, or decreased throughout the entire transplant. Spectral analysis will show a high-resistance waveform which can be quantified by use of the resistive index defined as the ratio of the difference of the peak systolic velocity and end diastolic velocity to the peak systolic velocity [(PSV-EDV)/PSV]. The hallmark of a high resistive waveforms is decreased or absent diastolic flow resulting in elevation of the resistive index (>0.7).

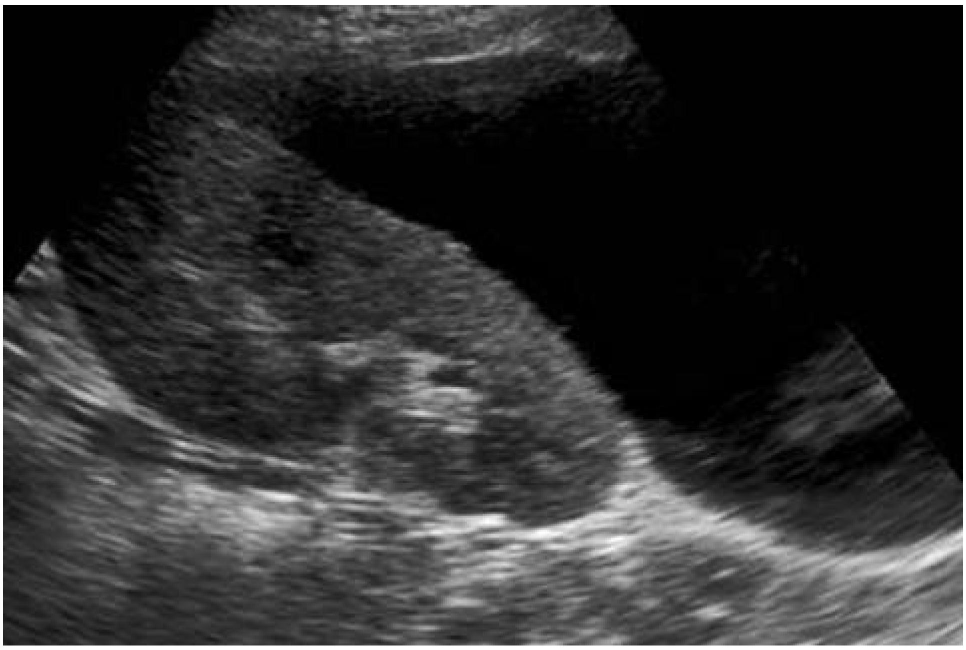

Figure 6. Perinephric fluid collection. Sagittal view shows an anechoic fluid collection along the dorsal margin of the transplanted kidney. Primary differential diagnostic considerations include seroma and urinoma.

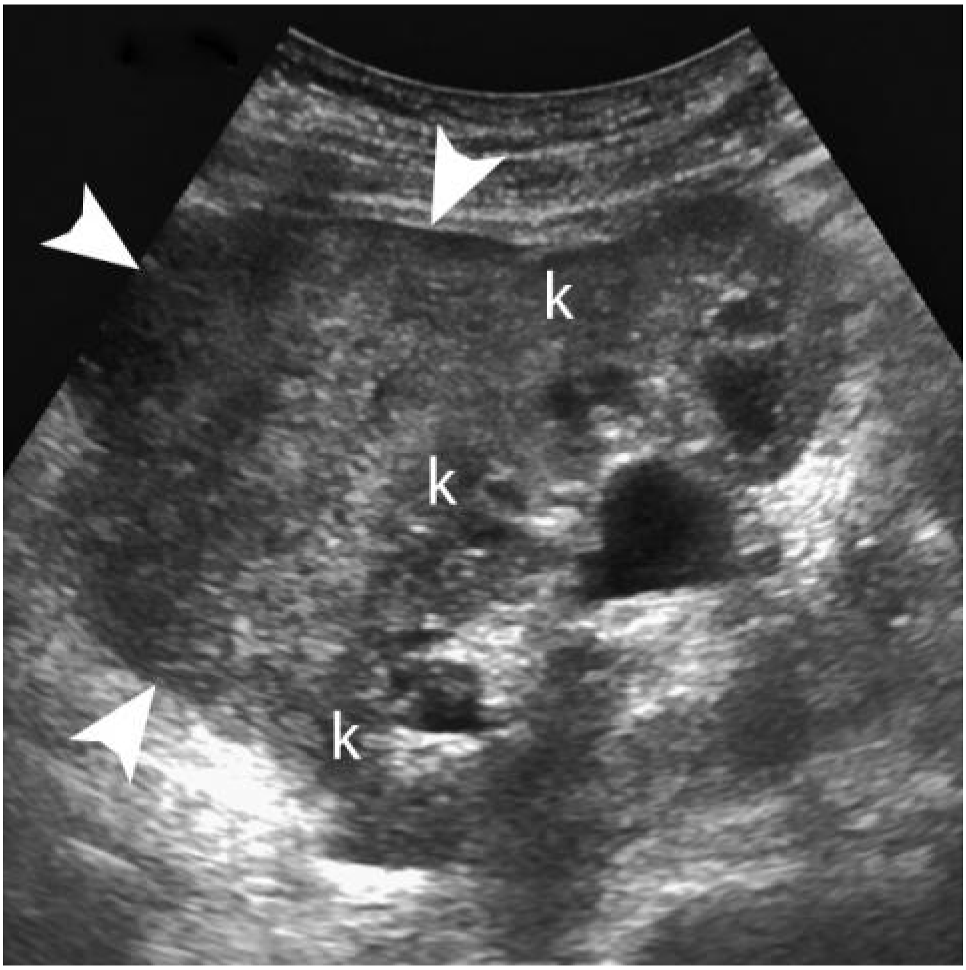

Figure 7. Perinephric hematoma. Sagittal view demonstrates an echogenic collection along the dorsal margin of the transplanted kidney due to post-operative hematoma.

Although less common, abscesses, urinomas and lymphoceles can also exert mass effect on the renal transplant. Abscesses typically consist of a well-marginated collection with extensive internal debris. While an abscess can be difficult to differentiate from a hematoma by ultrasound criteria alone, commonly associated clinical and laboratory findings of fever and leukocytosis are useful adjuncts. In some cases, color Doppler evaluation will show hyperemia in the wall and surrounding tissues of an abscess. Follow-up CT is often beneficial to elucidate the extent of the abscess and aid in planning percutaneous drainage. Lymphoceles are not observed in the immediate post-operative period, but typically arise approximately one to two months after surgery. Lymphoceles appear as rounded or slightly lobular anechoic collections which are most commonly located in the vicinity of the surgical anastomosis due to disruption of the adjacent lymphatic channels. Urinomas also appear as anechoic fluid collections which are often located closer to the urinary bladder due to compromise of the ureteral-bladder anastomosis. While ultrasound can readily identify and characterize a post-operative fluid collection, diagnosis usually requires image-guided catheter placement and laboratory analysis.
In addition to extrinsic compression, other physical causes of transplant hydronephrosis include renal calculi, clot, anastomotic edema, ureteral stenosis and urothelial neoplasms. It should be noted that anastomotic edema often results in transient hydronephrosis of the transplanted kidney. Typically, the dilatation will be observed to gradually decrease on serial ultrasound examinations. Also, apparent hydronephrosis may be the result of a denervated collecting system and increased hydrostatic pressure due to a full bladder; evaluation after voiding can avoid diagnostic error in this setting.
Focal parenchymal lesions in the renal transplant, whether hypoechoic or hyperechoic, are non-specific

findings (Figure 8). Differential considerations include focal pyelonephritis, rejection, hematoma, abscess, infarction, renal cell or transitional cell carcinoma and post-transplantation lymphoproliferative disorder (PTLD). Application of color Doppler can be used to further characterize the lesion; lesions with internal color flow are more concerning for potential neoplasm, although the lack of color flow within a lesion does not entirely exclude malignancy. Ancillary findings of malignancy and PTLD include adenopathy. In most cases, a follow-up imaging examination or tissue analysis are required to further characterize and diagnose the parenchymal lesion.

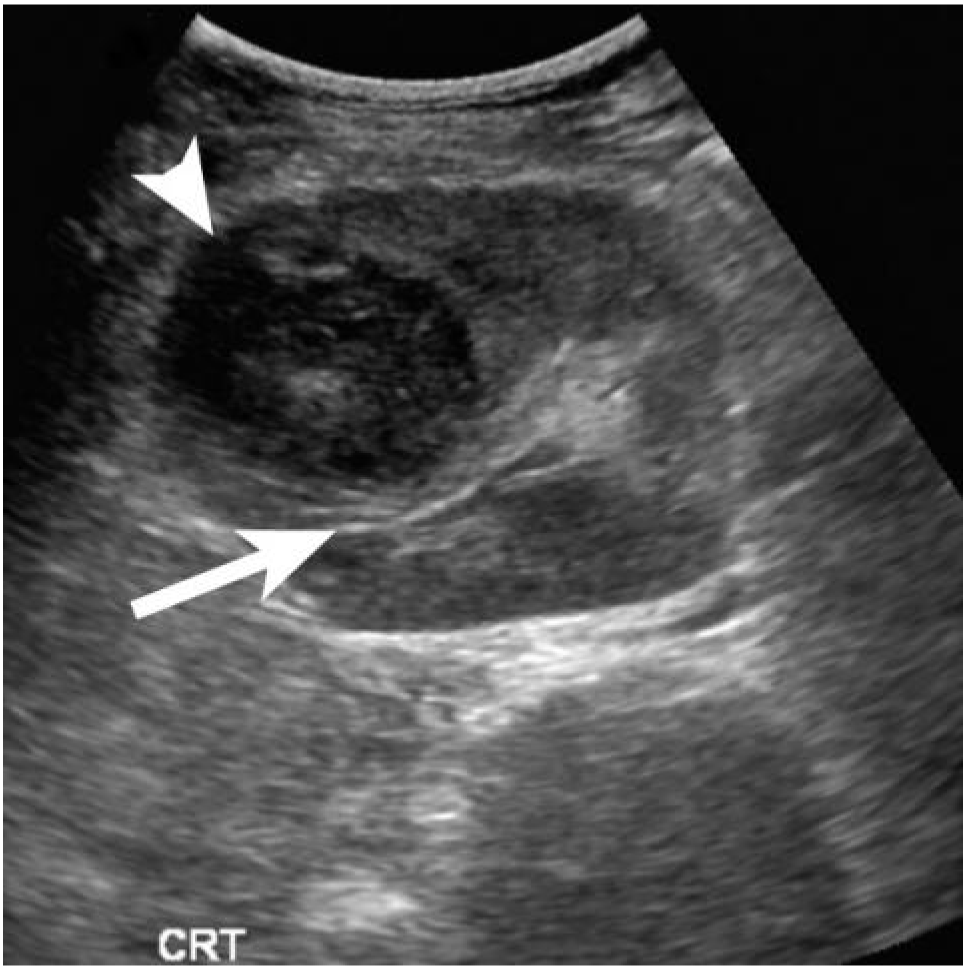

Figure 8. Intraparenchymal abscess. Transverse image shows a hypoechoic lesion (arrowhead) with internal echoes in the lateral aspect of the transplanted kidney. The lesion was due to an abscess and resulted in mild distortion of the renal sinus fat (arrow).

FUNCTIONAL COMPLICATIONS

Ultrasound plays a more limited role in the evaluation of functional complications. While ultrasound is useful in the detection of a funcitonal abnormality, the specificity is poor as cases of rejection, drug toxicity, peri-operative ischemia and acute tubular necrosis are difficult to distinguish from one another by imaging criteria alone. Ultrasound usually plays no role in cases of hyperacute rejection (humeral mediated) since the diagnosis is typically made immediately after transplant re-perfusion while still in the operating room. Cellular-mediated acute rejection is a pathologic diagnosis in the early to moderate phases as gray-scale as Doppler ultrasound findings have been shown to be unreliable in its diagnosis. In cases of severe acute rejection, the transplanted kidney becomes edematous and manifests as a globular, hypoechoic mass with poor differentiation of the central renal sinus fat (Figure 9). The edema leads to increased vascluar resistance and elevation of the resistive index (Figure 10). However, the finding of increased resistive index is a non-specific finding which can also be seen in the setting of infection, acute tubular necrosis, perioperative ischemia, hydronephrosis and extrinsic compression (Figure 11). Differentiation of these entities often requires ultrasound-guided biopsy. Follow-up ultrasound evaluation after adjustment of immunosuppression medications or treatment for underlying infection should be sought to assure resolution of the ultrasound findings and to assure that further complications, such as capsular rupture and hemorrhage, did not occur. If chronic rejection develops, the Doppler evaluation rarely demonstrates any reproducible or significant abnormalities and the diagnosis must be established by biopsy. Cortical thinning and mild hydronephrosis have been described in cases of chronic rejection. In summary, most cases of functional complications have non-specific imaging findings consisting of parenchymal edema and elevated resistive indices and require tissue analysis for diagnosis.

Figure 9. Acute transplant rejection. Sagittal gray-scale image shows an enlarged, gobular hypoechoic renal transplant with loss of the normal corticomedullary differentiation and ill-definition of the renal sinus fat due to extensive edema secondary to rejection.

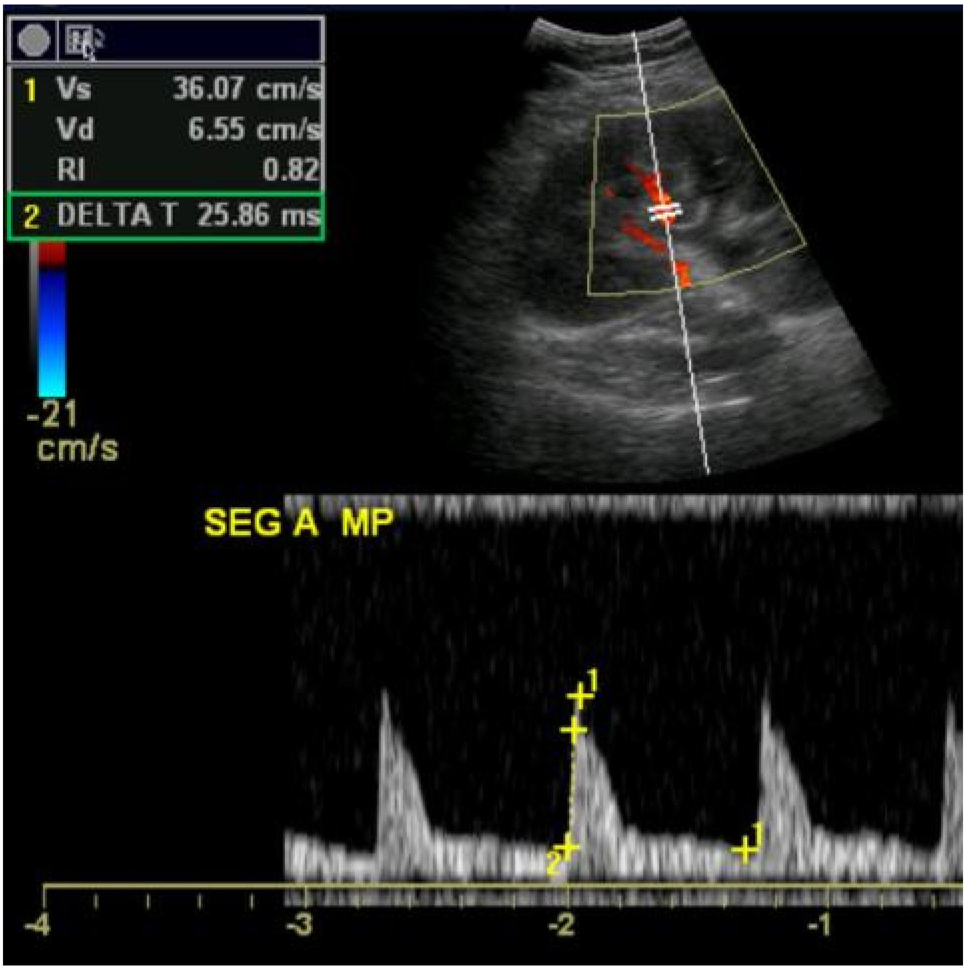

Figure 10. Acute rejection. Spectral Doppler image of a segmental artery reveals a mildly increased resistive index due to parenchymal edema. Biopsy indicated acute rejection.

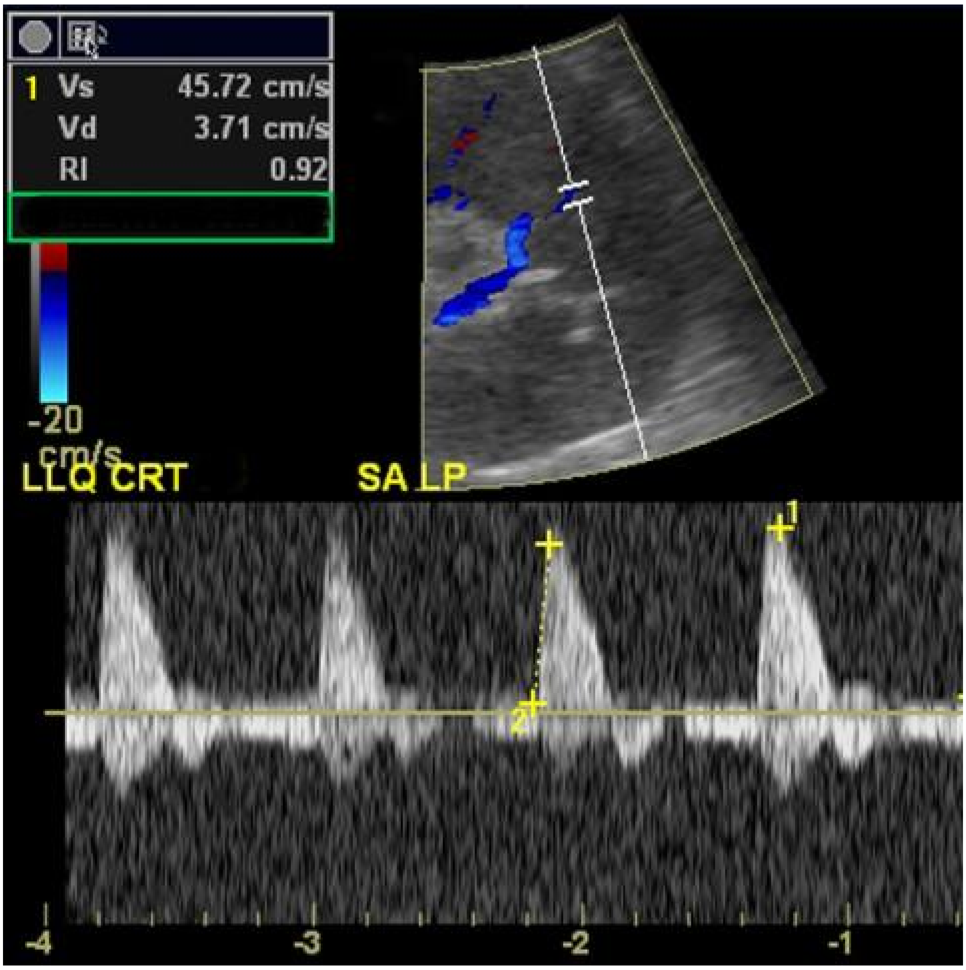

Figure 11. Acute tubular necrosis. Spectral Doppler image of a segmental artery reveals an increased resistive index, a non-specific finding which was due to acute tubular necrosis in this case.

VASCULAR COMPLICATIONS

Ultrasound plays a pivotal role in identifying and quantifying vascular complications of renal transplants. Vascular complications include arterial and venous stenosis and occlusion, kinking, arteriovenous fistulas and pseudoaneurysms. While vascular complications occur in less than 10% of transplant recipients, they are an important, and often correctable, source of morbidity and mortality in renal transplantation.

Renal Artery

Arterial stenosis usually occurs at the anastomosis or along the proximal aspect of the transplanted renal artery. However, the entirety of the renal artery should be thoroughly insonated and the segmental arterial waveforms should be reviewed on all ultrasound examinations of renal transplants. Focal arterial stenosis is typically a consequence of mural ischemia induced during vessel harvesting and re-implantation during surgery. While some cases of mild renal artery stenosis are clinically silent, patients can present with elevated blood pressure and renal dysfunction as the stenosis progresses.

At spectral Doppler analysis, turbulent flow with arterial velocity exceeding 200cm/s is consistent with a hemodynamically significant stenosis. When the elevated velocity in the renal artery is normalized to the velocity in the ipsilateral iliac artery, the velocity gradient is typically greater than 2 in cases of hemodymically significant stenosis (Figure 12).In cases of focal, significantly elevated arterial velocities, aliasing is often observed as a focus of disorganized color during color Doppler evaluation. In these cases, the pulse repetition frequency must be sequentially increased to properly expand the velocity scale and allow quantification of the velocity. An additional spectral Doppler finding of a hemodynamically significant stenosis is blunting of the normally brisk arterial waveform in the intrarenal branches. The blunted waveform manifests by a delayed systolic upstroke, loss of the early systolic notch and rounding of the systolic peak; this waveform is referred to as a tardus-parvus waveform and can be quantified by prolongation of the acceleration time (>0.08 seconds) and a decreased resistive index (<0.5) (Figure 13).In some renal transplants, such as those requiring multiple arterial anastomoses due to accessory renal arteries, the tardus-parvus waveform may be demonstrated only in the segments supplied by the affected artery. Additionally, although rare, focal arterial stenoses can occur in the intraparenchymal segmental and interlobar arteries due to parenchymal scarring or as a consequence of arterial injury during biopsy. While most stenoses located at the anastomosis or within the main renal artery are amenable to percutaneous angioplasty or stenting, those located more distally within the intraparenchymal vessels may be inaccessible and therefore have limited treatment options.

Renal artery thrombosis is rare and is usually due to a mechanical problem at the anastomosis rather than a consequence of acute rejection. The hallmark of arterial occlusion is absence of color and spectral Doppler flow despite parameter optimization. In cases of multiple arteries, occlusion of one of the arteries can lead to segmentally decreased perfusion or segmental infarct (Figure 14). In cases of suspected arterial occlusion, care must be taken to detect slow flow by drastically lowering the pulse repetition frequency and Doppler filter. Adjustment of these parameters will ensure that instances of severe stenosis with apparently flat waveforms are not mistaken for complete occlusion. A follow-up evaluation with magnetic resonance angiography is a useful adjunct in cases with indeterminate ultrasound findings or for further evaluation prior to surgical intervention. In cases of severe rejection with severely compromised arterial flow, the transplanted kidney will have a globular, edematous appearance; this is in contrast to the lack of edema in the non-rejecting kidney with arterial compromise.

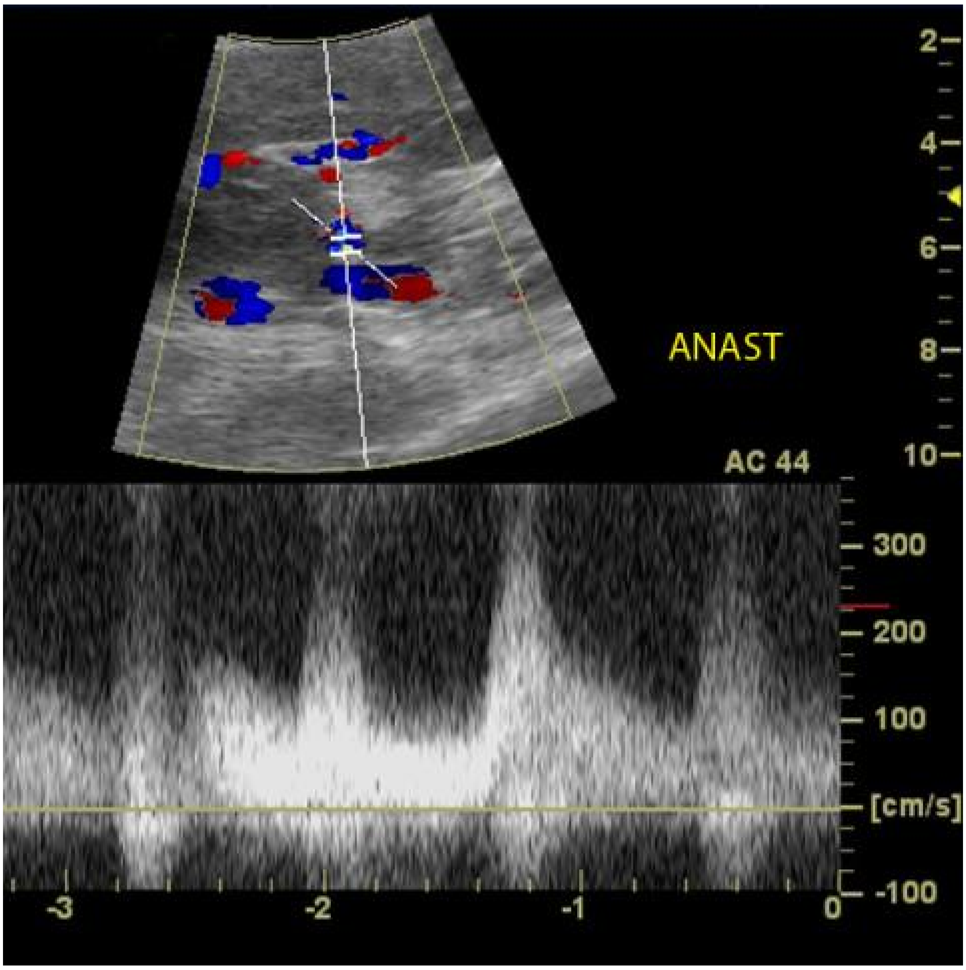

Figure 12a. Arterial anastomotic stenosis. a) Spectral Doppler ultrasound image shows focally elevated velocity (measuring up to approximately 300 cm/s) at the arterial anastomosis.

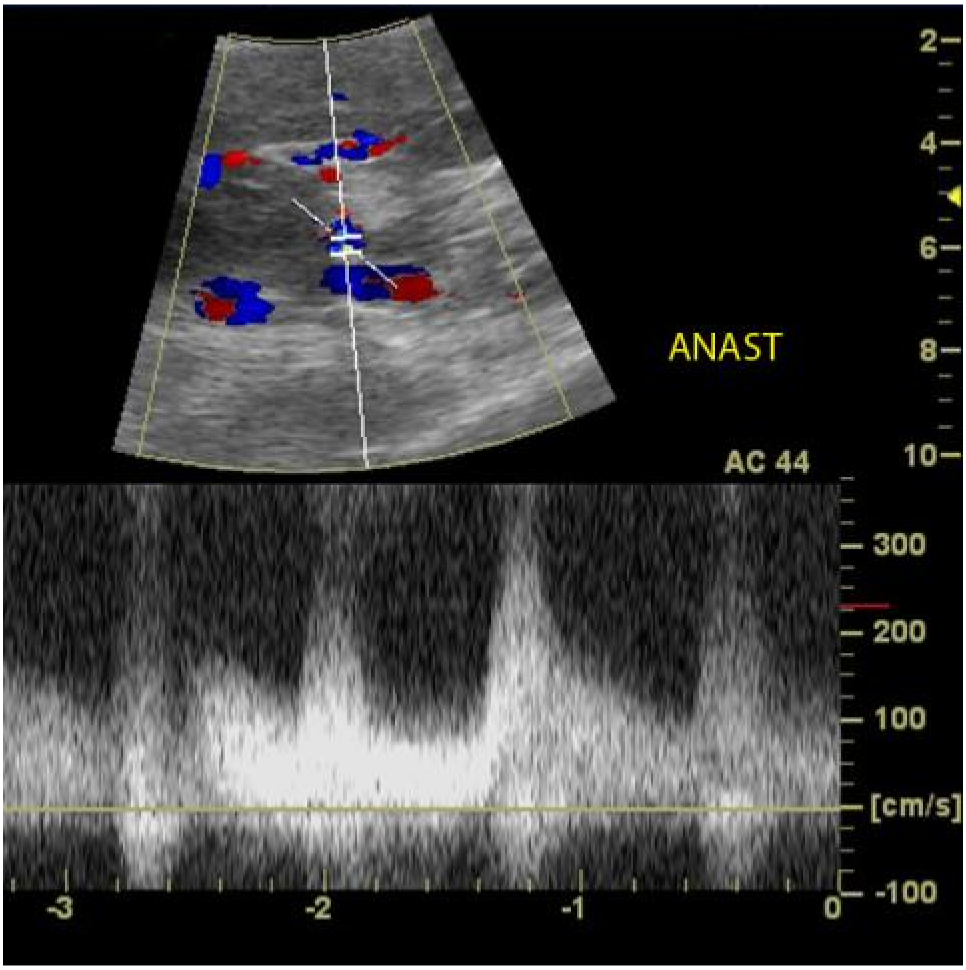

Figure 12b. Arterial anastomotic stenosis b) The velocity in the ipsilateral iliac artery was 50 cm/s, resulting in a 6-fold velocity gradient at the anastomosis when normalized to the iliac artery.

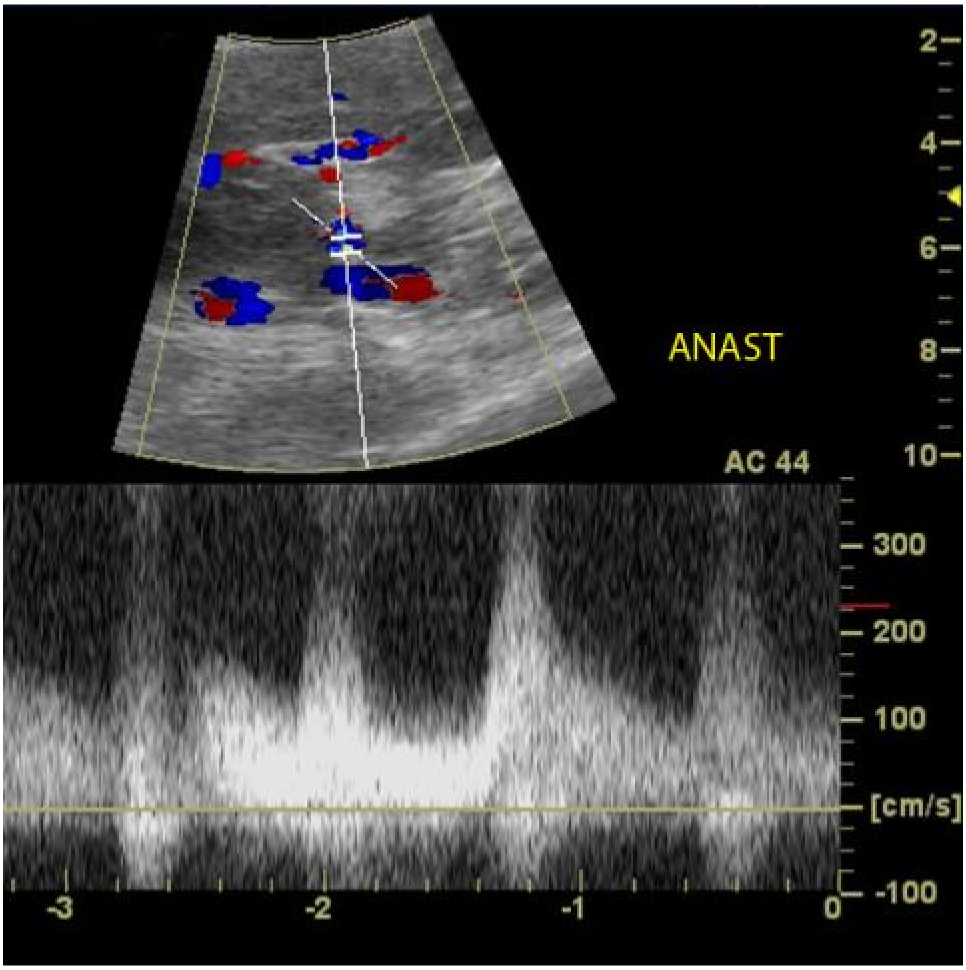

Figure 12c. Arterial anastomotic stenosis c) Maximum intensity projection MR image shows focal stenosis (arrow) at the arterial anastomosis.

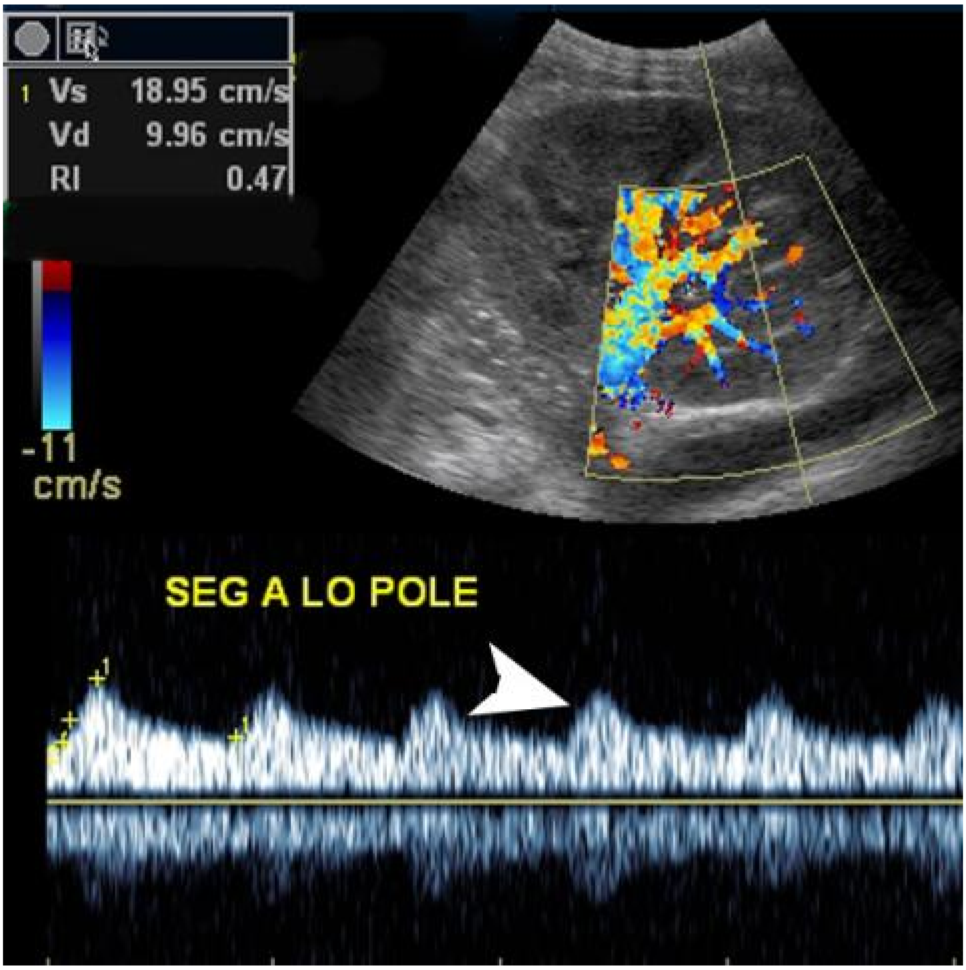

Figure 13. Renal transplant arterial stenosis. Spectral Doppler image demonstrates a delayed systolic upstroke and rounding of the systolic peak consistent with a tardus-parvus waveform (arrowhead).

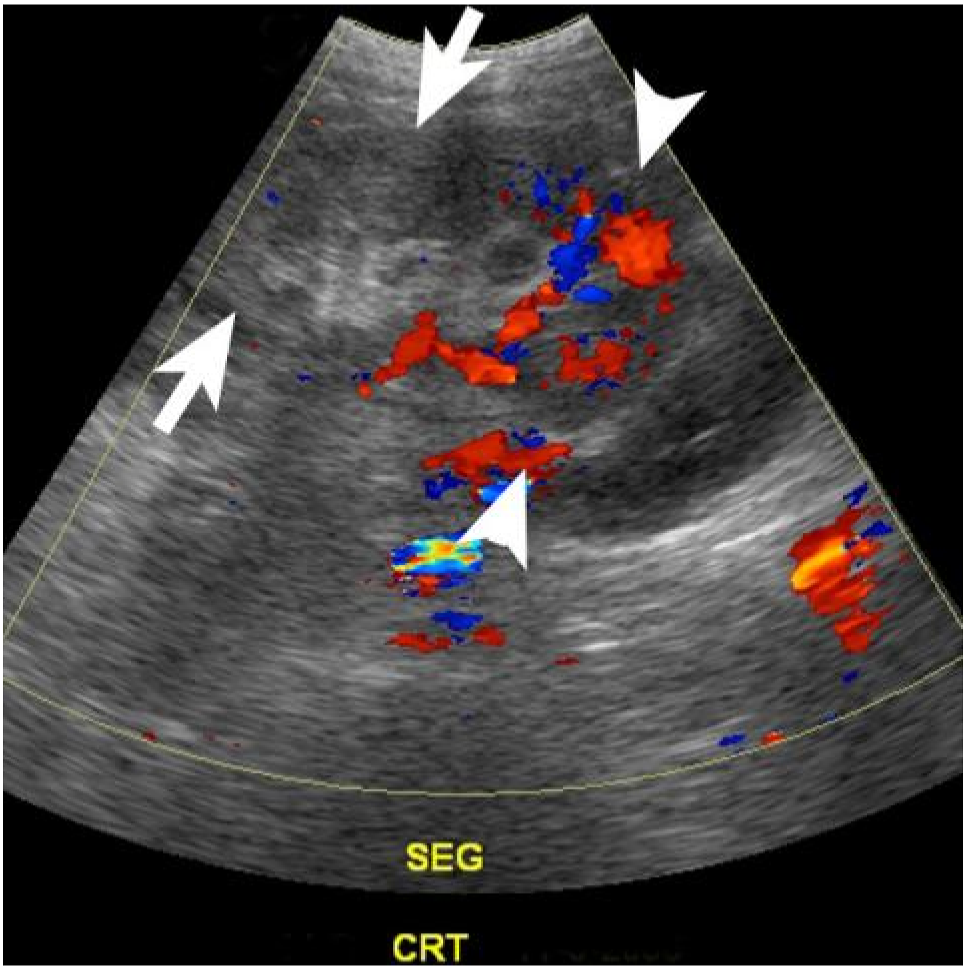

Figure 14. Segmental infarct. Color Doppler image shows normal flow (arrowheads) at the inferior third of the renal transplant but lack of flow in the mid and upper portions (arrows) due to segmental infarct.

Renal Vein

Stenosis of a transplanted renal vein is a rare complication of renal transplantation. Ultrasound findings of hemodynamically significant venous stenosis include focal narrowing with upstream luminal dilatation, focal color aliasing and focally increased velocity with 4-fold or greater gradient across the segment of suspected stenosis (Figure 15). Venous thrombosis can occur secondary to infection, severe rejection or technical problems with the anastomosis. The diagnostic ultrasound findings include absence of flow on Power, color and spectral Doppler analysis. Venous thrombosis results in a high-resistance vascular circuit and can result in subsequent reversal of diastolic flow in the arterial waveform (Figure 16); however, reversed diastolic flow is a nonspecific finding which can be seen in severe rejection, severe pyelonephritis, drug toxicity and extrinsic compression. Venous thrombosis results in renal transplant dysfunction and failure. Treatment options include anticoagulation, percutaneous mechanical thrombectomy and surgery.

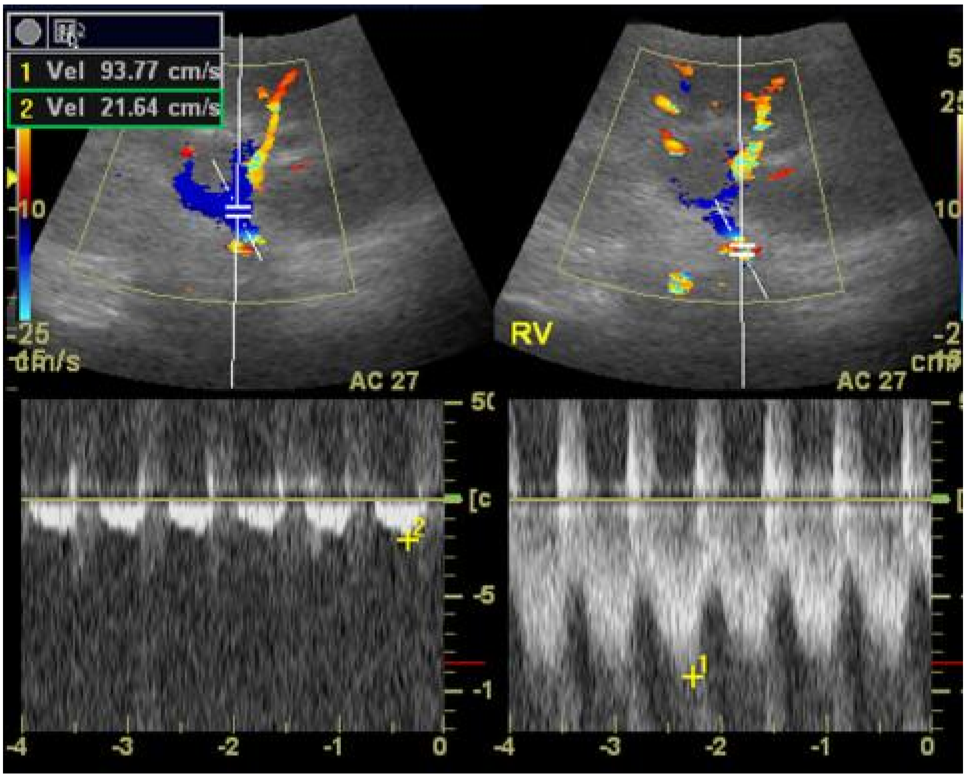

Figure 15.a Renal transplant venous stenosis. a) Spectral Doppler image demonstrates normal velocity in the renal vein at the level of the hilum. At the anastomosis, there is focal color aliasing and corresponding focally elevated velocity resulting in an approximately 4.3-fold velocity gradient.


Figure 15.b Renal transplant venous stenosis. b) Maximum intensity projection MR image shows focal stenosis at the venous anastomosis (arrow).

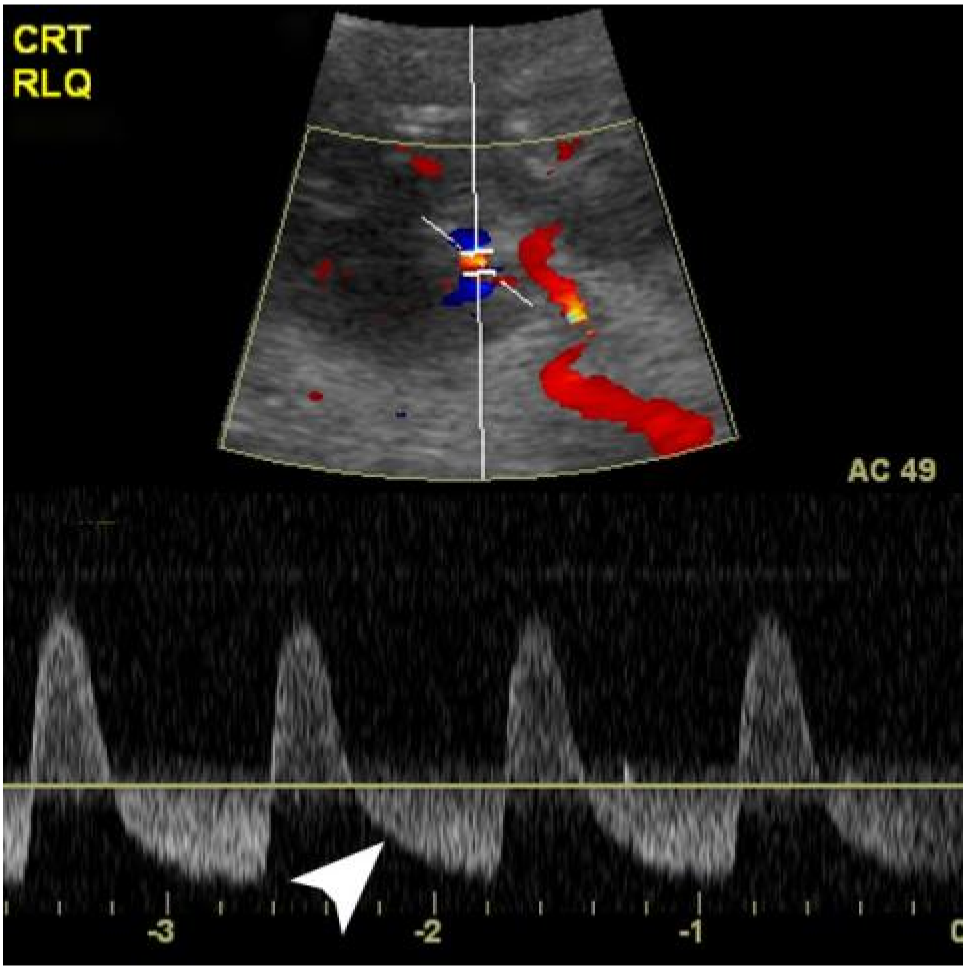

Figure 16. Renal vein thrombosis. Spectral Doppler image shows reversed diastolic flow (arrowhead) due to renal vein thrombosis

Arteriovenous Fistula, Pseudoaneurysm

The majority of arteriovenous fistulas and pseudoaneurysms are small, clinically insignificant and resolve spontaneously. Formation of arteriovenous fistulas and pseudoaneurysms is most commonly due to percutaneous biopsy of the renal transplant. At color Doppler evaluation, the tissue vibration secondary to disorganized flow between the feeding artery and draining vein of an arteriovenous fistula results in a focal flash of color within the parenchyma. During spectral Doppler analysis of the associated vessels, there is high-velocity, low resistance flow in the feeding artery (Figure 17) and turbulent, pulsatile flow in the draining vein. Pseudoaneurysms are less common but are commonly shown as a marginated anechoic, paravascular structure on gray-scale images. Application of color Doppler shows internal flow, often with a swirling, ‘yin-yang’ appearance. The spectral waveform corresponding to flow in the neck of the pseudoaneurysm shows a ‘to-and-fro’ pattern of turbulent flow. In cases of large or persistent arteriovenous fistulas or pseudoaneurysms, treatment options percutaneous embolization or possible surgery.

Figure 17.a Arteriovenous fistula. a) Gray-scale image illustrates the biopsy needle (arrowhead) within the superior pole of the transplanted kidney.

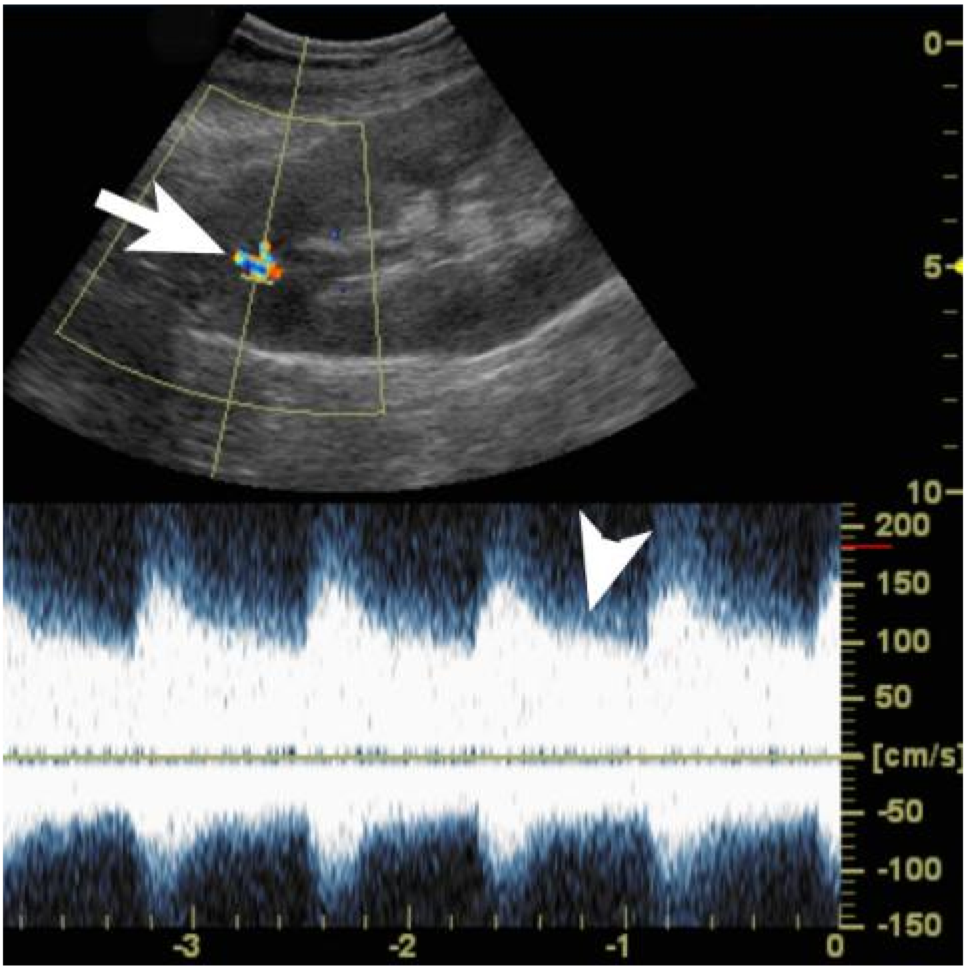

Figure 17.b Arteriovenous fistula. b) Follow-up spectral Doppler evaluation demonstrates focal color aliasing (arrow) at the superior pole biopsy site. There is a high velocity, low impedance waveform with increased diastolic flow (arrowhead) due to an arteriovenous fistula.

SUMMARY

The accessibility, portability and reproducibility of ultrasound allow it to play a critical role in the evaluation of patients with a renal transplant. The sensitivity and specificity of ultrasound are improved by optimizing the scanning parameters. Ultrasound can detect anatomic, functional and vascular complications of renal transplantation and help to direct treatment. Familiarity with scan optimization, normal renal transplant anatomy and common complications will allow rapid and accurate diagnosis.

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