

# Role of Point-of-Care Ultrasonography in the Evaluation and Management of Kidney Disease

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Imaging at the nephrology point of care provides an important and continuously expanding tool to improve diagnostic accuracy in concert with history and physical examination.

**T**he evaluation of acute kidney injury (AKI) often starts with the classic prerenal, renal, and postrenal causalities, delineating a practical workable approach in its differential diagnosis. Accordingly, the history, physical examination, urinalysis, and kidney-bladder sonography are standard resources in the initial approach to renal disease assessment. Ultrasonography has a well-established role as an important adjuvant for postrenal diagnosis of renal failure. Nevertheless, most of the causes of AKI are prerenal and renal.

Some etiologies of kidney injury are sequelae of systemic diseases in which sonography can be diagnostically analogous to the history and physical examination. Furthermore, ultrasonography may be informative in various clinical scenarios, for example, patients with chronic kidney disease (CKD) and end-stage renal disease (ESRD). In this narrative review, the contribution of point-of-care (POC) sonography to the evaluation and management of AKI, CKD, and associated diseases are explored beyond the traditional sonogram uses for kidney biopsy, central catheter placement, and/or screening of hydronephrosis.

Two important elements made possible the incorporation of POC sonography into nephrology practice.<sup>1,2</sup> First, the development of handheld reliable and portable ultrasound devices and, second, the derived capacity of POC sonography to obtain objective signs of physiologic and/or pathophysiologic phenomena. The latter clinical application is realized through the incorporation of POC

protocols into the modified focused assessment with sonography for trauma (FAST) examination in conjunction with limited echocardiography and lung sonography (Figure 1). The original FAST protocol was developed by the American Institute of Ultrasound in Medicine and the American College of Emergency Physicians.<sup>3</sup>

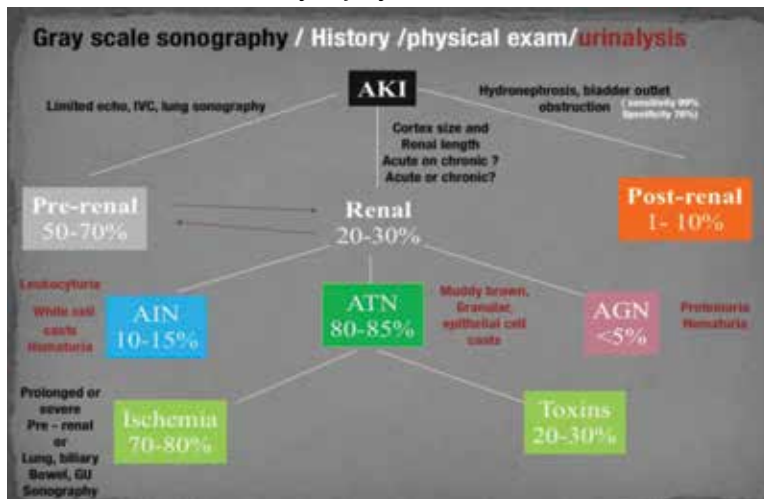
These protocols have allowed the evaluation of extracellular volume, which is important to measure for the diagnosis and management of renal diseases. For example, the evaluation of lung water by POC ultrasonography for patients with ESRD is emerging as a promising tool. In a study of patients with ESRD undergoing hemodialysis, POC ultrasonography detected moderate-to-severe lung congestion in 45% of patients, most of whom (71%) were asymptomatic. Two years of follow-up of patients was associated with 3 to 4 times greater risk of heart attack and death, respectively, compared with individuals without congestion on sonography.<sup>4-6</sup> Thus, ultrasound assessment of lung water in patients with ESRD may prove to be an essential tool to assure an adequate ultrafiltration and improve patient outcomes.

## ACUTE KIDNEY INJURY

### Prerenal

The physical examination provides evaluation of effective arterial circulatory flow (EACF) and is clinically useful in the evaluation of prerenal azotemia. The utility is more obvious in the extremes of EACF. However, in the case of blood volume losses of > 10% or the physiologic equivalent, heart rate, blood pressure,

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**FIGURE 1** Acute Kidney Injury Assessment

Abbreviations: AGN, acute glomerulonephritis; AIN, acute interstitial nephritis; AKI, acute kidney injury; ATN, acute tubular necrosis; GU, genitourinary; IVC, inferior vena cava.

skin turgor, urinary output, and capillary refill may be within normal limits. Obvious changes in these parameters during the physical examination are considered relatively late manifestations.<sup>7-10</sup> Therefore, prerenal failure is frequently diagnosed retrospectively after correction of the EACF through use of crystalloids, blood products, vasopressors, inotropic agents, discontinuation of antihypertensive agents, or treatment of its prerenal causes. Certain sonographic maneuvers, performed at the bedside during acute renal injury, may be useful in many patients to evaluate a multitude of prerenal causes of AKI.

Sonographic inferior vena cava (IVC) luminal diameter and inspiratory collapsibility together serve as a surrogate marker of preload venous return and right side heart function. Such imaging results have been shown to be more accurate than jugular venous distension on physical examination but only modestly helpful as a surrogate for central venous pressure (CVP), with more accuracy in the lower values of the CVP.<sup>11</sup> However, this procedure can be repeated often after volume resuscitation to achieve a 1.5- to 2.5-cm diameter dimension of the IVC and < 25% inspiratory collapsibility as a goal.

An IVC with a diameter > 2.5 cm in the context of a suspected prerenal AKI is more likely the consequence of heart failure (HF) rather than hypovolemia. The caveat to this

finding is that pulmonary hypertension may induce false-positive results.<sup>12,13</sup> Hepatic vein dilation is another sign of HF and/or pulmonary hypertension. Furthermore, sonographic images of the left ventricle either from the parasternal long axis or subxiphoid approach can identify supranormal left ventricular ejection fraction (LVEF) or hyperdynamic heart as an important clue of the absolute or relative decrease of EACF.<sup>14</sup> Conversely, a decrease in EACF in patients with low LVEF can be assessed qualitatively at the bedside in patients with systolic HF. Supporting evidence of prerenal azotemia as the result of HF can be suggested by the presence of pleural effusions and bilateral comet/rockets tails or B lines in lung sonography.<sup>15</sup>

The easily recognizable hypoechoic ascitic fluid in the presence of small, hyperechoic gross changes in the echocardiographic texture of liver may indicate a hepatorenal component as the cause of prerenal failure. A small increase of > 20% in the diameter of the portal vein with deep inspiration indicates portal hypertension, with a sensitivity of 80% and a specificity of 100%.<sup>15,16</sup> Other clinical scenarios leading to AKI in association with systemic hypotension may be identified quickly with the aid of POC sonography. These scenarios include cardiac tamponade, tension pneumothorax, right ventricular dysfunction (as a surrogate of pulmonary embolism), or an acute coronary event.<sup>16,17</sup> Alternatively, identifying the presence of severe left ventricular hypertrophy through POC ultrasonography in a patient with AKI and normal or low normal blood pressures may alert clinicians to the diagnosis of normotensive renal failure in individuals with previously unrecognized severe hypertension. In this clinical context, keeping mean arterial pressures higher than usual with vasopressors may improve renal function while decreasing dialysis utilization.<sup>18-21</sup>

Likewise, in clinical scenarios of shock with AKI, POC ultrasonography has proven to be an indispensable tool. For example, rapid exploration of the biliary tree demonstrating anterior gallbladder wall thickening, a stone or sludge, common bile duct dilation, or perigallbladder inflammation suggests acute cholecystitis and/or cholangitis as the cause. The presence of dyspnea

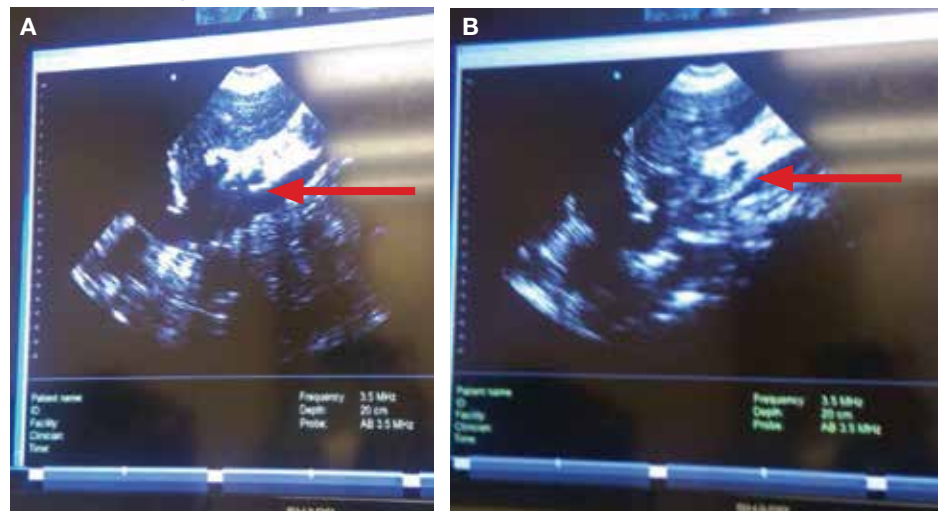
in association with hypotension and unilateral signs of a higher proportion of comet tails and/or a lung consolidation suggests pneumonia. Rapid differentiation between acute respiratory distress syndrome (ARDS) and pulmonary edema from HF is possible with ultrasonography. When pleural line abnormalities are seen, ARDS is a common cause.

POC ultrasonography will be key in management of ARDS, as ultrasound results will help avoid the use of excessive diuretics, which can result in renal hypoperfusion and AKI.<sup>22</sup> In trauma patients, the ultrasound examination will identify free fluid (bleeding) as the source of the prerenal failure, along with its cause (aortic dissection, hepatic hemorrhage, splenic hemorrhage, ectopic pregnancy, etc).<sup>23</sup> Sonographic free air observed in the abdomen can provide the clue of a perforated viscus.<sup>24</sup> The sonographic image of an inflamed pancreas can suggest pancreatitis as the cause of the systemic hypotension. Ultimately, intravascular losses in the hypoechoic edematous bowel wall in obstruction, ileus, pseudomembranous, or infectious or autoimmune enterocolitis can lead to significant decreases in the EACF and cause prerenal injury.

### Intrinsic Renal Disease

In intrinsic AKI, acute tubular necrosis (ATN), glomerulonephritis, and interstitial nephritis are the typical causes. Although no signs are specific to each of the potential causes, a poor corticomedullary differentiation, kidney size < 9 cm, and cortex size < 1 cm help to distinguish CKD from AKI, especially if no previous serum creatinine values are available. The early diagnosis of ATN continues to be clinically relevant in the management of acute renal failure. Despite not being a practical tool for POC sonography currently, the use of bedside Doppler repetitive renal vasculature measures of resistive index predict occurrence and severity of ATN in the critical care set-

**FIGURE 2** Sonograms of the Inferior Vena Cava Entering the Right Atrium During (A) Inspiration and (B) Expiration (arrows)



ting and are an independent risk factor for poor survival in arterial hypertension and HF.<sup>25-30</sup>

Other POC sonographic evaluations of intrinsic AKI have been helpful in the following clinical scenarios. The presence of an ultrasonographic sign of sinusitis in the context of nephritic sediment and a rapid decline of renal function suggest antineutrophil cytoplasmic antibody (ANCA)-related vasculitis. Likewise, in younger adults, nephritic sediment and bilateral sonographic lung interstitial fluid in the absence of infection and a normal POC echocardiogram without significant edema elsewhere suggest glomerulonephritis in the category of pulmonary lung syndrome caused by antiglomerular basement membrane antibodies.

In the elderly, a similar systemic presentation suggests an ANCA vasculitis. Pleural effusion, synovitis, proteinuria, and/or hematuria will suggest lupus nephritis. Another important cause of acute renal failure in the critical care setting is intra-abdominal compartment syndrome. Here, bladder pressure measurement protocols are the standard of care. A human model evaluated the predictive value of intra-abdominal compartment syndrome pressures using the IVC square surface. In this study, a normal surface area of the IVC of > 1 cm<sup>2</sup>/m<sup>2</sup> excluded the presence of intra-abdominal hypertension 87.5% of the time. However, the sensitivity of

**FIGURE 3** Sonogram of a Renal Cyst (arrow)



detection of the intra-abdominal hypertension was only 67.5% when the surface area of the IVC was  $< 1 \text{ cm}^2/\text{m}^2$ .<sup>31</sup>

#### CKD AND ASSOCIATED DISEASES

The diagnostic validity of ultrasonography is well established in adult-onset polycystic kidney disease. Bedside visualization of a parathyroid adenoma may be an important clue for a patient with CKD, echogenic kidneys, or nephrolithiasis with or without hypercalcemia to diagnose primary hyperparathyroidism. The sonographic diagnosis of abnormal parathyroid gland compared with parathyroid surgical exploration had a sensitivity, specificity, and positive predictive value of 74%, 96%, and 90%, respectively.<sup>32</sup> In the clinical presentation of severe hypertension with headaches, ultrasonography at bedside can provide valuable diagnostic and risk assessment information of endocranial hypertension from measuring the optic nerve sheath. Sensitivity and specificity of papilledema was 90% and 79%, respectively, when 3.3 mm was the cutoff of the nerve sheath with a 30-degree sign.<sup>33</sup> The carotid artery intima media thickness measured on sonography correlates with the future development of atherogenesis, left ventricular hypertrophy, cognition deficits, CKD, and cardiovascular disease in asymptomatic patients. An intima media thickness of  $> 1.1 \text{ mm}$  has been associated with a higher cardiovascular mortality.

**FIGURE 4** Sonogram of the Lung Demonstrating Absence of Fluid



B lines (also known as comet or rocket tails) were absent in all lung fields imaged.

Early initiation of antihypertensive medications and/or statins has been suggested to lower risk in these asymptomatic patients.<sup>34</sup> The size and contour (smooth or irregular) of kidneys may provide clues to reflux nephropathy, dysplastic kidneys, radiation nephritis, or chronic pyelonephritis. The presence of nephrotic syndrome and abnormal free light chains ratio with a bedside echocardiogram showing the typical refractile myocardial walls with a peculiar speckled pattern is strongly suggestive of amyloidosis.<sup>35</sup> Conditions associated with chronic hypercalcemia, medullary sponge kidney, milk alkali syndrome, sarcoidosis, and distal renal tubular acidosis are causes of nephrocalcinosis. Some degree of CKD is a constant feature in nephrocalcinosis. The initial imaging of choice in nephrocalcinosis and specially the medullary type is ultrasonography preferable to X-ray and perhaps to computed tomography.<sup>36</sup>

#### End-Stage Renal Disease

In a patient undergoing peritoneal dialysis with exit-site infection, the presence of  $> 1 \text{ mm}$  radiolucent rim around the subcutaneous catheter after antibiotics has a bad prognosis and prompts catheter removal. This sonographic sign has a positive and negative predictive value for a tunneled infection of 84.6% and 94.1%, respectively.<sup>37,38</sup> A risk factor for peritonitis in peritoneal dialysis is

air in the peritoneum, which can be seen in one-third of patients. These individuals have 2.4 times more risk of peritonitis compared with patients without pneumoperitoneum. The sensitivity and specificity of sonographic detection of pneumoperitoneum is 94% and 100%, respectively, using the scissor technique.<sup>39</sup> Proper training in performing home peritoneal dialysis decreases the incidence of pneumoperitoneum. Although not formally assessed, patient education and change in procedure techniques may decrease the incidence of pneumoperitoneum and peritonitis. The use of prelaparoscopic ultrasonography before insertion of the peritoneal dialysis catheter has detected intra-abdominal adhesions (visceral slide sign) with a sensitivity of 90% to 92%.<sup>40</sup>

History and physical examination are frequently helpful in the diagnosis of malfunctioning arteriovenous fistulas (AVF) for inflow or outflow disturbances, with sensitivity ranging from 70% to 100% and specificity ranging from 71% to 93% compared with angiography. Frequently, POC limited ultrasound can be helpful for a problematic AVF, either for cannulation or diagnosis. The congruence of duplex sonography with arteriogram is 85% to 96%. Various etiologies of a dysfunctional AVF (pseudo- or true aneurysm, poor development, stenosis, thrombi, or accessory veins) can be observed in the dialysis unit through limited sonography.<sup>41-44</sup>

After placement of a hemodialysis catheter using real-time ultrasonography, pneumothorax can be diagnosed reliably and rapidly. Catheter misplacement outside of the right atrium was detected by thoracic echocardiogram with a sensitivity of 96%, a specificity of 83%, and a positive predictive value of 98%.<sup>45,46</sup> Ultimately, ultrasonography may replace chest X-ray in most cases after central vein dialysis catheter placement in the acute care setting.

### Postrenal Failure

The sensitivity of ultrasonography to detect dilation to hydronephrosis of the pelvicalyceal system is well established. Sonography is the diagnostic examination of choice in pregnancy and the initial screening test for the non-pregnant patient. Computed tomography is the preferred imaging study in nephrouretero-

lithiasis; however, due to ionizing radiation and cost, ultrasonography is gaining popularity for initial and/or follow-up evaluations. The ureteral jet is a relatively unexplored color and Doppler sonographic methodology that can provide insight into pelvicalyceal peristalsis, potentially yielding evidence of functional obstruction.<sup>47-51</sup> Postvoid bladder residual volumes and bladder wall hypertrophy may provide important clues as to the cause(s) of the obstructive uropathy.

### Telenephrology

In our institution, sonography is used in the evaluation of IVC, lungs, and kidneys via telemedicine. The probe is handled by trained nurses at the distant site. The nurses perform and obtain sonographic images under direct supervision provided by a trained attending physician via real-time transmission of the tele-encounter. Figures 2 to 4 are real-time photos taken to evaluate the IVC (Figure 2), the kidneys (Figure 3), and lungs (Figure 4), respectively, during a clinic video teleconference. The use of “tele-POC sonography” may eliminate unnecessary traveling by patients and lower health care utilization costs while providing real-time assessment of a multitude of clinical issues.

### Cardiac Arrest in ESRD

Patients with ESRD may have sudden cardiac arrest as a result of several etiologies. During the advance cardiac life support algorithm, there is a brief period of evaluation of the electrical rhythm in which echocardiography can be helpful with the diagnosis immediately after the 2 initial minutes of cardiopulmonary resuscitation. An enlarged right ventricular cavity (> 2/3 of the left ventricle) is a sonographic sign of a pulmonary embolism.

Bedside sonography has the potential to alter the current guidelines of advance cardiac life support management. For example, if the

**FIGURE 5** Echocardiogram of the Right and Left Ventricles



This image was taken from the apical cardiac position during cardiac arrest in a patient with end-stage renal disease; the enlarged right ventricle (thin arrow)—similar in size to the left ventricle—provides a potential clue as to the etiology of the arrest, which was secondary to a pulmonary embolism; the thick arrow points to the left ventricular cavity.

bedside echo shows a significant pericardial effusion, a pericardiocentesis could be performed faster as it would be diagnosed faster. In addition, at times the heart may appear to be beating rapidly but there is a small amount of fluid (blood) within the cardiac chambers. This may be from an extreme case of dehydration for which rapid administration of IV fluids may help manage. Therefore, a quick bedside point of care echocardiography may reveal a cardiac anomaly that may be able to be restored in a efficient manner. Pulseless electrical activity is the most common rhythm found in ESRD. The presence of hypercontractile myocardium in the absence of a pulse would suggest the need for fluids or blood instead of the usual epinephrine and cardiopulmonary resuscitation (Figure 5).

### CONCLUSION

Ultrasonography at the POC provides an important and continuously expanding tool to improve nephrological diagnostic accuracy in concert with history and physical examination. Extracellular fluid evaluation is paramount in all kidney disease conditions. Recent clinical studies in lung ultrasonography suggest that the learning curve for the medical provider is quicker than with other organs. Because POC sonography in association with limited bedside echocardiography may reveal discriminatory signs of pneumonia and differentiate between cardiogenic vs noncardiogenic pulmonary edema, such imaging may be important cost-effective strategies in the management of dyspnea and in the categorization/etiology of AKI. Therefore, incorporation of POC sonography into clinical practice will require that medical schools, residency programs, and nephrology fellowship programs design teaching strategies within their respective curricula. Research studies with outcomes regarding diagnosis, morbidity, and mortality are necessary in these areas.

### Author disclosures

The authors report no actual or potential conflicts of interest with regard to this article.

### Disclaimer

The opinions expressed herein are those of the authors and do not necessarily reflect those of *Federal Practitioner*, Frontline Medical Communications Inc., the U.S. Government, or any of its agencies.

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