An Introduction to Point-of-Care Ultrasound: Laennec to Lichtenstein

Abhilash Koratala and Amir Kazory

Point-of-care ultrasonography (POCUS) is rapidly evolving as a noninvasive adjunct to physical examination among various specialties. POCUS increases the sensitivity of conventional physical examination by providing the answers to simple clinical questions at the bedside. As such, it can reduce fragmentation of care and expedite management. In addition, using bedside ultrasound as the first-line investigation may eliminate unnecessary radiation and contrast exposure. The advent of highly portable and affordable ultrasound devices has made the use of POCUS more practical and user-friendly, making it the stethoscope of the 21st century. This review will provide an overview of the rationale for integrating POCUS into nephrology practice. We also discuss the current scope of POCUS practice and state of training.

Key Words: Point of care ultrasound, Physical examination, Nephrology

BACKGROUND

Careful physical examination not only allows physicians to narrow the differential diagnosis and/or arrive at a definitive diagnosis but also aids in building and maintaining the patient-physician relationship. The art of methodical history-taking followed by physical examination including direct auscultation dates to over three thousand years ago, when Hippocrates and his colleagues laid the foundations for modern physical diagnosis. Practice of medicine has changed a little ever since till the dissection of human bodies was resumed for educational purposes in the 16th century. In the 18th century, evolving knowledge of morbid anatomy allowed clinicians to correlate the antemortem symptoms and signs with the postmortem findings, thanks to the pioneering work of Morgagni.[1,2] After that, the invention of stethoscope in 1816 by René-Théophile-Hyacinthe Laennec, a French physician, has revolutionized physical examination and enhanced our understanding of the pathophysiology, particularly of chest diseases. It can indeed be considered the first technological aid in bedside diagnosis (ie, a diagnostic point of care device), which has become an "icon" of the medical profession and represents the use of science and technology in conjunction with the human skill of listening to diagnose ailments.[3]

Now, more than two centuries after the introduction of stethoscope, point-of-care ultrasonography (POCUS) is emerging as a powerful adjunct to physical examination across a broad spectrum of medical specialties. POCUS is a limited bedside ultrasound examination performed by the clinician to answer "focused questions" needed to guide patient management. For example, a nonradiologist physician can quickly evaluate the presence or absence of hydronephrosis, pulmonary edema, pericardial effusion, and so forth and integrate the finding(s) into clinical decision-making. While POCUS is relatively a recent development, ultrasonography is a time-tested imaging modality that is being used by various medical specialties for several decades. The foundation for sonography was laid long time ago in 1880s, when French physicist brothers Pierre Curie and Jacques Curie discovered piezoelectric effect, which means conversion of mechanical vibration into electrical energy. Piezoelectric crystals are an important component of the modern-day ultrasound transducer. In the first half of the 20th century, during World Wars I and II, Sonar (SOund Navigation and Ranging) technology was developed, which uses high-frequency sound waves to navigate, communicate with, or detect vessels on or under the surface of the water. In 1940s, Dr Karl Dussik, an Austrian neurologist, along with his physicist brother Friedrich attempted to locate cerebral ventricles and brain tumors using ultrasound, which is widely credited as the first clinical application of sonography. Thereafter, physicians from various specialties including cardiology and obstetrics ventured into this exciting field, and ultrasound technology continued to evolve. In 1980s, real-time ultrasound was developed allowing users to view sonographic images without a lag between signal generation and display of the image. This paved the way for bedside ultrasound evaluation of trauma patients in the emergency settings, which eventually became standard of care for the detection of hemoperitoneum and hemopericardium, known as the Focused Assessment with Sonography for Trauma (FAST) examination.[4,5]

Furthermore, description of the lung ultrasound signs, more precisely B-line artifacts of alveolar-interstitial syndrome in 1990s by a French intensivist, Daniel Lichtenstein, radically changed lung examination at bedside, particularly in the emergency and critical care settings.[6] Interestingly, although medical ultrasound has been around for a while by then, it was thought to have little or no utility for the evaluation of the lung as air is reflective to the ultrasound waves. With the technological advances and miniaturization of the ultrasound devices, POCUS seems to be evolving into a component of physical

From the Division of Nephrology, Medical College of Wisconsin, Milwaukee (A.Koratala); Division of Nephrology, Hypertension and Renal Transplantation, University of Florida, Gainesville (A.Kazory).

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Address correspondence to Abhilash Koratala, MD, Division of Nephrology, Room A 7633 8701 W Watertown Plank Rd, Wauwatosa, WI 53226. E-mail: akoratala@mcw.edu

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examination for the modern-day physician adding value to inspection, palpation, percussion, and auscultation.

Once confined to procedural guidance such as kidney biopsy and dialysis catheter placement, the role of POCUS is being increasingly recognized in the field of nephrology for diagnostic applications.[7,8] Nevertheless, diagnostic POCUS remains largely underutilized at this time,[9] and in this narrative review, we provide an overview of the rationale behind incorporating POCUS into nephrology practice and education.

CONVENTIONAL PHYSICAL EXAMINATION HAS LIMITATIONS

Unfortunately, physicians tend to overestimate their physical examination skills while the decline in these skills among the trainees has been long recognized.[10,11] In a multicenter cross-sectional assessment of internal medicine residents' and cardiology fellows' auscultatory proficiency, the median accuracy was only 19.3% for the residents and 22% for the fellows. Interestingly, residents were never more proficient than third-year medical students and improved only little with each year of training.[12] In another multicenter study including 453 trainees from 8 internal medicine and 23 family medicine residency programs, the participants could identify only 20% of the commonly encountered cardiac events.[13] It is noteworthy that both these studies were published more than twenty years ago, and there is no indication in the literature to suggest that the auscultation skills of medical trainees have drastically improved since then.

Apart from declining skills, the classic signs and physical examination findings are not always sensitive. For instance, in a cohort of 50 patients with known chronic heart failure and a mean ejection fraction of 18% in whom hemodynamic measurements were available, the combined sensitivity of rales, pedal edema, and elevated jugular venous pressure was only 58% to detect a pulmonary capillary wedge pressure of more than or equal to 22 mm Hg.[14] Similarly, orthopnea, a symptom that is frequently relied upon to diagnose acute heart failure, has shown to be only 52% sensitive and 70% specific for this diagnosis in a meta-analysis.[15] In one study including 79 patients on hemodialysis, the combined sensitivity of the crackles and pedal edema was only 13% to detect pulmonary congestion identified on lung ultrasound, defined as more than 30 B-lines.[16] In all these studies, the specificity of the physical examination findings was high despite the low sensitivity. This is likely a reflection of the fact that conventional physical examination usually detects a disease after the tissue damage has already occurred. Moreover, the "classic" signs and symptoms of cardiovascular disease were described in an era when late-stage presentations were common, typically after the onset of significant symptoms.[17] Therefore, a more sensitive bedside tool is needed to detect pathology before progressive organ damage has ensued and guide timely patient management.

CLINICAL SUMMARY

- Point of care ultrasonography serves as a valuable noninvasive bedside tool to improve the diagnostic accuracy of physical examination and guide patient management.
- Nephrologists can use bedside multiorgan sonography to enhance patient care in various clinical settings in addition to procedural guidance.
- Point of care ultrasonography has the potential to reduce the need for further diagnostic workup as well as improve patient satisfaction.

POCUS ENHANCES THE DIAGNOSTIC ACCURACY OF PHYSICAL EXAMINATION

Ability of the clinician to perform bedside ultrasonography increases the diagnostic accuracy, which is crucial for appropriate management. In a prospective study including 32 patients with acute respiratory distress syndrome by Lichtenstein and colleagues, lung ultrasound significantly outperformed auscultation as well as chest X-ray for detection of pleural effusion, alveolar consolidation, and alveolar-interstitial syndrome.[18] Similarly, in a study including 926 critically-ill patients admitted to the intensive care unit, 51% of those who had pulmonary edema on lung POCUS demonstrated normal auscultatory findings.[19] This is of utmost relevance to nephrologists, who often rely on auscultation findings and radiographs to titrate diuretic or ultrafiltration therapy in the intensive care unit. In addition, as mentioned before, lung ultrasound is far more sensitive than auscultation to detect pulmonary congestion in patients undergoing hemodialysis, which helps for effective estimation and adjustment of their ideal (ie, dry) weight.[16] In fact, it has been shown that dry weight reduction guided by lung POCUS has a favorable impact on ambulatory blood pressure as well as cardiac chamber sizes and left ventricular filling pressure in these patients.[20,21]

With respect to cardiac examination, the addition of focused cardiac ultrasound has shown to significantly increase the sensitivity of traditional diagnostic approaches using history, physical examination, and electrocardiographic interpretation.[22,23] In a recent meta-analysis of 9 studies, the sensitivity of POCUS-assisted examination for diagnosing left ventricular dysfunction and valvular disease was found to be superior compared with conventional assessment (84% vs 43% and 71% vs 46%, respectively).[17] In addition, the utility of cardiac POCUS for rapid evaluation and management of patients with undifferentiated hypotension, chest trauma, and possible pericardial tamponade is well-established.[24] Global assessment of the cardiac pump function is vital to accurately assess fluid status, a common clinical dilemma in nephrology practice.

POCUS allows us to visualize the patient's anatomy in real time, adding a new dimension to the bedside assessment, which was never possible before. For example, applications such as exclusion of obstructive uropathy or assessment of venous blood flow patterns to guide decongestive therapy cannot be accomplished through conventional examination.[25]

POCUS EXPEDITES CARE AND ENHANCES PATIENT SATISFACTION

Clinician-performed POCUS can instantaneously answer specific clinical questions obviating the need to wait for consultative ultrasound report. Moreover, it allows multiorgan assessment during the same encounter. In the outpatient setting, it may preclude the need for visits to other departments (e.g., radiology or cardiology) unless a referral scan is deemed necessary. For example, focused questions such as "Does this patient with hypertension have underlying cystic renal disease?", "Does this dialysis patient with hypotension have pericardial effusion?", "Is the newly placed arteriovenous access maturing well in this patient with advanced chronic kidney disease?" and so forth can be answered within minutes and expedite care. Not surprisingly, in a study on 60 patients presenting with respiratory or cardiovascular complaints, time to appropriate treatment was significantly shorter among patients in the POCUS group than that among controls (median time of 5 hours vs 24 hours, $P = 0.014$).[26]

There are also data suggesting that POCUS enhances patient satisfaction and their perception of the physician, which likely aids to strengthen the patient-physician relationship.[27,28] Furthermore, discussing POCUS findings with the patients may help them better understand their health issues. In a prospective controlled trial involving 60 hospitalized adults, patients for whom POCUS was performed demonstrated an increase in shared understanding with respect to their diagnosis and major contributors compared with the non-POCUS group (9.56 vs 7.62 and 9.65 vs 8.30, respectively, $P < 0.005$).[29]

POCUS MAY REDUCE THE HEALTH-CARE COST BURDEN

In the era of high-value patient care, the importance of optimal utilization of the health-care resources and subsequent reduction of cost burden is increasingly recognized. POCUS has the potential to reduce further diagnostic workup by enhancing the bedside clinical decision-making. For instance, in a study including 518 consecutive patients admitted to the internal medicine ward, the number of diagnostic tests ordered was significantly lower (ie, one-third) in those who were managed using POCUS than that in the non-POCUS group (0.43 tests per patient vs 1.29, respectively).[30] Similarly, in a large cohort impact study involving 1962 patients managed using pocket ultrasound devices in various clinical settings, further diagnostic testing was deemed unnecessary in 63% of the patients. In those undergoing further tests, the sensitivity of POCUS was 91%, and specificity 83%.[31] A small yet interesting study in the emergency medicine setting examined how this would translate into cost savings.[32] The authors found that POCUS use eliminated $1134.31 of additional testing for patients with private insurance, $2826.31 for uninsured or out-of-network patients, and $181.63 for Center for Medicare and Medicaid Services patients.

POCUS IN MEDICAL EDUCATION

In the last 2 decades, medical schools have been increasingly incorporating POCUS training into their undergraduate curricula to teach gross anatomy, physiology, correlative pathology, and physical diagnosis.[33,34] According to a 2012 survey of U.S. medical schools ($N = 82$), 62% reported to have integrated ultrasound training into their curricula, albeit with heterogeneity in the structure and organization.[35] More recently, University of California-Irvine took a step forward and provided all 104 medical students of the class of 2023 handheld ultrasound devices during the white coat ceremony, where traditionally stethoscopes would be presented.[36] As more medical students and trainees become proficient with POCUS-enhanced physical examination, lack of supervising physicians adequately trained in this skill potentially creates a confusion in the clinical decision-making process. This is particularly relevant to nephrology, where hemodynamic assessment is vital for the management of fluid and electrolyte disorders and conventional parameters suffer from limitations. Therefore, it is imperative that medical schools and hospitals lay emphasis on training practicing physicians in POCUS, especially those who supervise trainees.

THE SCOPE OF PRACTICE AND TRAINING

As ultrasonography traditionally has been a territory of radiologists covering a broad range of applications, the scope of practice of POCUS is frequently debated among specialties that are relatively new to this valuable tool. In 1999, the American Medical Association House of Delegates passed a resolution (Res. 802, I-99, reaffirmed 2020) that affirms that "ultrasound imaging is within the scope of practice of appropriately trained physicians" and each hospital medical staff should review and approve criteria for granting ultrasound privileges based on the physicians' background and training in accordance with recommendations developed by each physician's respective specialty.[37] Nevertheless, in most specialties outside of emergency medicine, clear recommendations on POCUS training and standards do not exist. Recently, there have been efforts within the field of internal medicine to address this gap through development of consensus statements published by professional societies.[38-41]

In the field of nephrology, POCUS use for procedural guidance such as dialysis catheter placement and kidney biopsy is established as standard of care, at least in developed countries.[42] However, there is no universally accepted standard for diagnostic POCUS partly because it is fairly recent that the nephrologists have started scanning beyond the kidney.[43] Based on our institutional experience, we have previously proposed a model curriculum for nephrology trainees and outlined the sonographic applications that we found helpful in day-to-day practice of nephrology.[7,44]

In a nutshell, the scope of POCUS can be divided into basic and advanced as represented in Figures 1 and 2

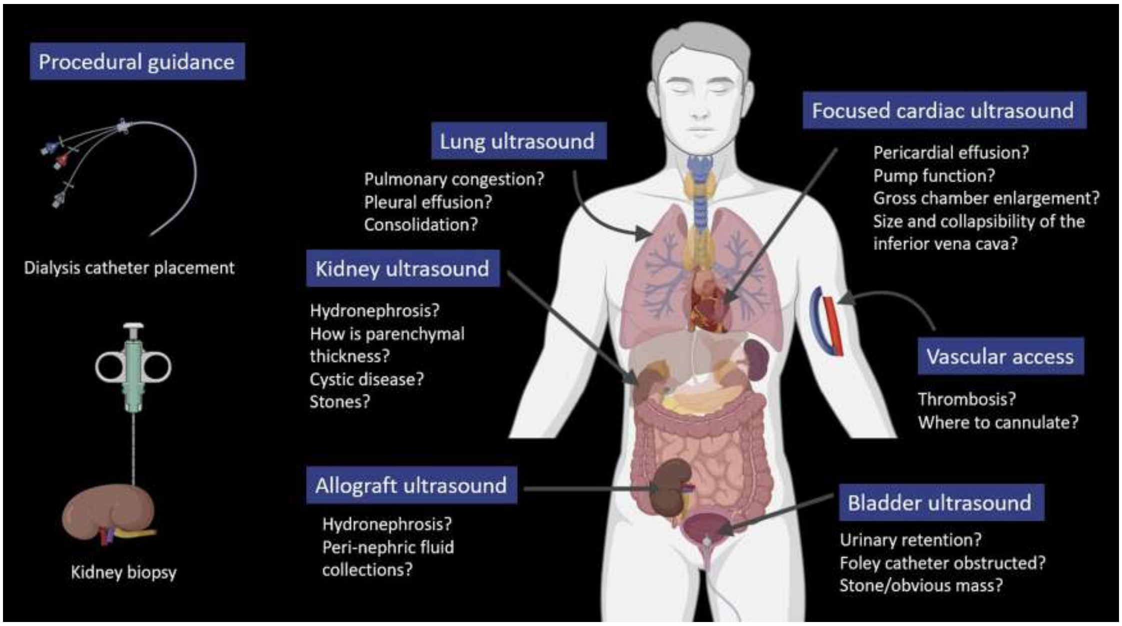

Figure 1. Basic nephrology-related point of care ultrasonography: organs examined and common clinical questions encountered are shown. Created with BioRender.com.

depending on the degree of skills and training required to acquire competence in these sonographic applications. Basic POCUS involves a multipoint examination without the use of spectral Doppler to answer focused clinical questions that are likely to change the management. Examples include scanning limited lung zones to exclude pulmonary congestion or pleural effusion, heart to exclude pericardial effusion and evaluate systolic function, kidneys to exclude hydronephrosis and assess parenchymal characteristics, and so forth, in addition to procedural guidance.[8] On the other hand, advanced POCUS involves spectral Doppler applications and is intended to answer more complex questions. Examples include assessing blood flow in an arteriovenous access and comprehensive volume status

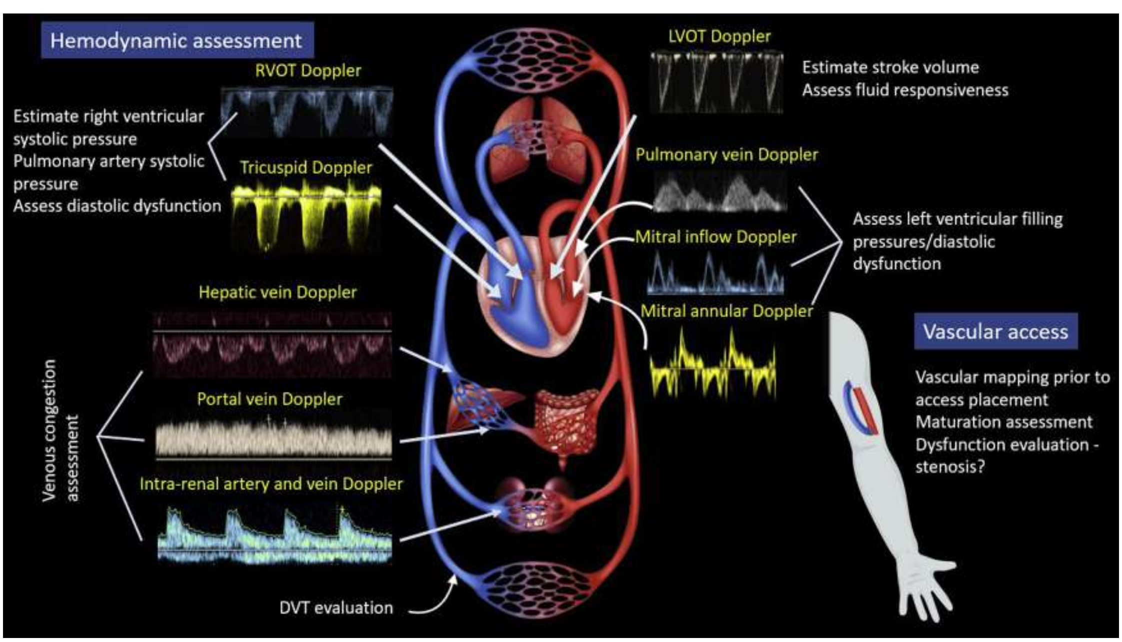

Figure 2. Spectral Doppler applications related to nephrology that constitute advanced point of care ultrasonography (in addition to basic applications). DVT, deep vein thrombosis; LVOT, left ventricular outflow tract; RVOT, right ventricular outflow tract. Hemodynamic circuit licensed from Shutterstock.

assessment using the "pump, pipes, and leaks" approach where pump represents Doppler echocardiography, pipes denote inferior vena cava ultrasound and venous Doppler, and the leaks indicate assessment of the extravascular lung water and ascites.[45] The scope of POCUS use is dynamic and continues to expand to include more applications as the expertise grows, depending on the practice setting. Most of these scans can be billed for if the images are properly archived, which helps offset the costs of the equipment.

With respect to training, it is generally accepted that longitudinal curricula have a favorable impact on long-term skill retention compared with "crash courses" and workshops.[40,46] Interestingly, one study showed that only 12% of the knowledge was retained at 2 weeks after a set of standardized ultrasound presentations.[47] As such, integrated POCUS training spanning over the 2-year nephrology fellowship offers conceivable advantage. Curriculum typically involves didactics and hands-on practice on volunteers as well as consenting patients. Simulation-based training can be a valuable adjunct where available.[48,49] Moreover, availability of the free open-access medical education resources such as NephroPOCUS.com and Renal Fellow Network minimizes the need to create didactic material from scratch by individual fellowship programs.[50,51] In addition, collaboration with expert faculty from other POCUS-performing specialties such as emergency medicine at the institutional level can provide an oversight and help with quality improvement.

LIMITATIONS AND FUTURE DIRECTIONS

Any technology, no matter how advanced, is not a replacement for astute clinical judgment and appropriate integration of clinical information. The same rule applies to POCUS, and the lack of attention to details, improper technique, and inability to interpret a finding may result in suboptimal or inappropriate management of the patient. Nonetheless, no element of patient evaluation including history-taking, conventional physical examination, and interpretation of laboratory and imaging data is exempt from "operator dependency." As such, experts and professional organizations should work together to develop guidelines to ensure proper training and accreditation process for POCUS in nephrology. Future studies need to focus on studying the impact of nephrology-specific longitudinal curriculum on learners' competency as well as developing protocols for enhancement of the diagnostic sensitivity of POCUS to improve patient outcomes.

Training opportunities for practicing nephrologists are limited at this time, needing them to rely on the workshops organized by various professional societies or commercial entities. Pursuing a well-organized multicomponent certification program such as one developed by the American College of Chest Physicians while taking advantage of the free open-access medical education helps with gaining confidence for independent scanning.[52] Courses focusing on nephrology-specific applications such as the Point-of-Care Ultrasound Immersion Course serve as an useful adjunct.[53] Recent technological advances such as ultraportable ultrasound devices with artificial intelligence–powered deep learning algorithms may have a promising role in facilitating image acquisition and interpretation by nonexperts.[54]

While the fear of missing ominous findings and consequent legal implications are often cited as a barrier to learning POCUS,[55] so far, no study has shown that missed findings on focused or limited ultrasound scans resulted in an adverse legal action against physicians as opposed to failure to perform POCUS in a timely manner.[56-59] Proper documentation and image storage facilitate timely expert review when the operator is unsure about the findings. Novel cloud-based image-archiving solutions make this process easier by allowing immediate sharing, access, and mobility of medical images and reports. Moreover, with lower maintenance costs, they might be financially more viable for small hospital systems and medical practices.

Any skill or technology that challenges the established practice patterns faces resistance in the beginning, but it is likely to be increasingly embraced as the positive impact on patient care becomes more evident. This is what exactly happened with the stethoscope. John Forbes, in his preface to the English translation of Laennec's "A Treatise on the Diseases of the Chest and on Mediate Auscultation," wrote,

> *"...That it will ever come into general use, notwithstanding its value, I am extremely doubtful; because its beneficial application requires much time, and gives a good deal of trouble both to the patient and the practitioner."*[60,61]

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