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CONCEPTS

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# Point-of-care ultrasound stewardship

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## Abstract

Rapid adoption and widespread use of point-of-care ultrasound (POCUS) has impacted diagnostic testing and clinical care across medical disciplines. The benefits of POCUS must be weighed against certain pitfalls, such as the risk of misdiagnosis and false assurance. Beyond technical error in image acquisition and interpretation, an important pitfall is reliance on POCUS results without considering pre-test patient characteristics or the diagnostic accuracy of POCUS in varying clinical contexts. In this article, we introduce the concept of POCUS stewardship that emphasizes critical evaluation of clinical indications prior to performing POCUS as well as the individual patient and test characteristics of POCUS when integrating results into clinical decisionmaking. Adherence to these principles can lead to optimized POCUS application and improved patient care.

KEYWORDS

integration, point-of-care ultrasound, pre-test probability, safety, spectrum effect, stewardship, ultrasound

## 1 | INTRODUCTION

Rapid adoption and widespread use of point-of-care ultrasound (POCUS) has influenced the bedside examination, clinical workup, and care of patients across multiple medical specialties.[1] The scope of POCUS application varies from identifying a targeted diagnosis such as presence or absence of deep venous thrombosis, to more elaborate evaluation of complex clinical syndromes such as shock, respiratory distress, or acute renal failure.[2–5] POCUS is now nearly universally recognized as a feasible and reliable test for an impressive array of clinical conditions.

Although traditionally framed as a risk-free intervention, POCUS can result in important pitfalls. Most notably, its use without considering the pre-test characteristics of the patient, variations in the

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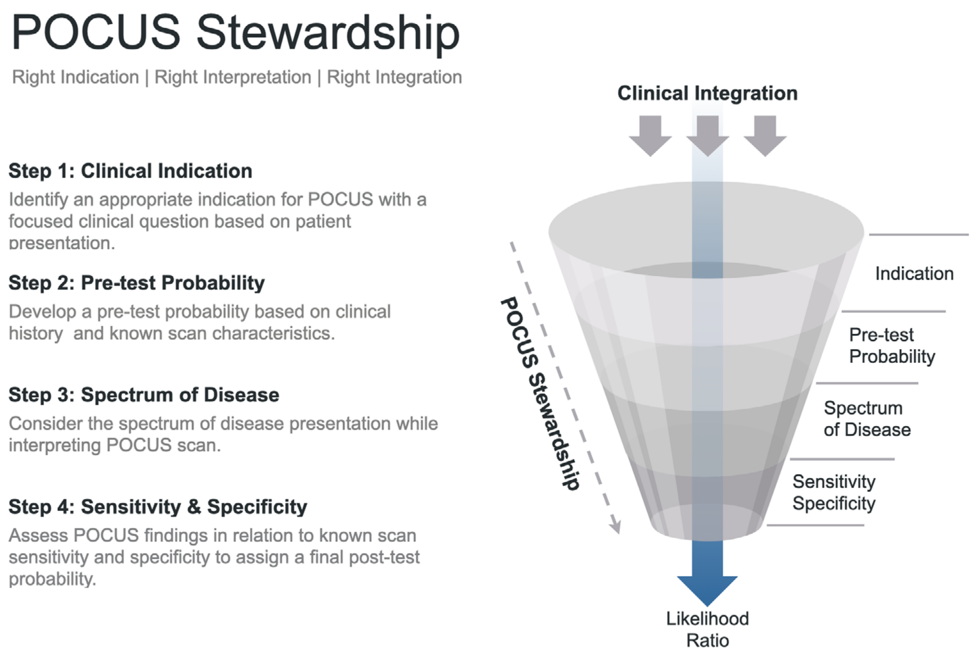


**FIGURE 1** 4-Step model of applying POCUS stewardship in clinical practice

diagnostic accuracy of POCUS, and the influence of the POCUS finding on clinical care can lead to errors in targeted medical decisionmaking. In this article, we propose the concept of POCUS stewardship—the application of POCUS with the proper consideration of pre-test probability, individual scan characteristics, and the influence of spectrum of the disease. The goal of POCUS stewardship is to ensure a safe and effective integration of POCUS in routine clinical practice by considering appropriate clinical indications and integration of POCUS results.[6]

## 2 | POCUS STEWARDSHIP

The elements of POCUS stewardship include: (1) optimizing clinical indications, (2) adopting pre-test probability, (3) staging the spectrum of the disease based on onset and severity of the pathological process, and (4) assessing the diagnostic accuracy of the test (sensitivity specificity and likelihood ratio) (Figure 1).

## 3 | POCUS CLINICAL INDICATIONS

POCUS often enhances clinical decision-making by enabling clinical providers to narrow down their diagnostic uncertainty. Unlike many protocol-driven tests, clinicians are able to use their clinical reasoning based on what the patient is reporting, in addition to what formal imaging protocols dictate. Therefore, POCUS scans are typically focused on evaluating a specific organ to answer a focused clinical question. Non-targeted scanning, however, can lead the diagnostic workup astray. As a common similar example, the D-dimer is a highly sensitive, but not very specific, test for thrombosis. Ordering a serum D-dimer test in a patient without clinical concern for thrombosis can create confusion and diagnostic uncertainty. If the pre-test probability for thrombosis were very low (for example, in a patient who meets the pulmonary embolism rule-out criteria), then the test would not change clinical management and therefore should not have been ordered.[7] However, in the face of an elevated D-dimer, the provider may feel compelled to pursue additional imaging regardless of the clinical picture at hand.

As in all aspects of clinical evaluation, properly formulating a differential diagnosis with thoughtful pre-test probabilities is critical prior to performing POCUS.[8–11] Existing guidelines such as the American Institute of Ultrasound in Medicine Ultrasound First and Choosing Wisely initiatives are devoted to education and increasing awareness of the effectiveness of ultrasound and other imaging in enhancing patient care. The American Institute of Ultrasound in Medicine Ultrasound First campaign identified ultrasound use as a first-line imaging test in >30 unique clinical indications, highlighting its use over immediate computed tomography scanning or magnetic resonance imaging usage.[2]

## 4 | PRE-TEST PROBABILITY: PATIENT CHARACTERISTICS

For any diagnostic study, clinicians must first consider the clinical indications for the test and the desired information resulting from the test. There should be sufficient concern for a particular pathology to warrant the workup as well as a benefit from confirming or refuting the workup. The exercise of identifying perceived likelihood of disease prior to a diagnostic workup is known as developing a pre-test probability.[12] Similar to other diagnostic testing, estimating the pre-test probability of a particular pathology prior to performing POCUS is crucial as it helps identify situations in which the likelihood of disease

**TABLE 1** Estimated post-test probability of pathology based on initial pre-test probabilities

| Test | Pre-test Probability | Pre-Test Odds | Likelihood ratio | | Post-test odds | | Post-test probability | |
|---|---|---|---|---|---|---|---|---|
| | | | Negative | Positive | Negative | Positive | Negative (%) | Positive (%) |
| DVT[8] | L-5% | 0.053 | 0.04 | 30.0 | 0.002 | 1.59 | 0.2 | 62.7 |
| | M-17% | 0.205 | | | 0.008 | 6.15 | 0.8 | 86.8 |
| | H-40% | 0.667 | | | 0.027 | 20.01 | 2.7 | 95.5 |
| PE[9,10] (dilated RV) | L-1.2% | 0.012 | 0.25 | 4.0 | 0.003 | 0.05 | 0.3 | 4.6 |
| | M-16.2% | 0.193 | | | 0.048 | 0.77 | 4.6 | 43.6 |
| | H-37.5% | 0.600 | | | 0.150 | 2.40 | 13.0 | 70.6 |
| Appendicitis[11] | L-3.9% | 0.041 | 0.09 | 30.3 | 0.004 | 1.23 | 0.4 | 55.2 |
| | M-29.4% | 0.416 | | | 0.039 | 12.63 | 3.7 | 92.7 |
| | H-52.9% | 1.123 | | | 0.104 | 34.07 | 9.4 | 97.1 |
| Kidney stone[12] | L-9.2% | 0.101 | 0.40 | 2.8 | 0.041 | 0.28 | 3.9 | 22.1 |
| | M-51.3% | 1.053 | | | 0.421 | 2.95 | 29.6 | 74.7 |
| | H-88.6% | 7.772 | | | 3.109 | 21.76 | 75.7 | 95.6 |
| Necrotizing STI[13] | L-4.2% | 0.044 | 0.13 | 13.2 | 0.006 | 0.58 | 0.6 | 36.6 |
| | M-64.3% | 1.801 | | | 0.228 | 23.71 | 18.6 | 96.0 |
| | H-96.6% | 28.412 | | | 3.593 | 374.02 | 78.2 | 99.7 |

DVT, deep venous thrombosis; H, high pre-test probability; L, low pre-test probability; M, medium pre-test probability; PE, pulmonary embolism; RV, right ventricle; STI, soft tissue infection.
For these 5 pathologies commonly evaluated with POCUS in the ED, the post-test probabilities vary significantly based on variable pre-test probability of disease.

can be substantially altered by an abnormal scan, or, conversely, may help a clinician recognize situations where a false negative scan is likely. Clinical integration of POCUS findings in patient care may drastically differ based on the pre-test probability.

Multiple strategies exist to aid in estimating pre-test probability such as clinical decision rules and clinician gestalt. Although in some cases pre-test probability may be a precise value, it is more common to encounter tiers of pre-test probability; "low risk" that often needs no further imaging, "moderate risk" that typically reaches a test threshold and warrants further imaging prior to treatment, and "high risk" condition that may reach a treatment threshold without a need for further imaging. For example, a patient presenting with progressive dyspnea on exertion and bilateral leg swelling would likely be considered to have moderate risk of venous thromboembolism. In this case, the clinician may perform cardiac and lung POCUS to confirm a suspicion for cardiogenic pulmonary edema before initiating medical treatment. In the case of flash pulmonary edema, where a patient presents with acute, severe respiratory distress, a clinician may likely initiate bi-level positive airway pressure and nitroglycerin prior to performing the same POCUS study as the pre-test diagnosis is more certain in this high-risk case. In tiers of risk, it is also important to consider the "no risk" patient. This is the patient in whom the clinician believes there to be no risk of disease; in this case, the harms of POCUS outweigh benefits, and the scan should not be performed. Table 1 highlights the important impact of pre-test probability on POCUS examination results and post-test probabilities for common ultrasound applications in the emergency department (ED).[8–11,13,14]

## 4.1 | Pre-test probability and the risk of cognitive biases in POCUS

POCUS is construed as a focused ultrasound examination to interrogate a specific clinical question with a predicted result. This practice can lead to confirmation bias. For example, if a 60-year-old male without history of nephrolithiasis presents with flank pain and hematuria, a clinician may suspect nephrolithiasis and perform a renal POCUS. However, given that new-onset nephrolithiasis in the elderly is uncommon, the clinician should consider aortic pathology as first on the differential. As both aortic aneurysms and kidney stones can cause hydronephrosis, the renal ultrasound should only be performed after a negative aorta POCUS. Performance of the renal ultrasound first may cause the clinician to erroneously anchor on the presence of hydronephrosis, without first considering life-threatening aortic pathology. As in this case, renal POCUS used in the wrong patient is potentially dangerous. POCUS stewardship takes into account the right patient and the pre-test probability given the clinical context, a concept that should direct the clinician toward alternative high yield diagnoses.

Diagnosis bias is another common error when performing POCUS. If a 40-year-old female with known cholelithiasis presents with upper abdominal pain and fever, a clinician may be more likely to identify the presence of gallbladder pathology on POCUS. However, it is possible that this patient only has cholelithiasis and is actually also experiencing a right lower lung pneumonia causing her acute symptoms. Because POCUS is often performed by the clinicians who initially evaluate the patient, final interpretation of any POCUS examination results can be both greatly informed and plagued by the pre-test probability.

## 5 | POCUS DIAGNOSTIC ACCURACY

Prior to performing a POCUS examination, a clinician sonographer must ask themselves "If a patient has a positive POCUS finding, how sure can we be that this patient has the disease?" and, conversely, "If we have a negative test finding, how sure can we be that this patient does not have the disease?" Similar to virtually all other imaging modalities, POCUS examinations have the potential for false–negative and false–positive results, thus appropriate application of POCUS results relies heavily on knowledge of test performance. Each POCUS scan has a unique set of test characteristics that are identified in the literature through evidence-based interrogation.[8–11,13,14] Working knowledge of these test characteristics are crucial to practicing responsible POCUS stewardship.

### 5.1 | Sensitivity and specificity in POCUS

The sensitivity of a test is its ability to identify true disease (the percentage of truly diseased individuals who test positive). The specificity of a test is its ability to identify true health (the percentage of healthy individuals who test negative). These statistics are characteristics of the test itself and are not influenced by disease prevalence.

Predictive values (ie, positive predictive value and negative predictive value) are probabilities that a test result actually represents a true result in regard to the presence of disease. In POCUS, positive predictive value represents the proportion of POCUS-positive patients that actually have the suggested disease, and negative predictive value is the proportion of POCUS-negative patients that do not have the disease. Unlike sensitivity and specificity, predictive values depend on prevalence of disease within the study population; they cannot be applied outside the context of a defined patient group. As such, the rate of false–positives and negative predictive value of a test increases with increasing rarity of disease regardless of a high sensitivity of POCUS. A test with a high positive predictive value is helpful for ruling in a disease, whereas tests with a high negative predictive value are helpful in ruling out disease. Often, application of POCUS will fail to adequately target the intended population, thus limiting the generalizability of the findings. For instance, in using POCUS for evaluation of pulmonary embolism, positive predictive value and negative predictive value obtained in the all-comer ED setting will differ greatly from intensive care unit setting, where the prevalence of pulmonary embolism may be much higher.

### 5.2 | Likelihood ratio in POCUS

Likelihood ratios (LR) speak to the influence of a particular test in question on the likelihood of disease. This test characteristic is used to determine if a chosen test result may be helpful in identifying the presence of a particular disease. LR are specific to a disease and chosen test, thus, unlike predictive values, are independent of disease prevalence. A LR answers the question "Given a particular test result, what is the likelihood of the patient having the particular disease in question"? A positive likelihood ratio (LR+) is equal to a tests sensitivity/(1-specificity), whereas a negative likelihood ratio (LR–) is equal to a tests (1-sensitivity)/specificity. A likelihood ratio of 1 suggests a test has no role in diagnosing a particular disease. Generally speaking, a positive likelihood ratio $>10$ or, conversely, a negative likelihood ratio $<0.1$ are considered helpful starting points for a clinically useful test.

In the case of POCUS, appropriate application of likelihood ratios would prompt a physician to ask, "Will the results of a POCUS for deep venous thrombosis change the probability that my patient has a deep venous thrombosis?". Examining Table 1, in contrast to POCUS for deep venous thrombosis that has a positive likelihood ratio of 30 and a negative likelihood ratio of 0.04, POCUS for kidney stone has a positive likelihood ratio of 2.8 and negative likelihood ratio of 0.4 suggesting that although POCUS results for deep venous thrombosis drastically alters post-test probabilities and odds and should subsequently alter clinical work up and treatment, POCUS for kidney stones perhaps should not receive as much weight, because it will not alter post-test probabilities or odds as significantly.

## 6 | POCUS AND THE SPECTRUM OF DISEASE: DISEASE CHARACTERISTICS

For many POCUS applications, there exists a continuum of findings varying from clear absence to clear presence of disease. An example of this would be the presence of a trace amount of intra-abdominal free fluid versus massive free fluid in patients with blunt abdominal trauma. In theory, neither sensitivity nor specificity of a POCUS scan should be affected by the severity of the presentation, although in practice, this is not the case. The spectrum of disease illustrates the variation in POCUS accuracy given disease severity at the time of assessment. This concept explains why multiple studies evaluating sensitivity and specificity of a given scan may demonstrate different results depending on the ease of detecting the positive finding in the population studied. These varying results are due, in part, to differences in disease severity at the time of presentation. For many pathologies, POCUS is demonstrably less reliable in detecting early stages of the disease but improves in accuracy with increased severity and more advanced pathology. Of note, although difference in operator skill can certainly also impact the reliability of POCUS findings, particularly in subtle or early disease presentations, this is an unrelated concept when compared to variations in the spectrum of disease.

If the spectrum of sonographic features within the group of patients with disease is narrow, the sensitivity of POCUS should vary minimally over time or between patients, assuming all other technical and interpretive factors remain constant. On the other hand, if the range of sonographic features is very broad (as in the case of trace vs large amount of intra-abdominal free fluid, for example), one can predict that the test will perform differently in different subgroups of patients who technically have the same disease but with variable presentations. This probably explains the higher sensitivity of POCUS in patients with appendicitis with prolonged symptoms compared to the cases of early appendicitis. In cases with prolonged duration of symptoms, there is more time to develop identifiable POCUS findings for appendicitis.[12] This trend has also been reported in other applications such as in the extended focused assessment with sonography in trauma in which sensitivity of the scan progressively increases as the time from the onset of injury increases. In theory, with a more prolonged onset of injury a greater volume of hemoperitoneum is accumulated thus allowing for easier detection by POCUS.[15]

## 7 | IMPLICATIONS FOR CARE

Integrating POCUS stewardship principles into clinical practice and existing workflow is feasible but must be accomplished in an intentional and thoughtful manner. To ensure that POCUS is used safely and effectively across the broad spectrum of clinical practices, we suggest careful adherence to POCUS stewardship elements, which include proper patient selection and clinical indication, consideration of pre-test probability, consideration of the spectrum of disease, and consideration of the accuracy of the test for the given clinical question.

Determining pre-test probability is a concept often taught in the context of developing differential diagnoses and can easily be repurposed when considering POCUS. The importance of proper education concerning the pre-test probabilities in POCUS must not only be taught, but the data must also be as accessible to assure proper stewardship. We suggest the development of an all-inclusive encyclopedia of POCUS test characteristics, which is backed by medical literature and easily accessible during a busy clinical shift. This can empower the clinician to continue developing and experimenting with his POCUS practice while ideally curbing non-specific and potentially inappropriate use.

The ability of the clinician to interpret POCUS results in real time and immediately incorporate results into medical decisionmaking to guide further diagnostics or therapies is unparalleled as far as time and resource utilization. With this approach, proper care is necessary to discern when clinical workup warrants alternative diagnostics, does not warrant imaging at all, or perhaps warrants repeat imaging. Provocative examples of this exist throughout clinical medicine.

With proper POCUS stewardship, further downstream effects include reductions in advanced radiology, ionizing radiation, and ED length of stay. There are a handful of meaningful examples in the literature of the potential impact of properly applied and integrated POCUS. Wilson et al[16] demonstrated that ED-performed first trimester POCUS decreases ED length of stay by 120 minutes in comparison to radiology-performed pelvic ultrasound. Boniface et al[17] demonstrated that ED-performed POCUS for suspected small bowel obstruction has also shown a significant ability to reduce time to diagnosis by 211 minutes compared to computed tomography (CT) while maintaining a sensitivity of 88% for small bowel obstruction.

There exists evidence supporting the idea that POCUS has the potential to decrease cumulative radiation doses. Smith-Bindman et al[18] randomized patients with suspected renal colic to initial imaging modalities of POCUS, radiology ultrasound, or CT imaging and showed a reduction in cumulative 6-month ionizing radiation exposure without significant differences in high-risk diagnoses, complications, or return ED visits in the groups randomized to ultrasound. This study outlines a radiation-saving benefit of POCUS, something that has huge implications for patient safety and healthcare costs.

In conclusion, POCUS stewardship is a concept designed to enhance the power of POCUS as a clinical reasoning tool by encouraging appropriate selection of patients, consideration of pre-test probabilities, the spectrum of disease, and the expected accuracy of the exam. POCUS stewardship is developed to assist clinicians on optimal use of the test, to reduce unnecessary workup, and improve patient care. Given the ubiquity of POCUS, gaining mastery of POCUS must extend beyond image acquisition and interpretation, rather incorporating the concepts discussed here represents the most responsible level of proficiency for this valuable clinical tool.

### CONFLICT OF INTEREST

The authors have no conflict of interest to disclose.

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