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Point-of-Care Ultrasound Education to Improve Care of Dialysis Patients

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Abstract

Point of care ultrasound (POCUS) is rapidly emerging as a bedside diagnostic tool that can enhance physical diagnosis and facilitate clinical decision-making. Although ultrasound is widely used by nephrologists for vascular access and kidney imaging, diagnostic POCUS skills in other anatomic areas are not part of routine nephrology training. In this narrative review, we will provide an overview of selected POCUS techniques, highlight potential uses of POCUS in routine nephrology practice, and describe a new curriculum implemented at Johns Hopkins University School of Medicine to teach diagnostic POCUS skills to nephrology fellows.

“Medicine is a science of uncertainty and an art of probability.”

Sir William Osler

Physical examination is at the core of patient assessment and diagnostic decision making. This component of clinical evaluation that begins with history-taking while observing patient demeanor, discomfort and non-verbal communication. Physical examination uses the examiner’s sensory perception (tactile, auditory, optic and olfactory) enhanced by point-of-care diagnostic tools that improve the objectivity of assessment, providing real-time data that are integrated by the clinician at the bedside for understanding the pathophysiology, making diagnostic decisions and engaging the patients in understanding their disease process. Many point-of-care diagnostic tools are in routine use including the stethoscope, weighing scale, sphygmomanometer, thermometer, pulse oximeter, otoscope, and ophthalmoscope. Improving the bedside clinical evaluation will require that the physician maintains the sensory perception skills while innovations ensure that the data provided by the point-of-care diagnostic tools are accurate, precise and reproducible, improving real-time diagnostic and management capabilities while simultaneously fortifying the physician-patient

connection. These advances in clinical assessment are needed to improve care of all patients, including those managed by nephrologists.

The stethoscope, a point-of-care device invented by Laennec over 200 years ago, was a technological advancement that radically changed our understanding of pathophysiology of disease and the practice of medicine¹. The success of the stethoscope as a point-of-care device comes from its versatility and ease of use which allows for diagnosis and real-time monitoring of disease processes². Recent technological advances have allowed for development of many new point-of-care devices. Of these, point-of-care ultrasound (POCUS) has great promise to enhance the physical exam by providing clinically relevant information in a fast and efficient manner. POCUS is in widespread use in nephrology for procedures, such as temporary dialysis catheter placement. However, diagnostic POCUS is vastly underutilized and is an opportunity to improve the care of patients with kidney disease^{3–5}. In the following sections, we will provide an overview of selected POCUS techniques, highlight potential uses of POCUS in routine nephrology practice, and describe a new curriculum implemented at Johns Hopkins University School of Medicine to teach diagnostic POCUS skills to nephrology fellows.

Selected POCUS techniques that are useful for nephrologists

POCUS can be used for formal ultrasound study or for more focused diagnostic imaging to augment physical examination. The following are the key focused diagnostic ultrasound skills that are easily taught and can contribute to improving care of patients seen in routine nephrology practice.

Focused Cardiac Ultrasound

The heart can be imaged from a number of different angles. The parasternal long-axis (PLAX) view takes less than 5 minutes to perform and can quickly provide valuable diagnostic information. The ultrasound probe is placed along the left sternal border at approximately the 4th intercostal space, perpendicular to the patient's chest with the probe index marker angled toward the patient's right shoulder⁶. This view allows visualization of the left atrium emptying into the left ventricle, the mitral valve flapping toward the interventricular septum, and the right ventricle as well as the surrounding pericardium and descending aorta (Figure 1). Using PLAX view, pericardial and pleural effusions are rapidly identified as dark black pockets of fluid around the heart. Left ventricular ejection fraction (EF) can be quantified using the mitral valve E point-septal separation (EPSS) method, which correlates the distance between the anterior mitral valve and the interventricular septum, with an estimated EF⁷. The greater the distance, the lower the ejection fraction – a distance of 1 cm or more corresponds to an EF of less than 45% – providing a quick bedside assessment of EF. POCUS cardiac image quality is comparable to the transthoracic echocardiography⁸. In previous diagnostic accuracy studies, compared to formal echocardiograms read by cardiologists, ejection fraction assessment using POCUS by non-cardiologists was highly reliable^{7,9–13}.

Inferior Vena Cava (IVC) Ultrasound

The IVC is imaged from a subcostal view, inferior to the xyphoid process, with the probe flat on the patient's abdomen (Figure 1). After locating the right atrium and keeping an eye on its wall, the probe is rotated to see the junction of the IVC and the right atrium and the long-axis of the IVC. At approximately 2 centimeters from the IVC-right atrium junction, the IVC diameter and collapsibility during inspiration is assessed. The IVC diameter and collapsibility can provide an estimate of the central venous pressure (CVP) – a wide (>2.5 centimeters) IVC with poor to no collapsibility (“fixed and dilated IVC”) generally indicates that the CVP is higher than 15–20 mm Hg whereas a small IVC (<1.5) with >50% collapse during inspiration (“flat IVC”) is indicative of CVP less than 5 mm Hg.^{14–18} In a number of studies, POCUS evaluation of IVC was highly reliable in estimating CVP⁷.

Focused Lung Ultrasound

A focused lung ultrasound can quickly allow assessment of pulmonary edema, pleural effusion and pneumothorax. The lungs are imaged by scanning the chest bilaterally anteriorly (mid-clavicular), laterally (mid-axillary), and posteriorly (mid-scapular). Pleural effusions are easily identified as dark black mirror images of the liver or spleen at the interface between the diaphragm and lung. Pulmonary edema can be identified and quantified by B-lines, also known as lung “comets” or “rockets” (Figure 1). B-lines are repeated reflections of ultrasound waves within lung parenchyma as a result of alveolar edema¹⁹. B-line counts can allow serial monitoring of patients with pulmonary edema. Higher B-line counts in dialysis patients are associated with higher risk of death²⁰. B-lines can also detect pulmonary edema in dialysis patients who may otherwise be considered euvolemic by routine physical examination^{21,22}. The ongoing Lung Water by Ultrasound Guided Treatment in Hemodialysis Patients (LUST) trial is testing the hypothesis that target weight setting in hemodialysis patients by using POCUS guided lung water measurement (B-line score) will prevent cardiovascular outcomes (including death, myocardial infarction, left ventricular dysfunction, hospitalizations)²³. In the emergency department, B-lines on POCUS can rapidly differentiate between different causes of dyspnea, shortening the time between evaluation and treatment^{24–27}.

Focused Kidney Ultrasound

POCUS can allow rapid evaluation of the kidneys in the outpatient or the inpatient setting. The kidneys are visualized through the lower lateral ribs at the midaxillary line in the supine position or at the costovertebral angle in the prone position (Figure 1). Transhepatic view of the right kidney allows determination of renal echogenicity by comparing it to normal liver. The longitudinal view of the kidney allows measurement of kidney length and can quickly identify marked hydronephrosis. Transverse views of the kidney can further delineate hydronephrosis and hydroureter.

Focused Bladder Ultrasound

Bladder ultrasound is one of the easiest skills to master and can rapidly identify patients with bladder outlet obstruction and urinary retention. The bladder is imaged with the ultrasound probe placed above the symphysis pubis, directed caudally toward the prostate or cervix. By measuring the maximum transverse and longitudinal bladder diameters, bladder volume is calculated using the following equation: Volume (mL) = length (cm) * width (cm) * height (cm) * (0.52)²⁸. Many POCUS devices can automatically calculate the bladder volume by using these measurements.

Bladder POCUS can detect urinary retention, avoiding unnecessary ultrasounds for post-void residual in the outpatient setting and reduce the need for bladder catheterization and its subsequent complications in settings of acute kidney injury and critical illness.

Focused Dialysis Fistula Ultrasound

The fistula is imaged by placing the ultrasound probe on the fistula. The cross-section of the fistula appears as a hollow dark black circle (Figure 1). The width of the fistula, the distance between the surface and fistula (depth) and the blood flow rate can be assessed using POCUS.

Integration of POCUS in Bedside Diagnostic Decision-Making

Diagnostic POCUS has been most widely used and systematically evaluated in emergency department and critical care settings. There are a number of established POCUS protocols in use in these settings.

The RUSH (Rapid Ultrasound in Shock) protocol is designed to distinguish between classic shock states. Focused on the heart and its function, RUSH evaluates patients for cardiac contractility, pericardial effusion, tamponade, IVC maximum diameter, and IVC collapsibility to categorize shock as hypovolemic, cardiogenic, obstructive, or distributive²⁹. The BLUE (Bedside Lung Ultrasound in Emergency) can rapidly distinguish causes of acute respiratory failure, and the FALLS (Fluid Administration Limited by Lung Sonography) protocol provides an ultrasound guided approach to acute circulatory failure³⁰.

The FAST (Focused Assessment with Sonography for Trauma) and the Extended FAST (E-FAST) protocol assess free fluid in pleural, peritoneal, and pericardial spaces following blunt trauma (FAST) as well as hemothorax and pneumothorax (E-FAST). The use of FAST protocols is supported by guidelines from the American Institute of Ultrasound in Medicine (AIUM) and the American College of Emergency Physicians (ACEP)³¹.

POCUS has also been rigorously evaluated in the emergency department setting for patients presenting with suspected nephrolithiasis. Routine use of ultrasonography in these patients significantly reduced the need for CT scanning, lowering radiation exposure without any increase in risk for nephrolithiasis-related complications³².

Diagnostic POCUS for Bedside Decision-Making in Nephrology

Patients with kidney disease often have many other comorbidities that influence overall patient management. In the following sections, we will discuss specific clinical situations in dialysis patients where POCUS can be helpful by providing bedside diagnostic information that can enhance clinical decision making. We will also briefly highlight other potential uses of POCUS in routine non-dialysis nephrology practice.

Shortness of breath in a dialysis patient: Is this volume overload?

Shortness of breath is a common symptom in hospitalized dialysis patients. In the setting of missed dialysis and clinical signs of volume overload, such as peripheral edema, elevated jugular venous pressure, and end-inspiratory crackles or X-ray findings of pulmonary edema, the diagnosis can be quite clear. However, not uncommonly, pedal edema may be due to venous insufficiency, jugular venous pressure may be difficult to assess, and lung exam or X-ray may be equivocal. Absence of both crackles and chest X-ray findings of pulmonary edema are also well-described in patients with chronic elevation of left ventricular end-diastolic pressure and are thought to be due to the enlargement of pulmonary lymphatics which prevent alveolar edema despite elevated left ventricular filling pressure^{33–35}. In dialysis patients with suspected volume overload, POCUS can provide valuable information. IVC POCUS can provide objective data on right sided filling pressures (IVC diameter and collapsibility). Lung POCUS can identify pulmonary edema (B lines) and identify additional pathology such as pleural effusion that may be contributing to dyspnea⁵. Cardiac POCUS may identify low ejection fraction or valvular abnormalities.

Dialysis patient with hypotension

Hypotension is common in dialysis patients and can present in a variety of settings. In dialysis patients presenting with unexplained hypotension, cardiac tamponade, myocardial dysfunction, and effective circulating volume depletion is often in the differential and POCUS can rapidly provide valuable diagnostic information. Similar to the RUSH protocol, POCUS can quickly identify pericardial effusion or tamponade and/or low ejection fraction. IVC examination can provide further diagnostic information on effective circulating volume. In the setting of intradialytic hypotension, serial POCUS evaluation of IVC may identify patients where hypotension is a result of decreased effective circulating volume (“flat” IVC)^{5,36,37}. Such patients may still have extravascular volume expansion and may require longer dialysis time or more frequent dialysis sessions. On the other hand, patients with intradialytic hypotension, normal ejection fraction and dilated IVC may develop intradialytic hypotension due to autonomic insufficiency with peripheral vasodilation³⁸. These patients more likely to respond to α -adrenergic agonists such as midodrine³⁹.

Target weight in dialysis patients

Identifying target weight for dialysis patients is challenging. Overestimation of target weight contributes to persistent volume overload and its sequelae whereas underestimation of target weight can cause intradialytic hypotension and its associated complications. POCUS can help identify patients with occult volume overload. As the Centers for Medicare & Medicaid (CMS) proposes new quality performance measures for ultrafiltration rate thresholds for

dialysis patients due to the associations of higher mortality⁴⁰, POCUS may serve as an invaluable tool to assist in appropriate assignment and adjustment of target weight. The ongoing Lung Water by Ultrasound Guided Treatment in Hemodialysis Patients (LUST) trial is currently testing this technique for volume management in hemodialysis patients²³. Persistence of lung B lines when the patient is at target weight may suggest persistent volume overload which may improve with targeting a lower weight.

Is this dialysis fistula ready for use?

In hemodialysis patients with a new fistula, there is often uncertainty if the fistula is ready for use. The K/DOQI guidelines recommend that a fistula can be assessed using the “rule of sixes” – it should be <6 mm deep, >6 mm wide, and have a blood flow rate >600 ml/min^{41–43}. POCUS can quickly provide measurements of depth and width of the fistula, providing objective data to monitor fistula maturation, communicate with vascular surgeons, and make decisions regarding cannulation.

Asymptomatic left ventricular dysfunction in dialysis patients

Left ventricular dysfunction is common in dialysis patients and reduced systolic function is associated with a high risk of death. The National Kidney Foundation’s Kidney Disease Outcome Quality Initiative (K/DOQI) guidelines recommend routine screening for reduced systolic function at dialysis initiation, after 3 years of dialysis, or if there are new symptoms suggesting left ventricular dysfunction⁴⁴. POCUS of the heart can provide quick assessment of ejection fraction and may allow early detection of new systolic heart failure.

Cardiorenal syndrome: Is this patient volume overloaded or depleted?

Managing patients with heart failure and acute kidney injury (AKI) is challenging as effective circulating volume can be difficult to assess. POCUS evaluation of the lungs (B lines) and IVC can provide objective data that can influence decisions to diurese or to stop diuresis⁵.

Patients presenting with uremia

A common scenario in nephrology practice is the presentation of a patient to an emergency department, without any known past history of kidney disease and laboratory data demonstrating elevated urea and creatinine. A POCUS evaluation of the kidney can provide useful diagnostic information in this scenario. Hydronephrosis can be quickly excluded and renal size and echogenicity may provide information on the chronicity of kidney disease. Bladder ultrasound can rapidly provide information on bladder outlet obstruction and potentially avoid unnecessary urinary catheterization and associated complications.

Hypertensive crisis: Does this patient have papilledema and malignant hypertension?

Assessment of optic fundus for papilledema is an important part of evaluating patients with severe hypertension. POCUS evaluation of the eye can allow assessment of intracranial pressure – with severe elevation of intracranial pressure, echolucent areas can be seen in the optic nerve sheath (the “crescent” sign)^{45,46}. The severity of papilledema can also be quantified.

Acute joint pain and swelling: Is this gout or pseudogout?

Gout and pseudogout are common in patients with kidney disease. Accurate diagnosis and differentiating between these two entities is essential for prevention of acute attacks and to avoid complications caused by uric acid lowering therapy. POCUS evaluation of joints can identify monosodium urate crystals on cartilage and tophi and can help with diagnostic decision making⁴⁷.

POCUS Education

Nephrology fellows nationwide have identified that increased training in ultrasonography is a desired element of their curricula⁴⁸. For POCUS to be incorporated into clinical care on a nation-wide level, educational curriculum and training programs need to be designed, tested, and integrated into physician training. Currently, many institutions have developed individualized programs; however, to standardize care and treatment, curricula must eventually be accepted and promoted on a national scale. Nephrology has not yet embraced any one educational curriculum as addressing a majority of encountered clinical dilemmas. However, other specialties, including emergency medicine and critical care^{25–27,29–32,49}, have started to adapt focused protocols and test their educational curricula. Internal medicine and medical schools^{50–53} are also starting to incorporate ultrasound basics to provide rising medical professionals exposure to ultrasound early in their training. POCUS education for nephrology fellows is being offered by some nephrology training programs but there are no competency guidelines provided by the American Board of Internal Medicine.

The Johns Hopkins Nephrology POCUS Curriculum

The Johns Hopkins Nephrology POCUS curriculum is designed to teach focused diagnostic POCUS skills to nephrology fellows. The goal of the curriculum is to provide nephrology fellows with basic ultrasound knowledge and develop skills to use POCUS for volume assessment and selective renal pathologies. The curriculum is designed to teach focused ultrasound skills to all fellows with options for advanced training in each area. The skills taught in the course are described in Figure 2 and Appendix 1. The course is taught by an experienced ultrasonographer (CM). The curriculum includes a combination of didactic sessions and hands-on image acquisition (Figure 3). The didactic sessions describe the image acquisition process and image interpretation for each selected area. The didactic session is followed by an image interpretation test which must be successfully completed (score 90%) before continuing with image acquisition. Knowledge and interpretation of what is being imaged improves the learner's engagement in the image acquisition process. Image acquisition training is comprised of guided sessions followed by independent scanning. All independent images are interpreted by the learner and verified by the teacher.

Assessment of the curriculum, experience, and skills is performed across multiple levels (Figure 4). At the end of each module, each learner's competency is evaluated using a POCUS Objective Structured Clinical Evaluation (POCUS-OSCE; Appendix 2). At the end of the course, each learner assesses the ease, utility, and skills developed in POCUS using a survey (Appendix 3). Learners are also provided a "Certificate of Completion". The

curriculum is modular – it is implemented in a 2-week elective block but can also be implemented one module at a time over a longer time period.

Positioning of POCUS Training in the Nephrology Landscape

Interest in nephrology as a career has seen a decline in interest⁵⁴ with trainees having different career interests compared to years past⁵⁵. Studies have shown that the top reasons for residents not choosing nephrology are the belief that patients with end-stage renal disease were too complicated, the lack of a mentor, and that there are insufficient procedures in nephrology⁵⁶. Recent innovations in nephrology curricula have focused on altering the inpatient experience^{57,58}, and providing additional training in physiology⁵⁹. Adding novel procedural and diagnostic aspects to a curriculum, including POCUS, may increase both the flexibility in skills for fellow trainees, and also combat the perceptions of what nephrology has to offer in a career. These experiences could be elective or required elements, as programs need to continue to demonstrate competency in the core aspects of nephrology⁶⁰. Formal ultrasound training also has the capability of adding items for reimbursement for nephrologists. The American Society for Diagnostic and Interventional Nephrology (www.asdin.org) offers pathways for certification for kidney and bladder ultrasound – expansion of this program with pathways for certification in other areas can expand the potential for billing services for nephrologists.

Conclusion

Diagnostic POCUS has a substantial potential to advance the practice of nephrology and improve patient care, particularly in the management of volume overload and acute kidney injury – two of the most common problems encountered in routine nephrology practice. Although we may never truly shift medicine away from being a “science of uncertainty,” with more accurate diagnoses and focused treatments, we can better master the “art of probability” and provide state-of-the-art care to our patients.

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Appendix 1: Nephrology Point-of-Care Ultrasound Curriculum

Goal

To provide nephrology fellows with knowledge and skills to use ultrasound for evaluating selective renal pathology, vascular access, and volume assessment at the point-of-care.

At the end of this course, nephrology fellows will be able to understand and perform the following functions:

A. Ultrasound basics

1. Basic principles of ultrasound imaging
2. Device features and functions (probes, gain, depth, image annotation)
3. Basics of image acquisition (orientation of the probe, handling probe)
4. Common ultrasound terminology (hypoechoic, anechoic, hyperechoic)
5. Common ultrasound artifacts (acoustic shadowing, mirror image)
6. Disinfection protocol for probe and machine

B. Renal Ultrasound

1. Clinical scenarios and ultrasound use
2. Image acquisition (right and left kidneys; longitudinal and transverse views)
3. Image interpretation (hydronephrosis, renal echogenicity, renal size, renal stones, renal cysts)

C. Bladder Ultrasound

1. Clinical scenarios and ultrasound use
2. Image acquisition
3. Image interpretation (bladder volume calculation)

D. Dialysis Fistula (and Graft) Ultrasound

1. Clinical scenarios and ultrasound use
2. Image acquisition (longitudinal and transverse views)
3. Image interpretation [depth (<6 mm), diameter (>6 mm), flow(>600 ml/min)]

E. Cardiac Ultrasound

1. Clinical scenarios and ultrasound use
2. Image acquisition (parasternal long axis view)
3. Image interpretation (effusion, global ejection fraction assessment, relative chamber size)

F. Inferior Vena Cava Ultrasound

1. Clinical scenarios and ultrasound use
2. Image acquisition
3. Image interpretation (fixed and dilated versus normal/collapsed)

G. Lung Ultrasound

1. Clinical scenarios and ultrasound use

2. Image acquisition (anterior, lateral, posterior)
3. Image interpretation (pulmonary edema, effusion, pneumothorax)

Appendix 2: Point-of-Care Ultrasound Objective Structured Clinical Evaluation (POCUS-OSCE)

Imaging Competency (Use separate form for each area):
☐ PLAX ☐ IVC ☐ Lung ☐ Kidney ☐ Bladder ☐ Fistula

Name: _____

Evaluator: _____

Date: _____

1. Image Acquisition Skill

☐ Unsatisfactory (Unable to use right technique to acquire images)	☐ Good (Adequate for point-of-care use)	☐ Outstanding (Can teach others)
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2. Image Quality

☐ Unsatisfactory (Unable to acquire images that can be used clinically)	☐ Good (Adequate for point-of-care use)	☐ Outstanding (Can teach others)
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3. Real-time Image Interpretation Skills

☐ Unsatisfactory (Inaccurate interpretation)	☐ Good (Adequate for point-of-care use)	☐ Outstanding (Can teach others)
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4. Humanistic Qualities/Professionalism

☐ Unsatisfactory (Unprofessional demeanor)	☐ Good (Caring and professional attitude)	☐ Outstanding (Role model)
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5. Counselling Skills

☐ Unsatisfactory (Unprofessional, cursory)	☐ Good (Adequate description)	☐ Outstanding (Role model)
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Appendix 3: Renal Fellows Point-of-Care Ultrasound Pretest/Posttest

Please answer the following questions (Note: These questions refer to experience prior to starting fellowship):

Date: _____

Name (First Last): _____

Years since graduation from Med School: _____

Years since completion of Internal Medicine Residency:

☐ 0
☐ 0-5
☐ >5

1. Have you ever used an ultrasound machine for diagnostic purposes (Does not include ultrasound for invasive procedures)?

☐ No (skip to Q2)
☐ Yes
 If yes, have you had training in using ultrasound?
☐ No (skip to Q2)
☐ Yes
 If yes, was it by:
☐ Peers/Senior Residents
☐ Ultrasound course (separate from residency training)
☐ Ultrasound curriculum incorporated in Residency or Med School?

2. Have you ever had formal education regarding use of ultrasound for diagnostic purposes (Does not include ultrasound for invasive procedures)?

☐ No
☐ Yes

	Extremely Unconfident (No idea how to use it)	Somewhat unconfident	Neutral	Confident	Extremely Confident (I can teach this)
3. How confident do you feel in your understanding of the principles behind the use of ultrasound technology?	☐	☐	☐	☐	☐
How comfortable do you feel with the following skills:					
4. Basic operation of ultrasound machine?	☐	☐	☐	☐	☐
5. Identifying hydronephrosis?	☐	☐	☐	☐	☐
6. Measuring renal size?	☐	☐	☐	☐	☐
7. Identifying renal stones?	☐	☐	☐	☐	☐
8. Identifying renal cysts?	☐	☐	☐	☐	☐
9. Describing renal echogenicity?	☐	☐	☐	☐	☐
10. Assessing bladder volume?	☐	☐	☐	☐	☐
11. Identifying pericardial effusion?	☐	☐	☐	☐	☐
12. Assessing left ventricular dysfunction?	☐	☐	☐	☐	☐
13. Assessing inferior vena cava diameter?	☐	☐	☐	☐	☐
14. Assessing pulmonary edema?	☐	☐	☐	☐	☐
15. Assessing pleural effusion?	☐	☐	☐	☐	☐
16. Assessing dialysis fistula depth and diameter?	☐	☐	☐	☐	☐
17. Using ultrasound to guide assessment of volume status?	☐	☐	☐	☐	☐
18. Using ultrasound to guide management of hypotensive patient?	☐	☐	☐	☐	☐

Would formal ultrasound training:	Absolutely Not	Maybe	Neutral	Likely	Absolutely
19. Improve the care you provide for patients?	☐	☐	☐	☐	☐
20. Increase your level of enthusiasm for patient care?	☐	☐	☐	☐	☐
21. Improve patient satisfaction?	☐	☐	☐	☐	☐
22. Increase the interest of Internal Medicine housestaff in Nephrology?	☐	☐	☐	☐	☐
23. Make a Nephrology Fellowship program more attractive to you?	☐	☐	☐	☐	☐

Figure 1. Selected ultrasound images obtained using POCUS

- A) Cardiac parasternal long-axis view (Abbreviations: RV, right ventricle; LV, left ventricle; AO, Aorta; LA, left atrium; Note: left atrium is enlarged)
- B) Inferior vena cava from sub-costal view (Abbreviations: IVC, inferior vena cava; Note: wide and dilated IVC)
- C) Lung view demonstrating B lines
- D) Kidney longitudinal view (Note: significant ascites is also present)
- E) Bladder transverse view
- F) Dialysis fistula (Note: vertical diameter 1.16 cms)

IMAGE AREA	IMAGE ACQUISITION	PROBE
1 Heart	Parasternal Long Axis (PLAX)	Phased
2 Inferior Vena Cava	Subcostal	Phased
3 Lung	Anterior, Lateral, Posterior	Linear
4 Kidney	Longitudinal, Transverse	Curved
5 Bladder	Suprapubic	Curved
6 Dialysis Fistula	Longitudinal and Transverse	Linear

Figure 2.
Johns Hopkins Nephrology fellowship POCUS curriculum

Figure 3.
POCUS Curriculum Administration

Figure 4.
Assessment of the curriculum, experience, and skills across multiple domains