NARRATIVE REVIEW ARTICLE

Role of Point-of-Care Ultrasound in Emergency Airway Management Outside the Operating Room

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Tracheal intubation is one of the most frequently performed procedures in critically ill patients, and is associated with significant morbidity and mortality. Hemodynamic instability and cardiovascular collapse are common complications associated with the procedure, and are likely in patients with a physiologically difficult airway. Bedside point-of-care ultrasound (POCUS) can help identify patients with high risk of cardiovascular collapse, provide opportunity for hemodynamic and respiratory optimization, and help tailor airway management plans to meet individual patient needs. This review discusses the role of POCUS in emergency airway management, provides an algorithm to facilitate its incorporation into existing practice, and provides a framework for future studies. (Anesth Analg 2023;XXX:00–00)

GLOSSARY

AAA = abdominal aortic aneurysm; **ACLS** = advanced cardiac life support; **ACSA** = antral cross-sectional area; **Ao** = aorta; **ARDS** = acute respiratory distress syndrome; **ASA** = American Society of Anesthesiologists; **BiA** = biatrial; **BiV** = biventricular; **BLUE** = bedside lung ultrasound in emergency; **CL** = Cormack-Lehane; **CO_2** = carbon dioxide; **CPP** = cerebral perfusion pressure; **CTEPH** = chronic thromboembolic pulmonary hypertension; **CTM** = cricothyroid membrane; **CVP** = central venous pressure; **DL** = direct laryngoscopy; **Dsc Ao** = descending aorta; **DVT** = deep vein thrombosis; **EASy** = echocardiographic assessment using subxiphoid-only view; **EASy-ALS** = Echocardiographic Assessment Using Subxiphoid-Only View-advanced life support; **ECG** = electrocardiogram; **eFAST** = extended focused assessment of sonography for trauma; **ETT** = endotracheal tube; **FAST** = Focused Assessment of Sonography for Trauma; **FLUVA** = FLUid Bolus or a Low Dose VAsopressor Infusion on Cardiovascular Collapse Among Critically Ill Adults Undergoing Tracheal Intubation; **FRC** = functional residual capacity; **FTTE** = focused transthoracic echocardiography; **GERD** = gastroesophageal reflux disease; **ICP** = intracranial pressure; **ICU** = intensive care unit; **INTUBE** = International Observational Study To Understand the Impact and Best Practices of Airway Management in Critically Ill Patients; **IVC** = inferior vena cava; **IVF** = intravenous fluid; **IVS** = interventricular septum; **LA** = left atrium; **LUS** = lung ultrasound; **LV** = left ventricle; **LVH** = left ventricular hypertrophy; **NE** = norepinephrine; **NIV** = noninvasive ventilation; **NO** = nitric oxide; **NPO** = nil-per-os; **OR** = operating room; **PcE** = pericardial effusion; **PDA** = physiologically difficult airway; **PlE** = pleural effusion; **PLR** = passive leg raising; **POCUS** = point-of-care ultrasonography; **PPV** = positive-pressure ventilation; **PrePARE** = effect of a fluid bolus on cardiovascular collapse among critically ill adults undergoing tracheal intubation; **PREPARE II** = Preventing Cardiovascular Collapse With Administration of Fluid Resuscitation During Induction and Intubation; **RA** = right atrium; **RR** = respiratory rate; **RSI** = rapid sequence intubation; **RUSH** = rapid ultrasound in shock; **RV** = right ventricle; **SCCM** = Society of Critical Care Medicine; **TAPSE** = tricuspid annular plane systolic excursion; **TI** = tracheal intubation; **TV** = tidal volume; **WHO** = World Health Organization

Emergency airway management outside the operating room (OR) is associated with a high rate of cardiopulmonary complications, morbidity, and mortality. Most patients undergoing such procedures have minimal physiological reserves and are likely to develop cardiovascular collapse during or after the procedure. Furthermore, the lack of diagnostic information for patients in extremis predisposes them to increased risk of complications and poor outcomes during intubation and initiation of positive-pressure ventilation (PPV) due to the attendant alterations in physiology. The International Observational Study to

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Understand the Impact and Best Practices of Airway Management in Critically Ill Patients (INTUBE) evaluated 2964 critically ill patients undergoing tracheal intubation (TI) across 29 countries. It found that cardiovascular instability during intubation occurred in 42.6% of patients, severe hypoxemia in 9.3%, and cardiac arrest in 3.1%.[1] Moreover, patients experiencing peri-intubation hemodynamic instability were also at a higher risk of 28-day mortality. Similarly, in a recent randomized controlled trial evaluating the impact of fluid bolus administration on peri-intubation hemodynamics, cardiovascular collapse was observed in about 20% of patients.[2] This highlights the importance of hemodynamic optimization to improve outcomes during this high-risk procedure. It is incumbent upon the operator to assess the patients' physiologic status quickly but thoroughly and not only implement steps to best optimize patients for intubation, but also tailor their plans to each individual patient.

Point-of-care ultrasonography (POCUS) is defined as the acquisition, interpretation, and immediate clinical integration of ultrasonographic imaging performed by a treating clinician at the patient's bedside. It has shown promising results in identifying causes of respiratory and circulatory failure.[3,4] POCUS improves the likelihood of early diagnosis in patients with cardiorespiratory pathology, decreases the time to administration of treatment, and may improve survival of patients on the wards who develop acute respiratory or circulatory failure.[5–8] Similarly, handheld POCUS has shown promise as an airway management tool to screen for anatomic difficulty, to identify the cricothyroid membrane (CTM) for potential cricothyroidotomy, and to provide confirmation of proper endotracheal tube positioning.[9] The purpose of this article is to review the use of POCUS to identify patients at risk of decompensation with airway management and describe its role in optimizing patients with physiologic impairments to better withstand the procedure. We also provide an algorithmic approach to help clinicians integrate this promising technology into the management of patients with a physiologically difficult airway (PDA), while discussing future research ideas.

Physiologically Difficult Airway

A PDA is anticipated when a patient's physiologic perturbations predispose the patient to cardiorespiratory collapse and other complications during TI and conversion to PPV.[10,11] The combination of sympatholysis due to induction drugs, decrease in preload due to conversion from negative pressure ventilation to PPV, and the amelioration of the hypoxia- and hypercarbia-associated sympathetic drive all predispose these at-risk patients to hemodynamic collapse with intubation. Patients with preexisting hypoxemia or shock are even more likely to experience such complications during TI, including desaturation, hypoxic brain injury, cardiac dysrhythmias, and cardiac arrest.[12,13] The Table lists some of the common causes of a PDA.

Hemodynamic Optimization Before Emergency Airway Management

Several national and international guidelines as well as review articles provide guidance on airway management in critically ill patients.[14–17] Despite this comprehensive overview, there is minimal guidance on the preparation and optimization of the patient's

Table. Conditions Associated With a Physiologically Difficult Airway

Condition	Physiological alterations	Ultrasonographic findings
Hypoxia	Poor reserve Reduced FRC Ventilation/perfusion mismatch Shunt physiology	Elevated hemidiaphragm Loss of lung aeration: collapse/consoldation Effusions Pneumothorax
Hypotension	Vascular and cardiac effects of induction agents Initiation of positive-pressure ventilation Sudden removal of sympathetic stimulation (hypoxia/hypercarbia)	Decreased LV contractility, kissing ventricles RV dilation/dysfunction IVC collapsibility/plethora Pneumothorax/pericardial effusion
Severe metabolic acidosis	Bicarbonate buffering system overwhelmed Respiratory compensation plateaued	
Right ventricular failure		Reduced TAPSE
Full stomach/significant GERD	High risk of aspiration Supine position not well tolerated	Gastric ACSA >3.6 cm^2
Neurologic injury/raised ICP	Changes in blood oxygen and CO_2 levels affect ICP Hypotension decreases CPP Hypertension increases ICP	Enlarged optic nerve sheath diameter
Anterior mediastinal mass	Airway deviation Airway narrowing Inability to lie supine Airway collapse with induction	Airway deviation, narrowing, and lung collapse

Abbreviations: ACSA, antral cross-sectional area; CO_2, carbon dioxide; CPP, cerebral perfusion pressure; FRC, functional residual capacity; GERD, gastroesophageal reflux disease; ICP, intracranial pressure; IVC, inferior vena cava; LV, left ventricle; RV, right ventricle; TAPSE, tricuspid annular plane systolic excursion.

hemodynamics before and during the procedure.[18] Preintubation hypotension has been identified as a predictor for hemodynamic collapse in critically ill adults undergoing TI[19] and may be a modifiable target to improve outcomes. Subanalysis of the INTUBE study showed that peri-intubation cardiovascular collapse was associated with an increased risk of both intensive care unit (ICU) and 28-day mortality, and the choice of induction drugs had a major impact on outcomes.[20] Preemptive administration of a fluid bolus has shown mixed results. The PrePARE (Effect of a fluid bolus on cardiovascular collapse among critically ill adults undergoing TI) trial, a large, multicenter, randomized trial evaluating the administration of a crystalloid bolus before TI in critically ill adults, did not show a decrease in overall incidence of cardiovascular collapse with fluid administration. While minimal benefit was observed in patients who received PPV (bag-mask ventilation or noninvasive PPV) before TI, fluid loading was found to cause harm and lead to postintubation hypoxemia in nonvolume-responsive patients.[21] The more recent Preventing Cardiovascular Collapse With Administration of Fluid Resuscitation During Induction and Intubation (PREPARE II) trial, which selectively included patients receiving PPV during TI and randomized them to receive fluid bolus or not, showed no difference in the composite outcome of cardiovascular collapse with fluid administration.[2] On the other hand, the incorporation of an intubation bundle that included fluid loading before the procedure showed improved outcomes.[22] Mixed results from these large trials, and a trend toward lack of benefit with fluid bolus before TI, are likely due to the fact that one size does not fit all with regard to fluid administration and identifying suitable candidates by assessing fluid responsiveness is essential. Assessment of fluid responsiveness using POCUS before TI may help tailor fluid management before and during the procedure, and the impact of these interventions on outcomes needs empiric testing.

Push dose or infusion of vasoconstrictors and/or inotropes is another commonly used intervention to prevent peri-intubation hypotension.[22,23] While there is no clear evidence that this strategy works, the Effect of a FLUid Bolus or a Low Dose VAsopressor Infusion on Cardiovascular Collapse Among Critically Ill Adults Undergoing Tracheal Intubation (FLUVA trial NCT05318066) is currently underway to better delineate the role of fluid loading versus early use of low-dose vasopressors in decreasing the incidence of cardiovascular collapse during TI. The identification of patients most likely to benefit from these interventions is important, and personalized management guided by POCUS may help decide between fluid loading, vasopressor administration, ionotropic administration, or a combination. Current guidelines do not include recommendations regarding the use of POCUS for airway management in critically ill patients.[14] We believe that a benefit exists in evaluating the utility of a preintubation POCUS assessment as part of the intubation bundle, and that the role of this intervention in optimizing hemodynamics and avoiding complications needs further evaluation.

ROLE OF POCUS

Hypotension

Hypotension is frequently encountered in critically ill patients and is a major risk factor for a PDA. Commonly used induction drugs can further lower blood pressure and accentuate the challenges associated with TI in a hypotensive critically ill patient. As discussed above, PPV decreases preload and may be poorly tolerated in such patients. The Society for Airway Management recommends that patients with hypotension be screened for risk of hemodynamic collapse with intubation and, if possible, receive preemptive interventions before intubation.[18] POCUS is a quick and effective tool in these situations to help gather critical information rapidly and reliably and optimize patients before TI, while also guiding management strategies during TI. In a patient with acute-onset hypotension, the diagnosis of cardiac tamponade or hemothorax may be rapidly established using POCUS. Similarly, hypotension along with back pain may be indicative of an acute aortic dissection and can be detected using POCUS. The rapid ultrasound in shock (RUSH) protocol, which focuses on 3 main components, colloquially termed the pump, the tank, and the pipes, can be used to rapidly and reliably evaluate patients with hypotension during these situations.[24]

The "Pump". The assessment of the "pump" refers to determination of cardiac status. This utilizes the 4 basic views of bedside echocardiography (subxiphoid, parasternal long, parasternal short, and apical) to screen for pericardial effusion, decreased left ventricle (LV) contractility, and right ventricle (RV) dilation. The presence of any of these findings indicates a high risk of hemodynamic collapse on induction for TI.

Pericardial Effusion

The pericardial sac is visualized to look for pericardial effusion, which may be confused with a pleural effusion. A careful evaluation of the fluid in relationship to the descending aorta on the parasternal long-axis view can help differentiate between the 2. Pericardial fluid will be seen anterior to the descending aorta, while pleural fluid will be seen posterior to the descending aorta (Figure 1). If pericardial effusion is identified, the next step is to evaluate for signs

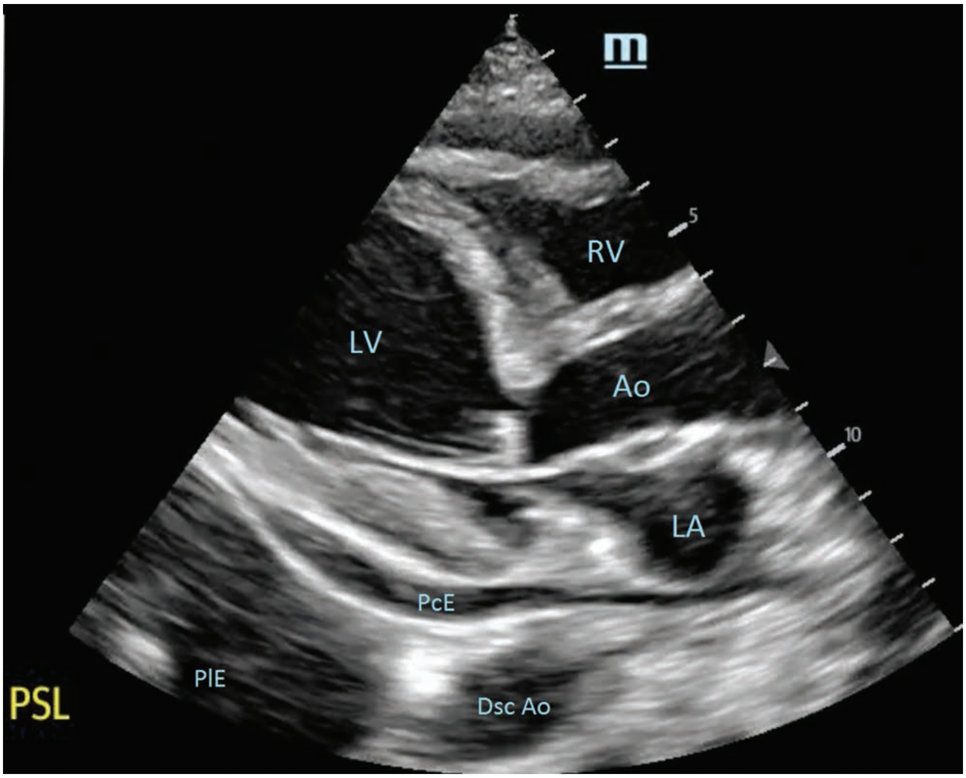

Figure 1. PIE and PcE visualized on the parasternal long-axis view. Ao indicates aorta; Dsc Ao, descending aorta; LA, left atrium; LV, left ventricle; PcE, pericardial effusion; PIE, pleural effusion; RV, right ventricle.

of tamponade. These could range from subtle inward serpentine deflection of the right atrial and/or the right ventricular wall to complete diastolic compression of either chamber (Supplemental Digital Content 1, Video 1, http://links.lww.com/AA/E189).[25] Other ultrasonographic signs, such as exaggerated interventricular interdependence, a plethoric inferior vena cava (IVC; >2 cm), right atrial collapse corresponding to the end of the T wave on electrocardiogram (ECG), and an inspiratory decrease in the mitral E wave velocity can also be observed.[26] In the presence of tamponade with unstable hemodynamics, emergent pericardiocentesis is recommended.[25] Pericardiocentesis should be strongly considered in patients requiring TI even with stable hemodynamics, as the physiological alterations of TI can induce profound hemodynamic instability. If performance of pericardiocentesis is not possible or if TI cannot be delayed, the induction of anesthesia for TI should be tailored to preserve hemodynamics in the presence of tamponade physiology.[27]

LV Contractility

Next, the LV is analyzed for global contractility. This assessment can guide the decision of fluid resuscitation versus inotropic support in hypotensive patients requiring TI. Visual evaluation of the volume change of the LV wall motion from diastole to systole is performed.[28] A poorly contracting ventricle will have minimal change in the movement of the walls between diastole and systole (Supplemental Digital Content 2, Video 2, http://links.lww.com/AA/E190), and will likely benefit from inotropic support before and during TI. Conversely, a hyperdynamic ventricle will demonstrate small chambers and vigorous, hyperkinetic contractions, which can indicate distributive shock or hypovolemic state. The ventricular walls may come together, termed "kissing ventricles," indicative of severe underfilling due to low preload. (Supplemental Digital Content 3, Video 3, http://links.lww.com/AA/E191). Patients with such echocardiographic findings will not respond well to inotropic drugs. Fluid administration and/or vasopressor support instead will help avoid hemodynamic collapse associated with TI.

RV Size and Dysfunction

The third goal-directed examination of the heart should focus on the evaluation of right ventricular strain, a potential sign of an increase in RV afterload. Conditions that increase pulmonary artery pressure will increase RV afterload, and pulmonary hypertension, whether diagnosed or not, is of critical importance during emergent intubation. Causes include pulmonary arterial hypertension (World Health Organization [WHO] group 1); any left heart dysfunction that increases left atrial pressure, such as aortic and mitral valve pathology as well as heart failure (reduced and preserved ejection fraction; WHO

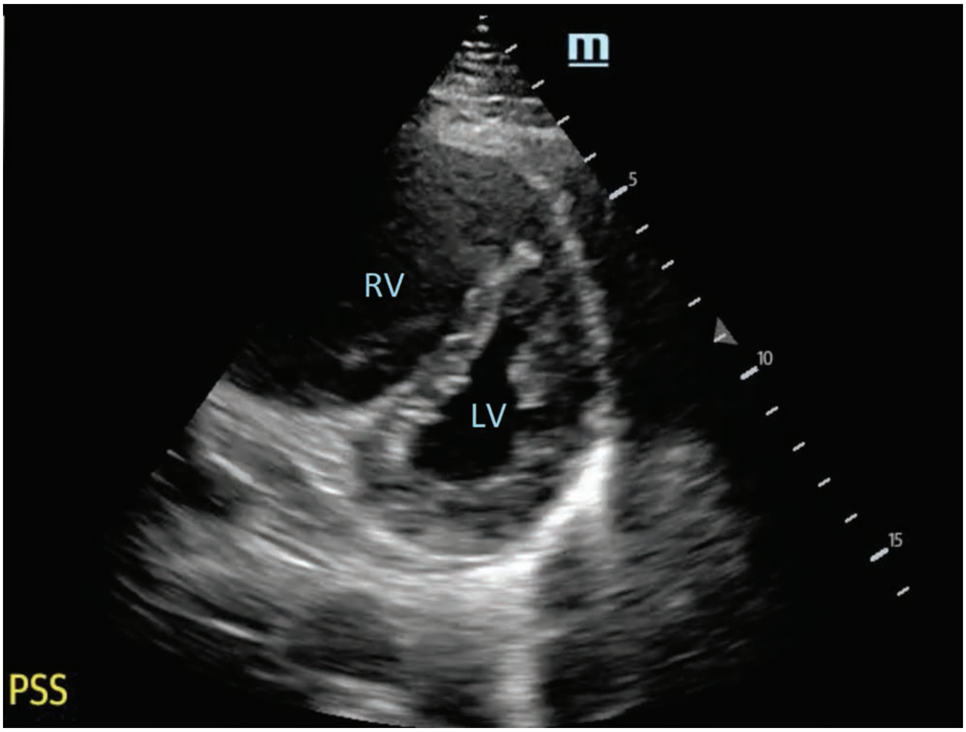

Figure 2. Parasternal short axis, midpapillary view showing a dilated RV. The RV is D-shaped ("D-sign") rather than the usual crescent-shaped. LV indicates left ventricle; RV, right ventricle.

group 2); hypoxia-associated lung disease (WHO group 3); and acute or chronic thromboembolic disease or chronic thromboembolic pulmonary hypertension (CTEPH; WHO group 4); as well as WHO group 5 pulmonary hypertension. The normal ratio of the size of the left-to-right ventricle is 1:0.6 on the apical view. Dilation of the RV, especially to a size greater than the LV, may be concerning for a large pulmonary embolus (Figure 2).[29,30] Similarly, the RV forming the apex of the heart, instead of the LV, indicates significant RV dilation and possible large pulmonary embolus (Supplemental Digital Content 1, Video 4, http://links.lww.com/AA/E192).[31] The tricuspid annular plane systolic excursion (TAPSE) correlates closely with RV function,[32] and could alert the proceduralist of possible cardiovascular collapse during or after the procedure. In hypotensive patients, with newly detected RV dilation/dysfunction on POCUS, a large pulmonary embolus should be considered, and the airway management team should be prepared to deal with acute RV dysfunction either during or after TI. Administration of inotropic agents such as epinephrine and vasoconstrictors with minimal effect of pulmonary vasculature such as vasopressin may help improve RV contractility. Similarly, inhaled pulmonary vasodilators such as prostaglandins and nitric oxide (NO) might prevent further increases in afterload during TI. The role of preemptive initiation of inotropes as well as pulmonary vasodilators before TI in patients with RV strain/dysfunction in preventing hemodynamic collapse needs further evaluation.

The "Tank". The "tank" refers to assessment of the intravascular volume status. Hypovolemia in a critically ill patient requiring TI may not be obvious because of the masking of clinical signs due to antecedent hypoxia- and hypercarbia-induced sympathetic hyperactivity. The IVC diameter is often used as a surrogate for central venous pressure (CVP) and volume status.[33] In spontaneously breathing patients, an IVC diameter <20 mm indicates a CVP <10 mm Hg, and an IVC diameter >20 mm with no respiratory variation often indicates an elevated CVP.[33] However, as with CVP, IVC diameter often fails to predict fluid responsiveness.[34] Respiratory variations in the IVC diameter can better predict fluid responsiveness, both in mechanically ventilated and in spontaneously breathing patients.[35,36] During spontaneous ventilation, the IVC collapses in inspiration, whereas during mechanical ventilation, the IVC collapses during expiration.[36] An IVC diameter <2.1 cm with >50% collapsibility with inspiration suggests fluid responsiveness, while an IVC diameter >2.1 cm with <50% collapsibility goes against the diagnosis of hypovolemia.[31,37] Before induction for TI, evaluation of the IVC may serve as a tool to determine whether the patient would benefit from a fluid bolus. However, IVC collapsibility may be operator dependent and varies in accuracy.[38,39] Hence, it may be used as an adjunct with other parameters that help assess fluid responsiveness such as passive leg raising (PLR) test and pulse pressure variation derived from an invasive arterial line waveform if available.

The evaluation of the tank also includes looking for sources of fluid extravasation either from active bleeding or from third-spacing, the latter of which can cause hypotension even in a state of volume overload.[40] The Focused Assessment of Sonography for Trauma (FAST) examination has been established as a valuable tool to quickly identify free fluid in the intraperitoneal spaces.[41] Ultrasound examination of the lungs, part of the extended FAST (eFAST) examination, can identify pleural effusions or pulmonary edema, indicating accumulation of fluid outside the intravascular space. Performing a preinduction eFAST examination can help strengthen the initial assessment of intravascular volume status and assist in the decision to give or withhold volume.

The "Pipes". The final component of the RUSH examination is assessment of the "pipes." This involves examination for vascular catastrophes of the arterial and the venous system, which may be life-threatening causes of hypotension and hemodynamic collapse during TI. Ruptured aortic aneurysms and aortic dissections can lead to cardiovascular collapse during TI. The abdominal aorta should be visualized along its entire course, especially the infrarenal portion, where most aneurysms are located. The rupture of an abdominal aortic aneurysm (AAA) typically occurs in the retroperitoneal space, which is an area difficult to visualize with ultrasound. A ruptured AAA should be part of the differential in a hemodynamically unstable patient with an AAA diagnosed by ultrasound. Unique considerations for TI in patients with AAA or aortic dissection include the need for strict heart rate and blood pressure control during TI to prevent aneurysm rupture or extension of the dissection and consequent hemodynamic instability.[42] Preemptive use of beta blockade with concurrent use of nonadrenergic vasopressors such as phenylephrine may be considered.

Hypoxemia

Acute hypoxemic respiratory failure is one of the most common indications for TI. Preexisting hypoxemia of all causes increases the risk of rapid hemoglobin desaturation during periods of apnea.[10] In these patients, TI may result in hemodynamic instability, hypoxic brain injury, and potentially cardiovascular collapse.[43,44] Identification of patients at risk for desaturation during TI and prolongation of the safe apnea time (time to desaturation) is critical. Optimal preoxygenation and denitrogenation are of utmost importance to reduce the risk of life-threatening complications during periods of apnea.[18] Time-permitting, bedside lung ultrasound (LUS), with its image artifacts (A-lines and B-lines) or direct images (lung consolidations and pleural effusions), can be integrated with clinical signs and symptoms before TI to better optimize the patient and prevent complications. Its use as a primary survey tool in the acutely dyspneic or hypoxemic patient can augment understanding of lung pathology and can influence therapeutic decisions.[6] In patients undergoing TI, LUS can help identify causes of acute hypoxemia such as pneumothorax, and indicate lung aeration, thus providing guidance on the appropriate means of preoxygenation depending on the severity of hypoxemia. Development of a targeted LUS protocol for time-constrained situations such as TI and its feasibility as well as impact on outcomes needs evaluation.

Meanwhile, the Bedside Lung Ultrasound in Emergency (BLUE) protocol, organized into profiles based on lung ultrasound signs,[45] can be applied for patients with hypoxia before TI. It provides a step-by-step diagnosis of the main causes of acute respiratory failure in acutely dyspneic patients.[46,47] Each profile is associated with lung pathologies. Anterior diffuse lung sliding with predominant A-lines makes the A-profile. The A-profile with lack of consolidation indicates nonparenchymal diseases (severe asthma and acute exacerbation of chronic obstructive pulmonary disease), and with lobar consolidation in dependent lung regions, it indicates pneumonia or acute respiratory distress syndrome (ARDS).[48] The presence of A-lines without lung sliding, lung pulse, and any B-lines (The A-profile) strongly suggests pneumothorax, confirmed by the presence of lung point with 100% specificity.[48–50] If the A-profile is associated with ultrasound-detected deep venous thrombosis (DVT) or echocardiography-detected RV strain, it strongly suggests pulmonary embolism.[51]

The B-profile is defined by anterior, bilateral, symmetrical B-lines (B-pattern) associated with lung sliding. The presence of B-pattern or lung rockets (3 B-lines within a rib space) bilaterally is indicative of interstitial edema and indicates cardiogenic pulmonary edema when homogeneous or ARDS when nonhomogeneous.[52] A unilateral B-pattern or B-pattern with lack of lung sliding (B-profile) suggests the presence of pneumonia. Finally, the C-profile indicates anterior lung consolidation, regardless of size and number, correlating with the diagnosis of pneumonia or ARDS.[45] The A/B profile is a half A-profile at one lung and a half B-profile at another. Along with the BLUE protocol, a scan of the posterior chest wall can be performed to identify posterior consolidations or pleural effusions.

Chest tube insertion should be considered before TI when pneumothorax is identified during the examination, as PPV during and after TI may lead to development of tension pneumothorax and hemodynamic collapse. Similarly, in patients with suspicion for cardiogenic pulmonary edema, findings should be collaborated with point-of-care echocardiography with a tailored induction for TI. LUS has also been used to assist in the diagnosis of ARDS with high sensitivity, specificity, and reproducibility.[53] The examination involves separating each lung into quadrants and assigning each quadrant a score from 0 to 3 based on the number of B-lines observed. A higher score correlates with more severe ARDS.[54] Patients with hypoxemia due to severe ARDS can have more rapid worsening of V/Q mismatch with the apnea encountered during TI. These patients respond to apnea with profound desaturation,[55] leading to an abrupt increase in pulmonary vascular resistance and exacerbation of right heart dysfunction, which may precipitate cardiac arrest.[56] Such patients may benefit from preoxygenation using noninvasive ventilation (NIV), with backup ventilation when the patient becomes apneic, which allows for improved alveolar recruitment and decrease in the shunt fraction.[10] Various preoxygenation techniques have shown mixed results in preventing desaturation during TI,[57] and LUS may be helpful in choosing an ideal preoxygenation technique based on each individual patient's physiologic alterations.

Aspiration Risk

Pulmonary aspiration of gastric contents is a leading complication and cause of death from TI.[58,59] Out-of-OR intubations are often performed as rapid sequence intubations (RSIs) to decrease aspiration risk due to unknown nil-per-os (NPO) status. POCUS can be used to evaluate gastric contents to mitigate aspiration risk. Austin et al[9] describe a simple method of estimating gastric volume by measuring the gastric antral cross-sectional area (ACSA) with the patient in a semiupright or reverse Trendelenburg position. The gastric ACSA is found by placing a curvilinear probe over the epigastrium in the parasagittal plane and measuring the anterior-posterior and cranio-caudal diameters of the smallest cross-sectional area visualized (Figure 3). The calculation is as follows:

$$ACSA = \frac{[(mean\ anterior - posterior\ diameter\ [mm]) * (mean\ craniocaudal\ diameter\ [mm]) * \pi]}{4}$$

Gastric ACSA >3.6 cm^2 correlates with a gastric volume of at least 0.8 mL/kg and is considered a high aspiration risk. This cutoff was determined in a single-center, prospective, cross-sectional study of 55 ICU patients using gastric volumes measured on abdominal CT as correlation.[60] This method for measuring gastric volume and contents is beneficial in such circumstances, as it can be performed quickly even in unstable patients and does not require the patient to maneuver into other positions. If a patient is indeed deemed high aspiration risk, precautions can be taken in addition to RSI. This includes elevating the head of the bed, placing a nasogastric tube for gastric decompression,[61] and using prophylactic antacids or H2 blockers.[62] If a patient has a known difficult anatomic airway as well as a high aspiration risk, an awake intubation in a controlled setting may be the best course of action.

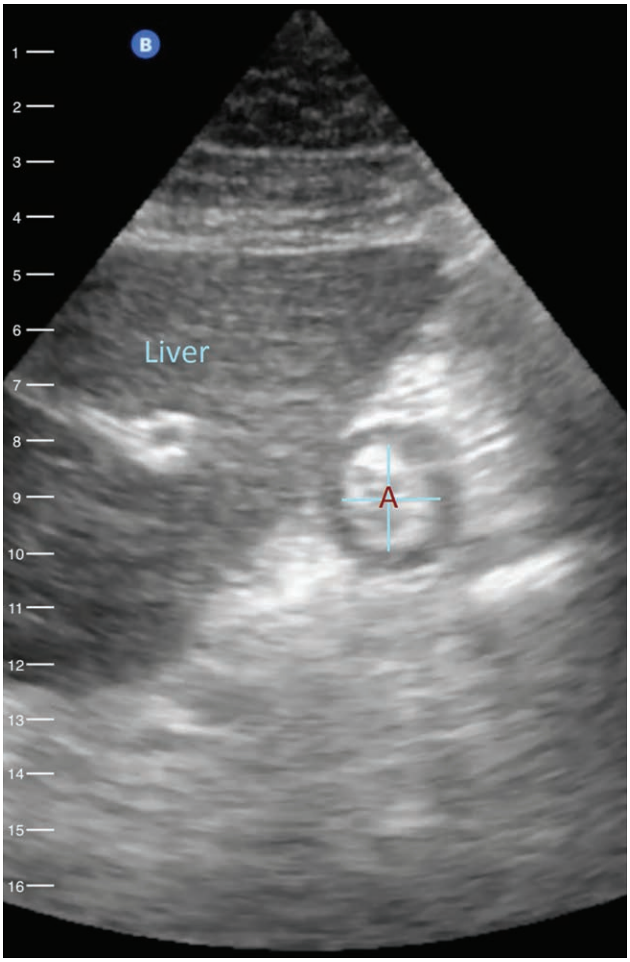

Figure 3. Gastric ultrasound demonstrating measurement of the antral cross-sectional area. A indicates antrum.

ECHOCARDIOGRAPHIC ASSESSMENT USING SUBXIPHOID-ONLY VIEW EXAMINATION

Depending on the presence, type, and degree of pulmonary disease, parasternal and apical views may be difficult to obtain. The subxiphoid window might be the only window readily available. From this view, the pericardium and all chambers of the heart are visible. Additionally, when rotating the probe 90° counterclockwise, the IVC comes to view. In a recently published case series, we demonstrated the feasibility of resident-performed echocardiographic assessment using subxiphoid-only view (EASy) examination during advanced life support (EASy-ALS).[63] Teaching

EASy-ALS simplifies the examination to train clinicians to evaluate patients with hemodynamic instability, increasing access to POCUS during critical events.

The EASy examination provides sufficient information in most patients to narrow the differential diagnosis of hemodynamic instability and respiratory failure and to determine intravascular volume status. This was recently evaluated by comparing EASy examination findings to focused transthoracic echocardiography (FTTE) findings from anesthesiology residents after standardized training. When reviewed by expert cardiologists and anesthesiologists, 80% of EASy examinations provided interpretable information with substantial agreement with FTTE. This included the presence of pericardial effusion, right ventricular contractility, and interventricular septal motion as surrogate for RV strain, and moderate to substantial agreement for assessing right ventricular size, left ventricular size, and left ventricular contractility.[64]

The main advantage of EASy over FTTE is the duration of training and time needed to examine the patient.[64,65] Recognizable phenotypes streamline training via visual patterns, which can be combined with pathology-specific interventions (Figure 4).[66] Major phenotypes are based on qualitative assessment of right and left ventricular size and function, IVC size and variability over respiratory cycle, and specific patterns of obstructive pathology. After training, clinicians can quickly recognize phenotypes associated with risk of hemodynamic collapse before TI due to either drug-induced vasodilation or myocardial depression and/or initiation of PPV. This recognition may ultimately lead to timely preemptive interventions. An unpublished case series presented at the Society of Critical Care Medicine (SCCM) annual congress in 2022 demonstrated the potential upside of EASy examination before TI in critically ill patients (Supplemental Digital Content 5, Video 5, http://links.lww.com/AA/E193).[65] The feasibility and usefulness of EASy examination before emergent TI need to be explored in a larger patient cohort.

OTHER USES OF POCUS DURING EMERGENCY AIRWAY MANAGEMENT

Screening for a Difficult Airway

The likelihood of an anatomically difficult airway in an emergent out-of-OR setting is high.[12,67,68] In the INTUBE study cohort, 46.8% of patients had at least one anatomical reason to anticipate a difficult airway.[1] Compared to the OR, the same patient may have a worse glottic view, lower first-time intubation success rate, and higher risk of complications in an out-of-OR setting.[69] While visual inspection of the patient's airway is a cornerstone of our practice to detect an anatomically difficult airway, the overall clinical value of these bedside airway examinations remains questionable.[70] Adequate time and patient cooperation for an airway examination may be limited in emergent out-of-OR airways. The use

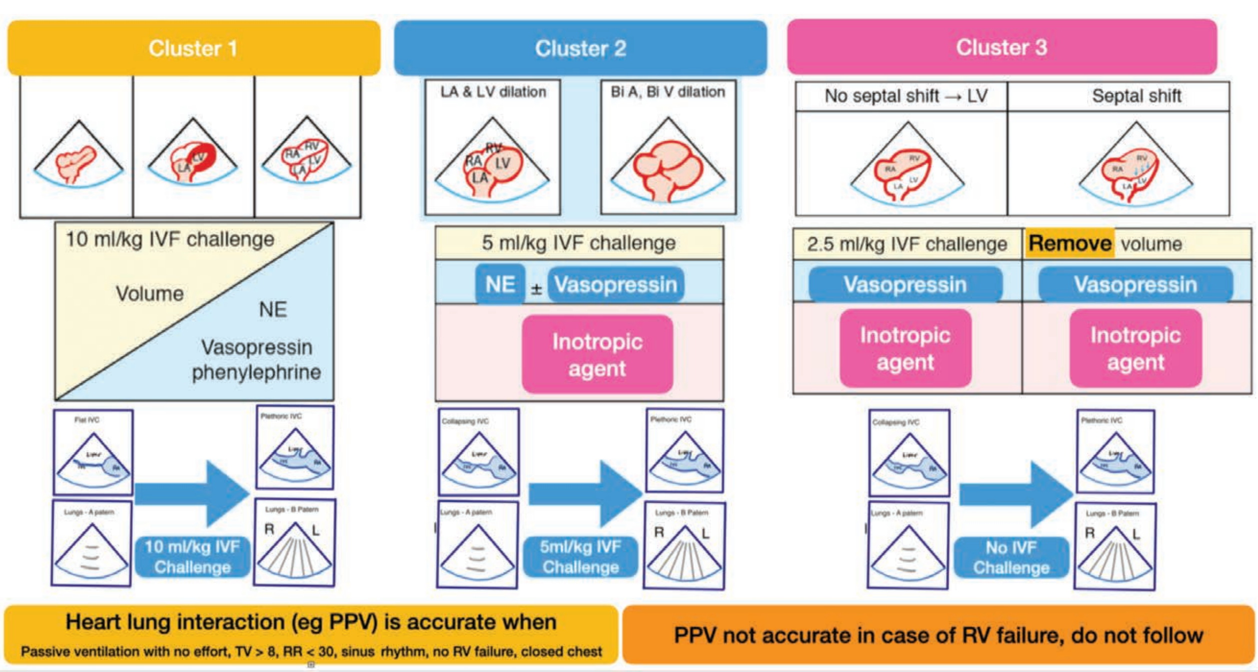

Figure 4. Echocardiographic assessment using subxiphoid-only phenotype-driven therapeutic management algorithms. BiA indicates biatrial; BiV, biventricular; IVC, inferior vena cava; IVF, intravenous fluid; IVS, interventricular septum; LA, left atrium; LV, left ventricle; LVH, left ventricular hypertrophy; NE, norepinephrine; PPV, pulse pressure variation; RA, right atrium; RR, respiratory rate; RV, right ventricle; TV, tidal volume.

of POCUS for airway assessment may help predict an anatomically difficult airway. Ultrasound visualization of the sublingual hyoid bone is associated with a favorable Cormack-Lehane (CL) grade 1 to 2 view.[71,72] There is a relationship between the hyomental distance on ultrasound examination and a challenging direct laryngoscopy (DL) view.[73] Recent evidence suggests that the ratio of preepiglottic space to epiglottic-vocal cord length, as assessed by ultrasound, may be a strong predictor of CL view.[73] Similarly, the distance between the skin and epiglottis on the anterior neck at the level of the thyrohyoid membrane can help identify patients with a higher CL grade.[74,75] A measured distance of ≥27.5 mm correlates with a CL view of 3 and 4 and may be associated with difficult laryngoscopy.[74] Of note, most studies utilizing POCUS for airway assessment involve patients undergoing elective surgery or otherwise healthy volunteers. Application of these measurements in critically ill patients is limited and requires further research.

Ultrasound can help identify the CTM, for performing an emergent invasive airway, should laryngoscopy fail. Although palpation has traditionally been used to identify the CTM, it is often unreliable, especially in urgent scenarios or in patients with less favorable anatomy.[76,77] Studies involving patients with altered neck anatomy have found ultrasound identification of the CTM to be more accurate than external palpation.[78,79] Identifying the CTM via ultrasound is relatively easy using either a transverse or longitudinal approach, and easy to learn with minimal training required.[9] POCUS-guided identification of the CTM is suggested in patients at high risk for difficult intubation before airway management.[79,80]

Confirming Endotracheal Tube Placement

The confirmation of proper tube placement after TI is important, as inadvertent esophageal intubation in these circumstances can lead to major complications, especially among critically ill patients with poor physiological reserve.[58,81] Although waveform capnography is the gold standard for confirming endotracheal tube (ETT) placement, confirmation of ETT placement can be especially challenging during conditions of low cardiac output, wherein the detection of end-tidal co_2 may be impaired.[82–84] In addition, waveform capnography is often unavailable in non-ICU out-of-OR locations.[1] The use of POCUS to confirm ETT position can be very useful in such situations. The 2015 American Heart Association Guidelines on Adult Advanced Cardiovascular Life Support include the use of ultrasound to verify ETT position by trained operators.[85] Proper ETT position can be confirmed using ultrasound by acquiring the tube dynamically during the procedure or statically immediately after the procedure.[86] With both forms of assessment, the ultrasound probe is placed transversely across the suprasternal notch. A successful TI yields a single air-filled structure with acoustic shadowing (Supplemental Digital Content 6, Video 6, http://links.lww.com/AA/E194), while an esophageal intubation produces 2 air-filled structures with acoustic shadowing (the "double tract sign").[87,88] POCUS evaluation can also be used to exclude inadvertent mainstem intubation by visualization of the ETT cuff balloon at the level of the sternal notch in a longitudinal view.[89] Proper positioning can also be confirmed by observing bilateral sliding of the visceral pleura against the parietal pleura during ventilation.[90] It is important to assess for bilateral lung sliding before the procedure, and in patients with preinduction bilateral lung sliding, the absence of lung sliding on one side after intubation should raise suspicion for endobronchial intubation. While the presence of bilateral lung sliding indicates aeration, the absence is nonspecific and is discussed extensively above.[91]

INTEGRATING POCUS INTO OUT-OF-OR EMERGENCY AIRWAY MANAGEMENT

We believe that it is important to integrate POCUS into the regular workflow of emergency out-of-OR airway management to heighten preparedness for a PDA. This integration requires adequate staffing and relies on a team-based approach. Ideally, one team member should have ultrasound proficiency and previous training in assessment techniques to perform a quick system-based assessment, while the rest of the team members gather history, assess vital signs and laboratory values, and set up the necessary airway equipment. There remains a possibility of misinterpretation of POCUS findings, and hence, it is important to integrate these findings with other clinical and laboratory/radiological data before decision-making. Establishing criteria for competency in POCUS before its integration in regular workflow is also important. Various professional societies, including the American Society of Anesthesiologists (ASA) and SCCM, have certification programs that have set criteria for competence in POCUS, which can be utilized for training and establishing proficiency. An airway team composed of an anesthesia-trained intensivist attending, ICU fellow, and anesthesia resident, wherein the fellow serves as the POCUS examiner, is one such example.[9] We propose the following algorithm using a system-based approach to patient assessment to augment patient safety when performing TI in patients who present with a PDA (Figure 5).

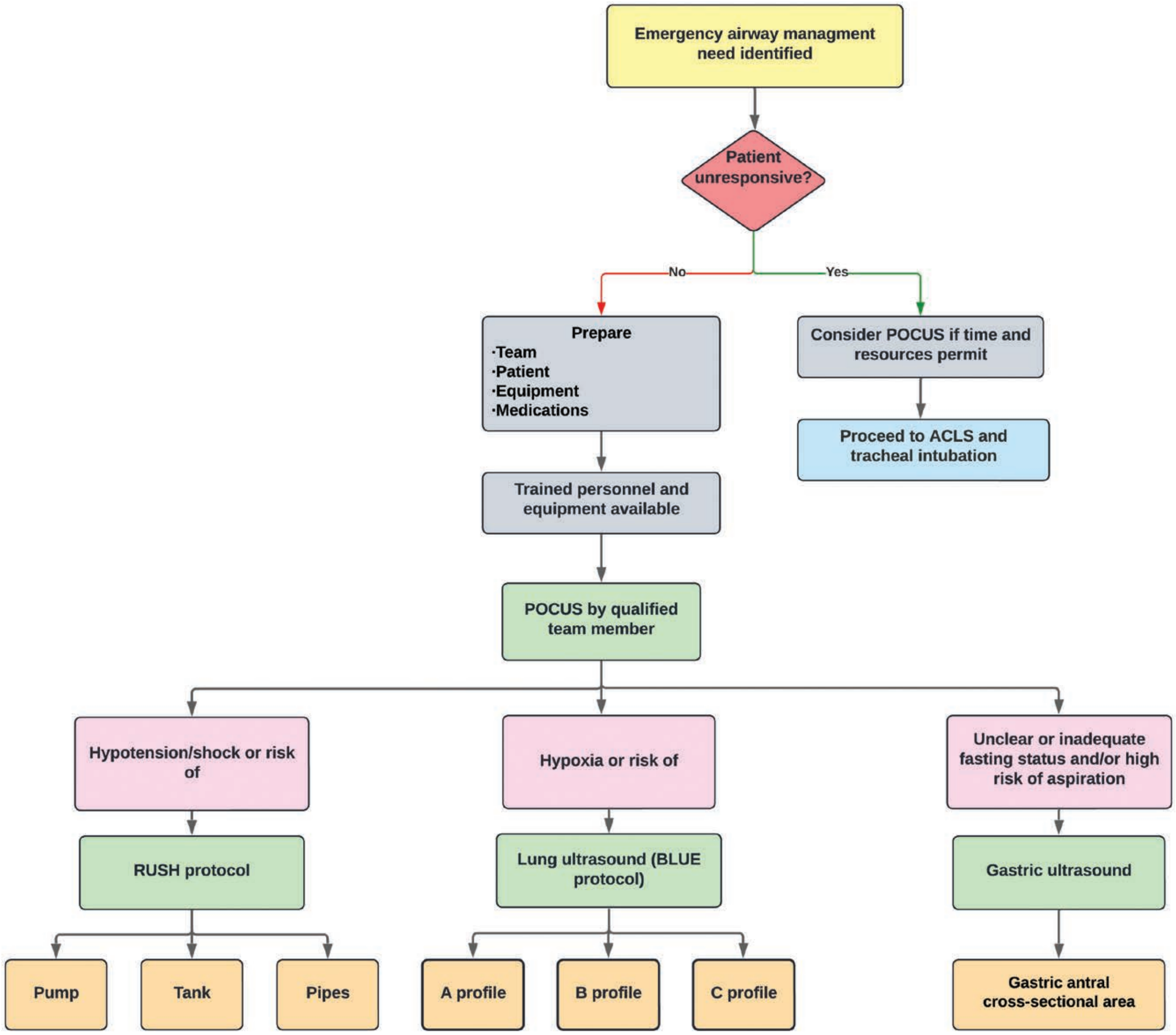

Figure 5. Our proposed algorithm for integrating POCUS in the workflow of managing a patient with a physiologically difficult airway. ACLS indicates advanced cardiac life support; BLUE, bedside lung ultrasound in emergency; POCUS, point-of-care ultrasound; RUSH, rapid ultrasound in shock.

FUTURE DIRECTIONS

The use of POCUS during emergency airway management shows promise in improving patient safety. Further research is needed to support the routine use of POCUS during emergency airway management in out-of-OR scenarios. Next steps include identifying which examinations are most helpful and clarifying the workflow and feasibility of a preintubation POCUS protocol. This will improve patient safety by optimizing high-risk patients to reduce the incidence of cardiovascular collapse, aspiration, anoxic injury, and death. The utility, proficiency, and training of a dedicated "POCUS examiner" as part of the airway team need to be examined.

Most studies exploring the use of POCUS have used traditional or cart-based ultrasonography machines, and there is limited evidence exploring the utility and efficacy of handheld ultrasound devices. Although the early generation handheld devices lagged the traditional ultrasound machines in image quality, newer devices are catching up. They provide several potential benefits, including lower cost, increased portability, and easier cleaning. Enhanced image quality on these devices and integration of machine-learning technology will improve image acquisition and interpretation. This may increase the use of handheld ultrasound during emergency airway management encounters. Despite the immense potential of POCUS to manage a PDA, caution should be exercised with adopting new technology that may increase cognitive workload and reduce efficiency in the acute setting. Integrating POCUS into the workflow to minimize the negative impact on team performance is essential and requires further study. Supplemental Digital Content 7, Table 1, http://links.lww.com/AA/E195 lists some of the research priorities for integrating POCUS into emergency airway management of critically ill patients.

CONCLUSIONS

There is emerging evidence suggesting a potential role of POCUS in preventing complications and improving the morbidity and mortality related to management of a PDA. This review summarizes the potential utility of POCUS to help optimize and manage patients with a PDA before and during emergent TI based on the existing literature. We believe that the use of our proposed algorithm will aid in patient safety. Finally, we highlight some of the knowledge gaps in this field that require future research.

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