Critical Care Ultrasound: A Review for Practicing Nephrologists

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The use of point-of-care ultrasound in the intensive care unit, both for diagnostic and procedural purposes, has rapidly proliferated, and evidence supporting its use is growing. Conceptually, critical care ultrasound (CCUS) should be considered an extension of the physical examination and should not be considered a replacement for formal echocardiography or radiology-performed ultrasound. Several CCUS applications are of particular relevance to nephrologists, including focused renal ultrasound in patients at high risk for urinary tract obstruction, real-time ultrasound guidance and verification during the placement of central venous catheters, and ultrasound-augmented assessment of shock and volume status. Each of these applications has the capacity to improve outcomes in patients with acute kidney injury. Although robust evidence regarding long-term outcomes is lacking, existing data demonstrate that CCUS has the potential to improve diagnostic accuracy, expedite appropriate management, and increase safety for critically ill patients across a spectrum of pathologies.

Key Words: Ultrasound, Critical care, Central venous catheter, Shock

INTRODUCTION

Point-of-care ultrasonography has become a standard tool in the evaluation and management of critically ill and injured patients, and its use by intensivists has expanded dramatically over the past decade. The Accreditation Council for Graduate Medical Education now requires formal training in bedside ultrasound for all critical care fellows, and the most recent Surviving Sepsis Campaign guidelines identify bedside cardiovzascular ultrasound as one of several tools recommended for the reassessment of patients with septic shock.[1,2]

The definition of critical care ultrasound (CCUS) has evolved as its use has expanded, but CCUS has always been intended to answer focused questions, such as "is there free fluid in the abdomen?" or "is there evidence of left ventricular dysfunction?" rather than to provide the kind of comprehensive assessment offered by formal ultrasonography and echocardiography. As such, CCUS should be viewed as a tool to supplement or extend the intensivist's physical examination and improve the safety of critical care procedures, rather than as a replacement for formal imaging studies. With an appropriate understanding of its limitations, CCUS can meaningfully expedite and improve the diagnosis of the underlying cause of organ dysfunction in the critically ill, especially when comprehensive imaging studies are not rapidly available.[3]

Several CCUS applications have particular relevance for nephrologists caring for critically ill patients, including focused renal ultrasound in patients at high risk of urinary obstruction or with acute kidney injury (AKI) of unclear etiology, ultrasound guidance for obtaining vascular access for temporary hemodialysis (HD) catheters, ultrasound-augmented evaluation of patients with undifferentiated shock, and focused cardiovascular and thoracic ultrasound in the assessment of volume status and fluid responsiveness. This review will describe the techniques, limitations, and evidence supporting each of these applications in the intensive care setting.

FOCUSED RENAL ULTRASOUND IN CRITICALLY ILL PATIENTS WITH ACUTE KIDNEY INJURY

Focused renal ultrasound involves imaging both kidneys and the bladder in 2 planes to assess for the presence of urinary tract obstruction. If hydronephrosis is identified, its severity is described in qualitative terms (mild, moderate, or severe). Although cortical echogenicity and decreased size may be incidentally identified and raise suspicion for CKD, this is not the purpose of the study, and focused renal ultrasound in the critical care setting should not replace formal renal ultrasound when indicated in the evaluation of CKD.

As AKI is common among critically ill patients, it is important to define the circumstances that should prompt the bedside clinician to consider focused renal ultrasound. In fact, current evidence suggests that the utility is quite limited. Multiple prior studies have reported very low rates of hydronephrosis (and even lower rates of hydronephrosis requiring intervention) among patients with AKI who lack risk factors for urinary tract obstruction.[4,5] Thus, although rapid, noninvasive, and relatively low-cost, focused renal ultrasound in the evaluation on AKI is most likely to be helpful only in patients with clear risk factors for urinary tract obstruction (such as prior hydronephrosis, recurrent urinary tract infections, or a diagnosis consistent with urinary tract obstruction such as abdominal cancer), or who lack another clear cause of

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AKI.[6] As discussed previously, focused renal ultrasound should also not replace formal renal ultrasound when clinically indicated, or when results are equivocal or identify incidental findings suggestive of CKD.

ULTRASOUND GUIDANCE FOR CENTRAL VENOUS CATHETER PLACEMENT

Numerous randomized clinical trials and meta-analyses have demonstrated the superiority of ultrasound-guided central venous catheter (CVC) placement over landmark techniques.[7] Although static imaging has been shown to be beneficial, real-time ultrasound guidance is preferred and has been recommended by the US Agency for Health Care Research and Quality since 2001.[8,9] The strongest evidence in support of real-time ultrasound guidance is for CVC placement in the internal jugular vein, although randomized trials have demonstrated superiority in femoral and subclavian vein placement as well.[10,11]

Despite the advantages of real-time ultrasound guidance, complications such as inadvertent arterial puncture and cannulation are known to occur.[12] Although in rare cases, this may be due to simple misidentification of the target vessel (eg, mistaking carotid artery for vein), most commonly arterial injury occurs due to uncertainty or misunderstanding of the exact location of the needle tip at the time that blood is aspirated, or due to inadvertent movement of the needle tip after initial aspiration.[13]

Several techniques have been advocated to reduce the risk of complication during CVC placement, even when real-time ultrasound guidance is used. First, several studies have examined whether a long-axis (longitudinal) view of the target vein is superior to the short-axis (transverse) view that is typically used and better studied. Although imaging in the short-axis allows simultaneous visualization of the target vein and helps avoid surrounding structures, the long-axis view may more reliably image the tip of the needle, thereby minimizing the risk of "past-pointing" and posterior vessel wall puncture.[14] Indeed, 1 prospective observational trial in life-like mannequins revealed that practitioners using the short-axis technique punctured the posterior vessel wall in the majority of cases.[15] Keeping the target vein and needle in the long-axis view during cannulation, however, may be technically more difficult, and novice practitioners may either inadvertently image the artery in long-axis or not be able to keep the needle in-plane with the ultrasound transducer. Two randomized clinical trials both demonstrated better success rates using short-axis rather than long-axis imaging.[16,17] In addition, 2 randomized trials using tissue-phantom simulators again demonstrated superior success with short-axis imaging but improved needle tip visualization using the long-axis technique.[18,19] Based on these data, current recommendations support the use of short-axis technique, although we feel use of the long-axis technique may be beneficial in certain situations (eg, to confirm needle tip location when the needle tip appears to be in the vein in the short-axis view, but no blood is aspirated into the syringe).[14]

CLINICAL SUMMARY

- Critical care ultrasound can meaningfully expedite and improve the diagnosis of the underlying cause of organ dysfunction in the critically ill.
- Critical care ultrasound is not a replacement for formal imaging studies.
- Critical care ultrasound applications that may be of particular relevance to the nephrologist include renal ultrasound in patients at high risk for urinary tract obstruction, real-time ultrasound guidance and verification during the placement of central venous catheters, and ultrasound-augmented assessment of shock and volume status.

The long-axis view may also be used to confirm wire placement within the target vein before dilation and cannulation (see Fig. 1). Prospective observational studies have demonstrated that ultrasound reliably detects guidewire placement and may help reduce the risk of inadvertent arterial cannulation.[20,21] For this reason, ultrasound is one of the techniques recommended by the American Society of Anesthesiology for confirming venous residence of the wire when there is any uncertainty about wire location.[7]

Finally, when a complication is suspected after CVC attempt or insertion, bedside ultrasound can be of immediate use in evaluating for the presence of hemothorax or pneumothorax, or for querying the location of the CVC.[22,23] As with other CCUS applications, however, the use of bedside ultrasound should not necessarily replace other techniques for preventing or evaluating for complications such as CVC placement, such as fluid columns and pressure-wave transduction.

In summary, real-time ultrasound guidance is recommended whenever feasible during CVC placement. In addition, to further reduce the risk of complications, practitioners should be aware of long-axis vessel imaging to assess needle tip location during difficult cannulations and confirm wire placement within the target vein before dilation. These techniques have particular

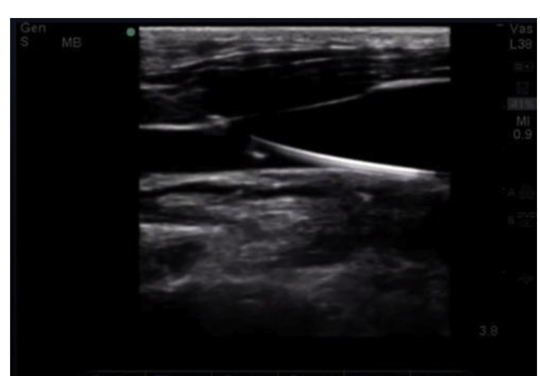

Figure 1. Long-axis view of central venous catheter guidewire traversing the soft tissue, entering the lumen of the target vein, and laying along the back wall of the vessel.