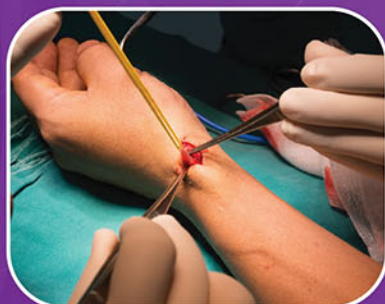


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Essentials of Interventional Nephrology



Editors
Vinant Bhargava
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Contents

SECTION 1: Introduction to Intervention Nephrology

- 1. Evolution of Interventional Nephrology in India 3**
Kasi Visweswaran R, Jishnu Mohan
- 2. Fundamental Principles of Dialysis Vascular Access 9**
Tushar J Vachharajani, Vaibhav Tiwari
- 3. Setting Up Training in Interventional Nephrology in Resource-Limited Settings 16**
Vineet Behera, Umesh B Khanna, Sandeep Mahajan

SECTION 2: Vascular Anatomy and Radiology

- 4. Vascular Anatomy for Dialysis Access 25**
Edwin Mervin Fernando, Shamnad P
- 5. Ultrasound/Doppler for Vein Mapping 32**
Nikhil Chaudhari
- 6. Renal Ultrasound 39**
Yimeng Zhang, Shalabh Srivastava, Sarah McCloskey, James Andrews
- 7. Interventional Radiology 45**
Oladunni O Akin-Akintayo, Daniel Rubin, Ram Kishore Gurajala
- 8. Preoperative Evaluation of Arteriovenous Fistula 53**
Shalini Priya, Vidhi Singla, Vinant Bhargava
- 9. Imaging for Peritoneal Dialysis Catheter Placement 58**
Anantharam Jairam, (Gp Cpt) Vijoy Kumar Jha

SECTION 3: Vascular Access Creation for Hemodialysis

- 10. Arteriovenous Fistula Creation..... 67**
 - 10.1 Surgical Arteriovenous Fistula 67**
Yogita Sharma, AK Bhalla, Ashwani Gupta, Sanjiv Jasuja
 - 10.2A Endovascular Arteriovenous Fistula: Mapping and Creation 75**
Adrian P Sequeira, Rashid Sharaf, Vinant Bhargava
 - 10.2B Endovascular Arteriovenous Fistulas: Options, Maintenance, and Salvage 83**
Sarvanan Balamuthuswamy, Vijayaprakash Sreenarasimhaiah
- 11. Arteriovenous Graft Placement 91**
Ambarish Satwik, Pranay Pawar

12. Tunneled Cuffed Catheter Insertion	96
<i>Prashant C Dheerendra, Karthikeyan Balasubramanian, Denis Dawle Tirkey</i>	
13. Vascular Access Creation for Hemodialysis by Nontunneled Catheters.....	102
<i>Shahbaj Ahmad, Smriti Sinha</i>	

SECTION 4: Postoperative Care and Follow-up of Vascular Access

14. Monitoring and Surveillance of Vascular Access	111
<i>Lalathaksha Kumbar, Manish Lalwani</i>	
15. Access Maintenance and Cannulation Techniques	117
<i>Aakash Kirit Shingada, Vivek Goel, Neil Saldanha</i>	
16. Pathophysiology of Vascular Access Dysfunction.....	122
<i>Dinesh Khullar, Lalathaksha Kumbar, Anish Kumar Gupta</i>	
17. Diagnosis of Vascular Access Dysfunction	128
<i>Bharat Sachdeva, Ruhani Sachdeva</i>	
18. Maintenance of Tunneled Cuffed Catheters	134
<i>Prashant C Dheerendra, Karthikeyan Balasubramanian, Denis Dawle Tirkey</i>	

SECTION 5: Interventional Cath Lab Techniques

19. Hardware Requirements for Cath Laboratory Interventions by Nephrologists	139
<i>J Balasubramaniam, Karthik Balasubramaniam</i>	
20. Angioplasty/Stenting	150
<i>Rajendran Vilvendan, Ayush Thomas</i>	
21. Thrombolysis Techniques.....	160
<i>Jia Shen-Goh, Rauri A Clerk, Saeed Ahmed, Shalabh Srivastava</i>	
22. Renal Artery Angioembolization.....	164
<i>Hardik B Patel, Rozil Jayesh Gandhi</i>	

SECTION 6: Vascular Access Related Complications and Management

23. Tunneled Cuffed Catheter Access Dysfunction and Salvage	171
<i>Hemant J Mehta, Wasiyeullah Z Shaikh</i>	
24. Catheter-related Infections and its Prevention	192
<i>Prem P Varma, Mehak Singla, Abhilasha Soni</i>	
25. High-flow Arteriovenous Fistula	197
<i>Sneha Anna Joy, Manish Rath</i>	
26. Stenosis or Thrombosis of Vascular Access.....	203
26.1 Central Veins	203
<i>Gireesh Reddy G, Sahil Arora, Cherin Josi C, Sumiran Mahajan, Dwarak S, Dileep Kumar P</i>	
26.2 Arteriovenous Fistula and Grafts	222
<i>Venkatesh Rajkumar S, Nikhil Sharma, Varinder Singh Bedi</i>	

27. Pseudoaneurysm and Hemorrhage	230
<i>Krishnaswamy Sampathkumar, Prabhu Kumarappan Chidambaram</i>	
28. Accessory Veins: Identification and Management	238
<i>Arushi Nautiyal, J Balasubramaniam</i>	
29. Steal Syndrome and Ischemia.....	244
<i>Vipul Prakash Sanghavi, Aadil Beigh</i>	

SECTION 7: Special Considerations in Vascular Access Procedures

30. Pediatric Vascular Access.....	255
<i>Sukanya Govindan, Srinivasavaradan Govindarajan</i>	
31. Vascular Access in Patients with Coagulopathy	259
<i>Abhijit Madhav Konnur, Sishir Dashrathmal Gang</i>	
32. Vascular Access in Patients with Complex Anatomy	268
<i>Sachin S Soni, Sanjay Srinivas, Umapati N Hegde</i>	
33. Cardiac Rhythm Devices and Vascular Access	283
<i>Valentine Lobo</i>	

SECTION 8: Nonvascular Access Interventional Procedures

34. Kidney Biopsy.....	291
<i>Vineet Behera, Tauhidul Alam Choudhury</i>	
35. Management of Complications Post-renal Biopsy	299
<i>Ajit K Yadav, Anurag Gupta, Darshan Thummar, Vineeth Kurki M</i>	
36. Renal Artery Angioplasty and Stenting	306
<i>Raghav Seth, Manish Malik, Tarun Kumar</i>	
37. Renal Denervation Techniques	314
<i>Kristin George, Ranjan Shetty</i>	

SECTION 9: Point-of-Care Ultrasound

38. Point-of-Care Ultrasound for Fluid Status Assessment	323
<i>ET Arun Thomas</i>	
39. Renal Allograft Complications and Their Management	331
<i>Vel Arvind, Karthik Balasubramaniam</i>	

SECTION 10: Future Directions and Innovations in Vascular Access

40. Artificial Intelligence for Vascular Access in Hemodialysis.....	347
<i>Priti Meena, Ashwani Gupta</i>	
41. Emerging Techniques for Vascular Access Creation, Maintenance, and Device Innovations.....	352
<i>Suresh Kumar Margassery, Vijayaprakash Sreenarasimhaiah</i>	

SECTION 11: Ethical and Legal Considerations in Intervention for Nephrologist

- 42. Patient Consent and Shared Decision-making.....383**
Manisha Sahay, AK Bhalla, Shyam B Bansal
- 43. Legal Aspects and Liability Issues in Vascular Access for Interventional Nephrologists in India392**
Narinder Pal Singh, Urmila Anandh

SECTION 12: Peritoneal Dialysis

- 44. Anatomy and Physiology of Peritoneum399**
Anirudha Datta, Pratik Das, Upal Sengupta
- 45. Preparing a Patient for Peritoneal Dialysis.....410**
Kulwant Singh, Namrata S Rao, Jitendra Kumar
- 46. Percutaneous Insertion of Peritoneal Dialysis Catheter415**
Pavitra Manu Dogra, Purva Suhas Bavikar
- 47. Surgical Techniques for Peritoneal Dialysis Catheter Insertion425**
Amrita Dua, Mrinal Pahwa
- 48. Complications Related to Peritoneal Dialysis Catheters433**
- 48.1 Non-infectious Complications.....433**
Santosh Varughese, Manish Lalwani
- 48.2 Infectious Complications442**
Rajdeb Saha, Saurabh Maruti Thanekar
- 49. Peritoneal Dialysis Catheter Insertion in Pediatric Patients453**
Sowrabha Rajanna, Kanav Anand, Rekulapally Praneetha

Index 461

Yimeng Zhang, Shalabh Srivastava, Sarah McCloskey, James Andrews

■ INTRODUCTION

Ultrasonography is an expanding field with increasing clinical practice globally. It does not use any ionizing radiation and is noninvasive, therefore it is a safe modality to evaluate the kidneys and urinary tract. Point-of-care ultrasound allows nephrologists to evaluate patients at the bedside, forming an extension of physical examination. This allows for real-time examination for a wide range of indications including abdominal or flank pain, renal dysfunction, detection and follow-up of masses in the urinary tract, renal stones as well as other pathologies described in this chapter.

■ EQUIPMENT

A low-frequency 3–6 MHz curvilinear transducer.

■ PREPARATION FOR KIDNEY ULTRASOUND SCANNING

- Kidney ultrasound is typically performed with the patient in the lateral decubitus position. In emergency settings, the supine position is often preferred. For those undergoing ultrasound as part of a native renal biopsy, the prone position is commonly used.
- Enhancing the visibility of the kidneys can often be achieved by having the patient raise their arms above their head and take a deep breath in.
- To obtain optimal views of the collecting system and bladder, it is recommended that the patient consumes approximately 500 mL of fluid 1 hour before the scan, ensuring that they avoid micturition. If a urinary catheter is present, it should be clamped for 1–2 hours prior to scanning.

■ LOCATING THE KIDNEYS

The kidneys are located deep to the posterolateral lower rib cage within the paravertebral gutters. They sit between

the levels of T12 and L4 vertebrae. The superior poles of the kidneys are tilted slightly posterior and medial with respect to the inferior poles.

The right kidney lies inferior and posterior to the right lobe of the liver. It is covered anteriorly by the liver and inferiorly by the right colic flexure and duodenum. The most effective approach for scanning the right kidney is through the intercostal spaces from the posterolateral side or mid-axillary line, utilizing the liver as an acoustic window.

The left kidney lies posterior and inferior to the spleen, with the stomach overlapping the front of the upper pole. Its lower half is covered by the descending colon and left colonic flexure, which passes around its anterior surface. Like the right, the left kidney is best scanned through a posterolateral approach using the intercostal spaces and spleen as an acoustic window. The left kidney is generally located higher and posterior compared to the right, making it more challenging to scan due to the intervening gas.

Start scanning both kidneys in longitudinal views. Once a clear image is acquired, fan the probe to cover the entire organ. Rotate the probe 90° to examine the kidney in the transverse plane, scanning from pole to pole. Both kidneys should be scanned routinely for comparison and to identify any anatomical variations.

Abnormalities in Kidney Location

- *Renal agenesis*: One kidney is absent, while the contralateral kidney may be enlarged.
- *Ectopic kidneys*: One or both kidneys may be located outside the normal renal fossa, often in the pelvis, but they may be obscured by bowel gas.

Renal Size

Kidneys can be measured in three dimensions: Length, width, and thickness (**Fig. 1**). The longitudinal scan is

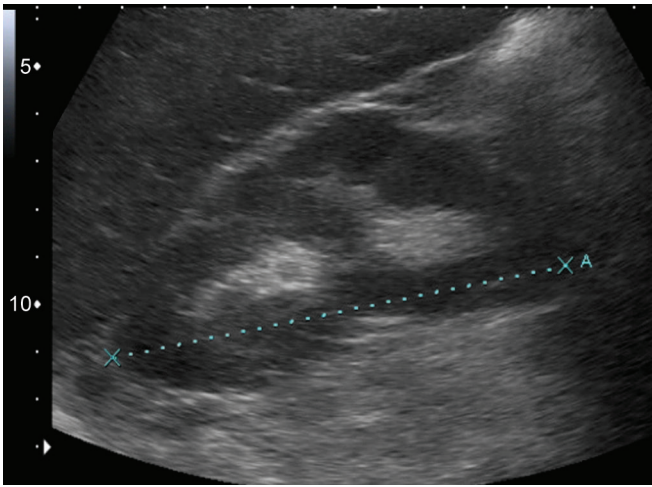


Fig. 1: Normal right kidney measuring 10.7 cm.

ideal for measuring renal length. Freeze the image and measure the maximum length from pole to pole. For width and thickness, the transverse view is most effective.¹

Normal renal dimensions:

- **Length:** 9–12 cm
- **Width:** 4–7 cm
- **Thickness:** 3–5 cm

Small Kidneys

Causes of bilateral small kidneys include:

- Chronic renal diseases such as glomerulonephritis, renal artery stenosis, reflux nephropathy, and chronic pyelonephritis
- Aging
- Low body weight or height

Enlarged Kidneys

Renal enlargement can be seen in conditions like acute glomerulonephritis, hydronephrosis, and amyloidosis. Renal masses or cysts, such as in polycystic kidney disease,² can also cause the kidneys to appear enlarged (**Fig. 2**).

APPEARANCE OF THE KIDNEYS ON ULTRASOUND

The kidneys are bean-shaped with a smooth surface. It is not uncommon for older patients to exhibit surface indentations. Pyelonephritis can also cause such indentations. The parenchyma of the left kidney often forms a bulge beneath the spleen's border, creating a “dromedary hump”.

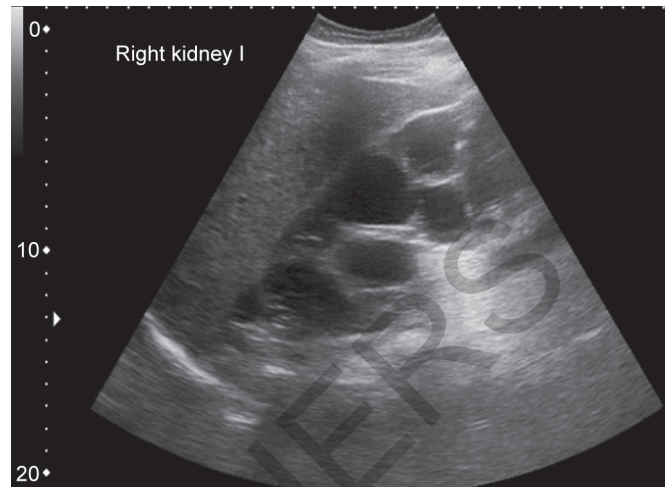


Fig. 2: Polycystic kidneys containing multiple hypoechoic cysts with no internal shadows.

Anatomical variants:

- **Horseshoe kidney:** The two kidneys are connected at their lower poles by a parenchymal isthmus, forming a U-shape.
- **Duplication of the collecting system:** This developmental abnormality results in two ureters.
- **Extrarenal pelvis:** In about 10% of individuals, the renal pelvis lies outside the renal hilum. The renal pelvis is formed by the major calyces and the extrarenal pelvis can appear dilated, leading to a false impression of urinary obstruction.

Renal Parenchyma and Sinus

The kidneys consist of three main layers: The cortex, the medulla (collectively referred to as the renal parenchyma), and the renal sinus. The kidneys and adrenal glands are encased in a dense fibrous capsule called Gerota's fascia. Just beneath this capsule is the cortex, which typically measures 5–7 mm in thickness and decreases with age. The columns of Bertini are projections of cortical tissue that extend into the medulla. These columns separate the 8–10 renal pyramids, which have a characteristic hypoechoic appearance on ultrasound. This is especially prominent in younger patients and can be mistaken for renal cysts.³

The apex of each renal pyramid forms a papilla, which excretes urine into a corresponding minor calyx. Several minor calyces converge to form the major calyces, which then merge to form the renal pelvis. The latter tapers through the renal hilum into the proximal ureter. The transition between the renal pelvis and ureter is the

ureteropelvic junction (UPJ), which is a common site of obstruction from ureterolithiasis. This is typically at the level of the hilum, where blood vessels, lymphatics, and ureters pass through. Collectively, the minor and major calyces, intrarenal blood vessels, and surrounding fat tissue constitute the renal sinus, which is the hyperechoic central region of the kidney.

The collecting system and ureters are usually not visible on ultrasound unless hydronephrosis is present. The ureters descend across the psoas muscle, crossing the common iliac vessels at the pelvis brim and then anteriorly and medially to empty into the bladder via the ureterovesical junctions (UVJs) at the two superior corners of the trigone. In severe urinary retention, the distended bladder can extend to the level of the umbilicus.

Circumscribed Lesions

- **Hyperechoic:**
 - **Angiomyolipomas:** These are benign tumors, round, homogeneous, well-circumscribed masses. They are typically within the renal parenchyma containing blood vessels, muscle tissue, and fat. They are usually solitary and asymptomatic, if multiple and bilateral can be associated with tuberous sclerosis.
 - Renal scars
 - Calcifications (**Fig. 3**)
- **Isoechoic:** Renal cell carcinoma (RCC)
- **Hypoechoic:**
 - Intracystic hemorrhage
 - Abscess: Appears with irregular margins and possible bright internal echoes

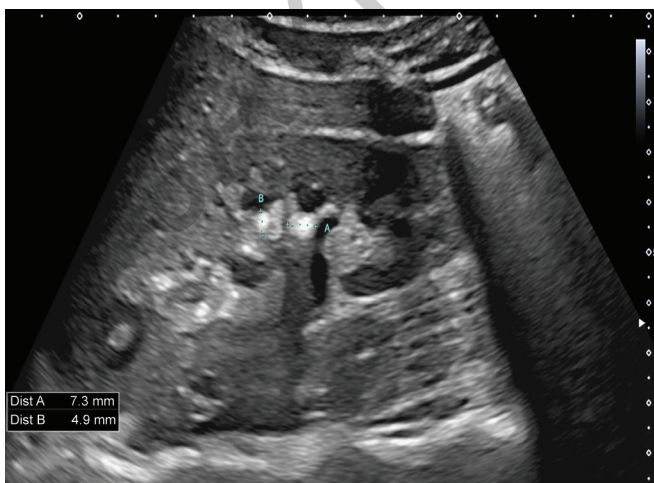


Fig. 3: Renal calcification/urolithiasis.

- **Echo-free: Simple cysts (Fig. 4):** Smooth, thin-walled, round or oval-shaped cysts with posterior acoustic enhancement. These may be solitary or multiple. Cysts are classified by their location: Pararenal, cortical, or parapelvic. Cysts that have irregular borders, septations, calcifications, or heterogenous echo density should be referred for further evaluation.

Polycystic Kidney Disease

Polycystic kidney disease is a hereditary condition with multiple cysts of various sizes, with compression and thinning of the renal parenchyma, leading to the eventual replacement of renal parenchyma by cysts.

Renal Cancer

Renal cancer has a varied appearance on ultrasound. Any unexplained mass or disruption of the renal architecture should be considered for referral for further imaging. Smaller RCCs can be hyperechoic and may be mistaken with angiomyolipomas; however, they tend to be less well defined. Larger RCCs may show cystic degeneration, calcification, and disorganized blood flow on color Doppler.

Intrarenal Hematomas

Intrarenal hematomas can appear as hyperechoic, isoechoic, or hypoechoic, depending on their stage. Acute hematomas may appear heterogenous and hyperechoic, becoming more hypoechoic or cystic over time. Subcapsular hematoma appears as a crescent-shaped fluid collection between the renal parenchyma and capsule.

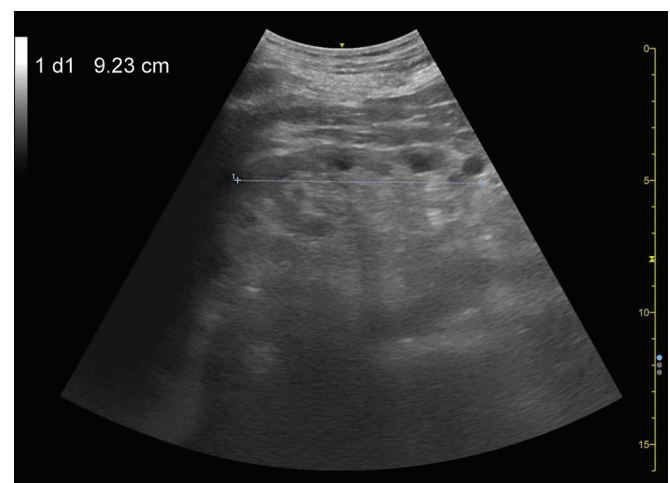


Fig. 4: Simple cyst at the lower pole in an atrophic kidney.

Diffuse Changes

In health, the renal parenchyma is relatively hypoechoic and appears less echogenic than the adjacent liver or spleen.⁴

- **Cortical atrophy (Fig. 5):**
 - Length usually <9 cm depending on body size
 - Length and echogenicity can be normal
 - Cortical thinning with accentuation of lobulation
 - Sign of chronic kidney disease due to the loss of functional tissue
- **Medullary disease:** Increased echogenicity leading to greater corticomedullary differentiation, which may suggest sloughing of the papillae (**Fig. 6**)

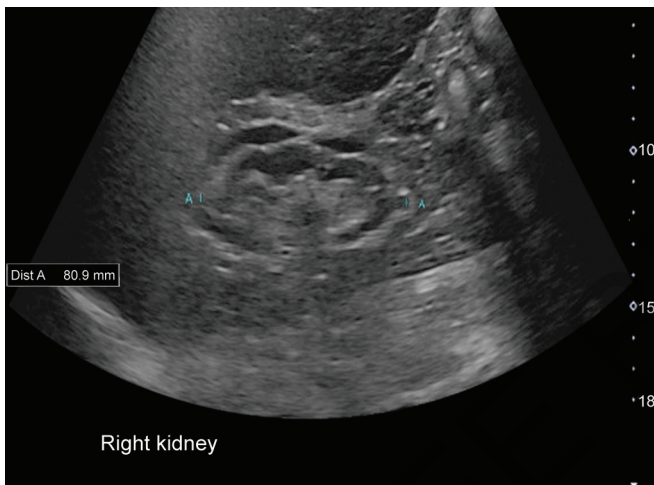


Fig. 5: Reduced corticomedullary differentiation demonstrating cortical atrophy in a small kidney.

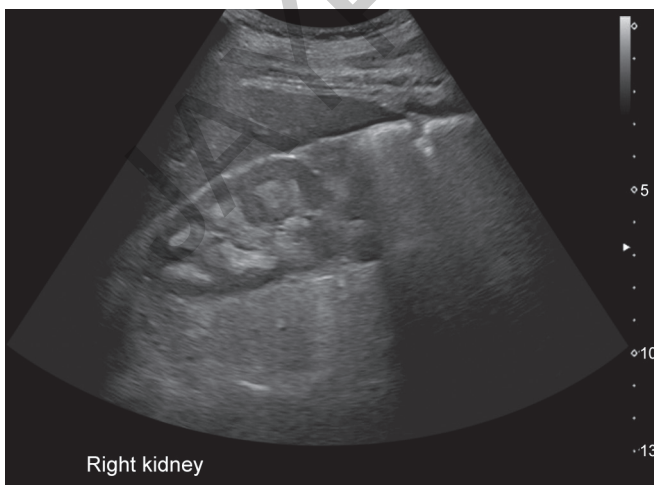


Fig. 6: Medullary nephrocalcinosis.

- **Diffusely increased cortical echogenicity:**
 - Increased renal echogenicity is a nonspecific finding but can represent several underlying conditions.
 - Causes include various renal conditions associated with inflammation or swelling of the renal cortex or chronic kidney disease such as:
 - ♦ Acute glomerulonephritis
 - ♦ Diabetic nephropathy
 - ♦ HIV nephropathy
 - ♦ Renal amyloidosis
 - ♦ Sickle cell disease
 - Chronic glomerulonephritis leads to a decrease in renal size. The echogenicity of the parenchyma is uniformly increased. There may be loss of definition of the medullary pyramids with an indistinct corticomedullary junction.

Hydronephrosis (Figs. 7 and 8)

Ultrasound imaging of hydronephrosis will demonstrate a dilated pelvicalyceal system. The severity can be classified into mild, moderate, or severe or graded from 1 to 4 based on sonographic criteria:

- **Grade 1:** Dilated renal pelvis with no calyceal dilatation with thinning of the parenchyma
- **Grade 2:** Dilatation of the renal pelvis and calyces with thinning of the parenchyma
- **Grade 3:** Cystic dilatation of the renal pelvis with a thin rim of parenchyma
- **Grade 4:** Parenchyma no longer demonstrated

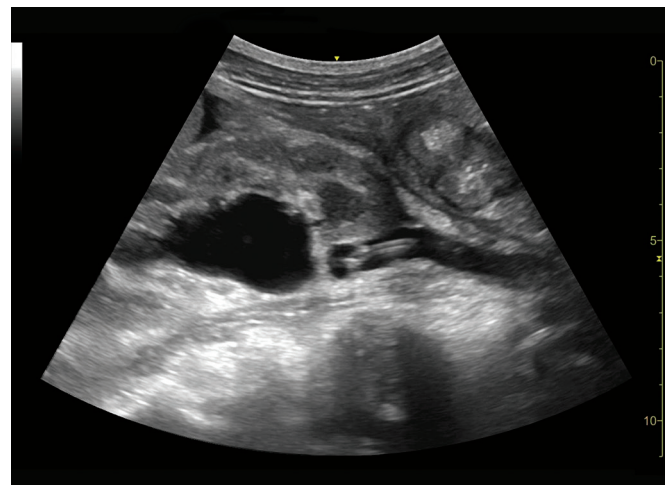


Fig. 7: Native left proximal ureter around blocked urinary stent and hydronephrotic kidney.

Thinning of the renal cortex in the context of hydronephrosis usually implies chronicity.

Once hydronephrosis is identified, further scanning or imaging is often required to further assess to determine the underlying cause. Always scan the lower urinary system. Dilation of the renal pelvis does not always indicate obstruction. A dilated renal pelvis can be a normal variant in some people; other causes include pregnancy, large diuresis, reflux disease, and papillary necrosis. A very full bladder may result in a bilaterally prominent pelvicalyceal system; this should be reassessed post-void for change in the degree of pelvicalyceal dilatation. Conversely, dehydration may prevent the development of hydronephrosis. Scanning may be repeated after hydration.

Ureterolithiasis

The cause of nephrosis, including ureterolithiasis, may not always be identifiable on ultrasound, with CT imaging of the abdomen and pelvis being the gold standard for stone evaluation. Small stones can often be undetectable on ultrasound, and ureteral stones are generally difficult to visualize.

On ultrasound, calculi typically appear as bright, echogenic foci accompanied by posterior shadowing. In the renal sinus, the echo may be indistinguishable from the surrounding fat, and stones can sometimes be identified purely by the shadow. Ureteral stones are most commonly located at the UVJ. To visualize this area effectively, the ultrasound gain settings should be adjusted to make the bladder appear entirely black, while the structures behind the bladder should display varying shades of

gray. Additionally, color Doppler can reveal a “twinkling artifact”, characterized by alternating colors behind the stone, simulating turbulent blood flow.

Ureteric jets, which represent the normal periodic reflux of urine into the bladder, are commonly observed in well-hydrated individuals. These jets appear as brief bursts of low-level echoes from the vesicoureteral junction (VUJ) and can be seen on color Doppler as a sudden burst of color within the bladder lasting a few seconds. In cases of obstruction, no jet will be detected. With partial obstruction, the jet may show a variety of patterns, including increased or decreased flow, or even a continuous, dribbling jet.

■ ULTRASONOGRAPHY OF THE BLADDER

To begin the scan, position the probe transversely above the symphysis pubis and angle it caudally. Rotate the transducer 90° to examine the bladder longitudinally along the midline, just above the symphysis pubis. Tilt the probe to visualize the entire bladder (**Figs. 9 and 10**).

Normal Anatomy

The bladder appears as an echogenic cavity within the pelvis. Under normal conditions, the bladder empties completely during voiding. However, in older individuals with detrusor dysfunction, there may be a residual volume ranging from 5 to 100 mL. Bladder volume can be estimated using the following formula, which includes a correction factor for the bladder's ellipsoid shape:

$$\text{Bladder volume} = 0.75 \times \text{width} \times \text{length} \times \text{height} \\ (\text{all in millimeters})$$



Fig. 8: Hydroureteronephrosis without stent.

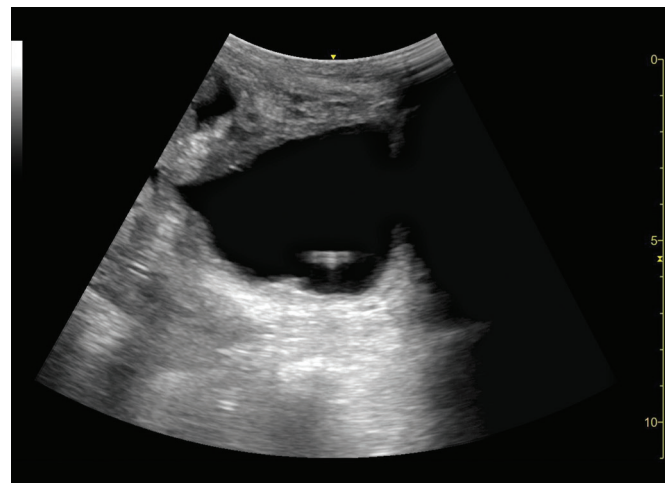


Fig. 9: Urinary bladder with a stent in situ.

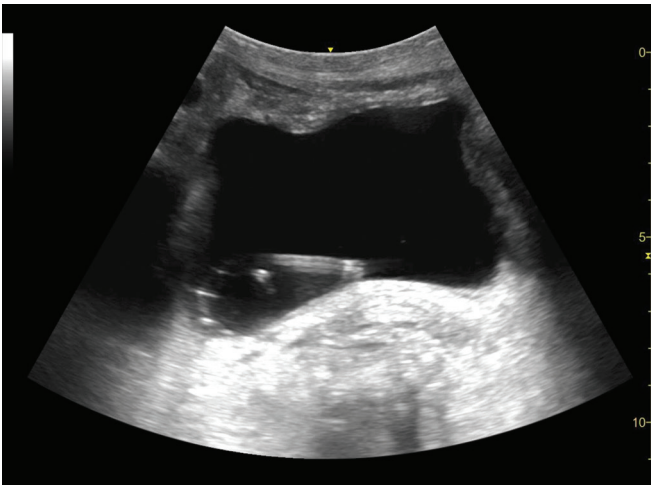


Fig. 10: Transverse bladder with a urinary stent.

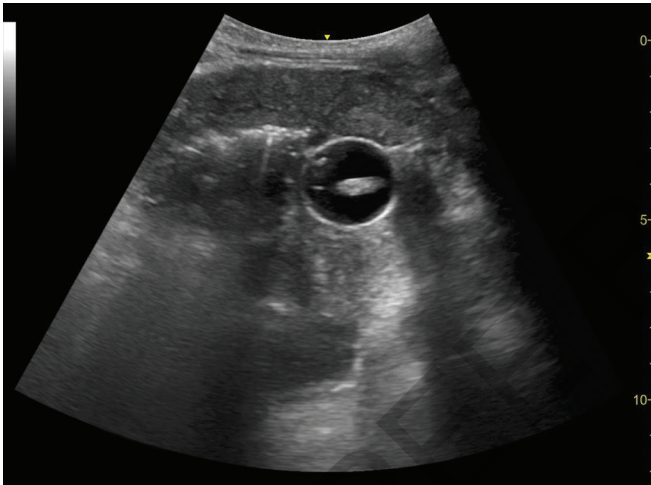


Fig. 11: Longitudinal bladder post-catheter insertion for macroscopic hematuria. Grossly thickened bladder wall superiorly, inflated bladder catheter balloon next to air within the remainder of bladder. Transitional cell carcinoma (TCC) confirmed on cystoscopy.

Pathology

Bladder outlet obstruction is characterized by a bladder containing more than 100–150 mL of urine after an attempt to void. In addition to volume measurement, ultrasound can often identify conditions such as prostatic hypertrophy or neoplasm, diffuse thickening of the bladder wall from detrusor hypertrophy, and/or the presence of bladder diverticula. Additionally, bladder stones and neoplasms can be detected during the scan (**Fig. 11**).

CONCLUSION

The increased accessibility and widespread use of portable ultrasound has allowed it to be successfully used as an adjunct in clinical decision making. An appreciation of normal renal anatomy and ultrasound appearance is crucial in detection of variants and pathological features. There remains a significant intra and interoperator variability with subjective interpretations of imaging, highlighting the importance of formal education and additional training. Cross-sectional imaging such as CT or MRI scans may be required to assist in obtaining a definitive diagnosis.

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