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REVIEW

POCUS series: Assessment of shock using the rapid ultrasound in shock (RUSH) protocol

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Abstract

In the last docade ultrasound has found its place in the intensive care unit. Initially, ultrasound was used primarily to increase safety and efficacy of line insertions but now many intensivists use point-of-care ultrasound (POCUS) to aid in diagnosis, assessment of therapy and to guide therapeutic interventions. In this series we aim to highlight one specific POCUS technique at a time, which we believe will prove to be useful in clinical practice. Our aim is to provide the reader with a short and practical description of the technique as well as its merits and pitfalls. In this issue we describe the use of the rapid ultrasound in shock (RUSH) protocol to quickly investigate shock in the ICU.

Introduction

Point of care ultrasound (POCUS) is increasingly adopted in critical care settings. Initially, ultrasound was used primarily to increase safety and efficacy of line insertions, but now many intensivists use POCUS to aid in diagnosis, assessment of therapy and to guide therapeutic interventions. This article is part of the POCUS series in the Netherlands Journal of Critical Care, in which we aim to highlight POCUS techniques that will improve decision-making in daily clinical practice on the intensive care unit (ICU) and beyond, for example in the emergency room.[1-4] We aim to provide intensivists with an overview of easy, quick and reliable methods to improve the care of patients admitted to the ICU. In this issue we will focus on the use of the rapid ultrasound in shock (RUSH) protocol to diagnose the cause of shock in the ICU or emergency care setting. With a little experience you may be able to do this examination in under 10 minutes and you may gain a plethora of knowledge in this short time window.

Shock is one of the main reasons for unplanned ICU admissions and can be defined as a state of impaired tissue perfusion, which leads to cellular hypoxia resulting in metabolic derangements, cellular injury and end organ damage. Shock can be divided into four main pathophysiological subtypes: cardiogenic, obstructive, distributive and hypovolaemic, each needing different therapeutic interventions. In some cases, the subtype of shock is clear by taking the patient's medical history and physical examination. However, additional diagnostic tests are often necessary to make a diagnosis.

POCUS has become more and more routine in daily practice in the ICU. The RUSH protocol is a quick and easy ultrasound protocol that contributes to differentiating between the different types of shock and identifying the underlying cause.[5,6] The protocol consists of three components which are simplified as 'the pump', 'the tank' and 'the pipes', containing relatively easy to learn and quick to perform POCUS elements which we will discuss below.[5,6]

1. The pump

Examination of the heart is the first step of the RUSH protocol. For this a phased array probe is used. Quick examination of the

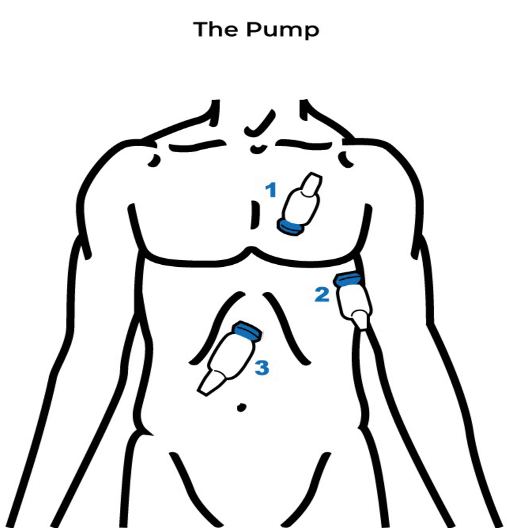

Figure 1. For examination of the pump, the phased array probe is used (blue). 1: parasternal long/short axis views; 2: apical view; 3: substernal view.

heart is performed by visualising four classical cardiac windows: the parasternal long and short axis, and the apical and substernal views *(figure 1)*. First focus is on signs of cardiac tamponade as a cause of obstructive shock, looking for pericardial effusion and, if present, for signs of tamponade of the right ventricle, which may vary from a slight inward deflection to complete diastolic collapse of the chamber. Pericardial effusion can be the result of a type A aortic dissection, which can be diagnosed in the parasternal long axis where one may look for aortic root dilation (more than ≥4 cm in adults) and an aortic intimal flap. Of note, this can be easily missed.[5]

The next step is to focus on left ventricular (LV) contractility, by visually estimating (known as 'eyeballing') the change in volume from diastole to systole, identifying dilation of the ventricle and global screening for local wall motion disorders. LV function can be classified as normal, mild-moderately impaired, or severely impaired, which would be consistent with a diagnosis of cardiogenic shock. In case of distributive or hypovolaemic shock a hyperdynamic state can be seen, characterised by hyperkinetic, vigorous contractions of the left ventricle.

Finally, the right ventricle is assessed for signs of strain caused by sudden elevation of the pulmonary artery pressure, as can be seen in pulmonary embolism or pulmonary hypertension from another cause. These signs may include dilation of the right ventricle and a D-shaped left ventricle, caused by a shift of the interventricular septum towards the left ventricle which is most easily visualised in the parasternal short axis. In chronic pulmonary hypertension, characterised by right ventricular (RV) hypertrophy which may be combined with RV dilatation, it may be hard to exclude acutely elevated pulmonary artery pressure. When obstructive shock caused by acute pulmonary embolism is suspected, these findings empower the clinician to initiate thrombolysis in those cases where the risk of waiting for and/or transporting to computed tomography is too high. Since 70% of pulmonary embolisms originate from deep venous thrombosis of the legs, in some cases the suspicion may further be empowered by a quick ultrasound examination of the leg veins, which will be discussed in the third section of this article.[7] Tension pneumothorax should not be forgotten as a cause of obstructive shock, and will be addressed in the following section.

2. The tank

The next step is evaluation of the intravascular volume status by imaging the inferior vena cava (IVC) in the longitudinal plane in the substernal window still using the phased array probe, where the size and respiratory dynamics of the vessel can give an estimation of the central venous pressure (CVP). Measurements should be made distally to the point where the hepatic veins join the IVC, at about 2-3 cm from the junction where the IVC enters the right atrium.[5,6] M-mode can be used for measuring the percentage of collapse of the IVC on inspiration in a spontaneous breathing situation. Of note, the IVC has an oval shape and therefore there is a risk of underestimation when the vessel is not visualised exactly in the middle. Before interpreting this parameter, it should be taken into account that the diameter and collapsibility index of the IVC is influenced by many different factors, such as vigorous inspiratory effort, positive pressure ventilation, positioning of the patient, tricuspid valve regurgitation, elevated abdominal pressure and conditions that cause IVC dilation in normal right atrial (RA) pressure.[8] Although the European guidelines recommend cut-off values of 2.1 cm and 50% collapsibility in spontaneous breathing patients,[9] recent research has shown poor accuracy of measurements compared with invasive RA pressure measurements obtained through right heart catheterisation.[10] It seems safer to limit interpretations to extreme values for a rough estimation of high or low CVP and intravascular volume status, also considering other indices of RA pressure. Of note, positive pressure ventilation affects the respiratory dynamics on the IVC, since positive intrathoracic pressure increases the volume in the IVC. Especially in case of positive end-expiratory pressure (PEEP) the compliance of the IVC is decreased and the end-expiratory diameter will be relatively enlarged. Therefore, no interpretations of IVC measurements can be made in mechanically ventilated patients, except that a small IVC points toward the absence of elevated RA pressure.[11]

Measurement of the intravascular fluid status should be performed after examination of the heart, since findings may then be correlated to the condition of the pump. Low intravascular volume is caused by either absolute loss i.e. bleeding, fluid extravasation or fluid accumulation in a third compartment, or vasoplegia which is a relatively underfilled state. Repeated measurements can be used to guide fluid therapy, although there may be better predictors for this, such as repeated velocity time integral measurements, which were discussed in a previous episode of the POCUS series in this journal.[1]

Next the low-frequency curvilinear ('abdominal') probe can be used to look for leaks, i.e. bleeding in the pleural cavity and the intraperitoneal space (this is also known as the focused assessment with sonography in trauma or FAST exam). A quick look at the level of the diaphragm at the right and left midaxillary line *(figure 2)* should be enough for diagnosing pleural effusion and/or perihepatic and perisplenic fluid accumulation. The perihepatic region where fluid most easily accumulates is called Morrison's pouch and may be visualised as the space between the tip of the liver and the right kidney. Find the kidney first and then scan though the medial area of the kidney to view this space. In the perisplenic space, fluid may accumulate between the kidney and the spleen but may also be seen above the spleen between the spleen and the diaphragm. In addition, fluid may accumulate suprapubically in Douglas' pouch, which is located

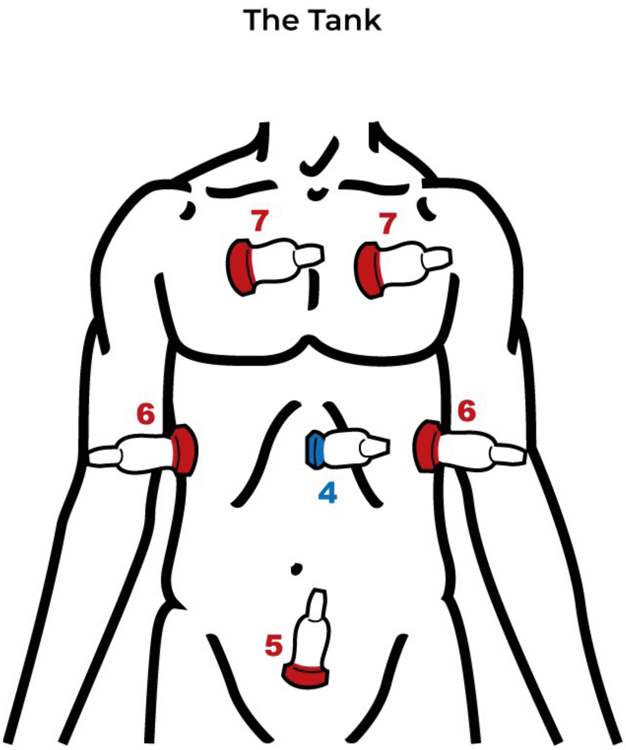

Figure 2. For examination of the tank, the phased array probe (blue) and the low-frequency curvilinear probe (red) are used. 4: substernal IVC view; 5: pelvic view; 6: the right/left upper abdominal quadrant and pleural views; 7: right/left ventral pleural views

dorsally of the bladder and can be detected in the suprapubic window. For this, it is easiest to keep the ultrasound beam in the sagittal plane with the probe marker facing in a cranial direction and free fluid will be seen behind the bladder in males and behind the uterus in females. In the transverse plane the exact direction of the ultrasound cut though this area is more difficult to interpret and this may lead to misinterpretations, such as mistaking fluids in the seminal vessels for free fluid. When the nature of the free fluid found in the peritoneum is uncertain, an ultrasound-guided puncture can be performed to show if this is blood or not, after which the sample obtained can be used for further diagnostics if its contents are uncertain. Of note, bleeding in the retroperitoneal space cannot be excluded with this protocol.

Still using the curvilinear probe, pulmonary examination can be performed by quickly scanning each lung at the six locations described in the BLUE protocol,[12] but for the purpose of diagnosing the cause of shock using only four locations is likely to be sufficient. For the probe positions see *figure 2*. Look for B-lines i.e. 'lung rockets' as a sign of pulmonary oedema, and at the same time for the presence or absence of lung sliding as a sign of pneumothorax or tension pneumothorax, with the characteristic 'seashore sign' in M-mode when visceral and parietal pleura rub against each other during a respiratory cycle and the 'barcode sign' when pleural rubbing is absent, e.g. when the lung is not ventilated or in case of pneumothorax. When a pneumothorax is suspected, search for the lung point where the visceral pleura begins to separate from the parietal pleura.[7] In case of absence of pulmonary oedema and pneumothorax a repetitively performed lung ultrasound can be used perfectly to guide fluid administration, as described in the FALLS protocol.[13] The change from an A-profile to a B-profile is an early sign of interstitial syndrome and a direct marker of fluid overload, even before symptoms of progressive hypoxaemia appear.

3. The pipes

When evaluating the vascular system in a context of shock, circulation can be impaired due to rupture or obstruction.

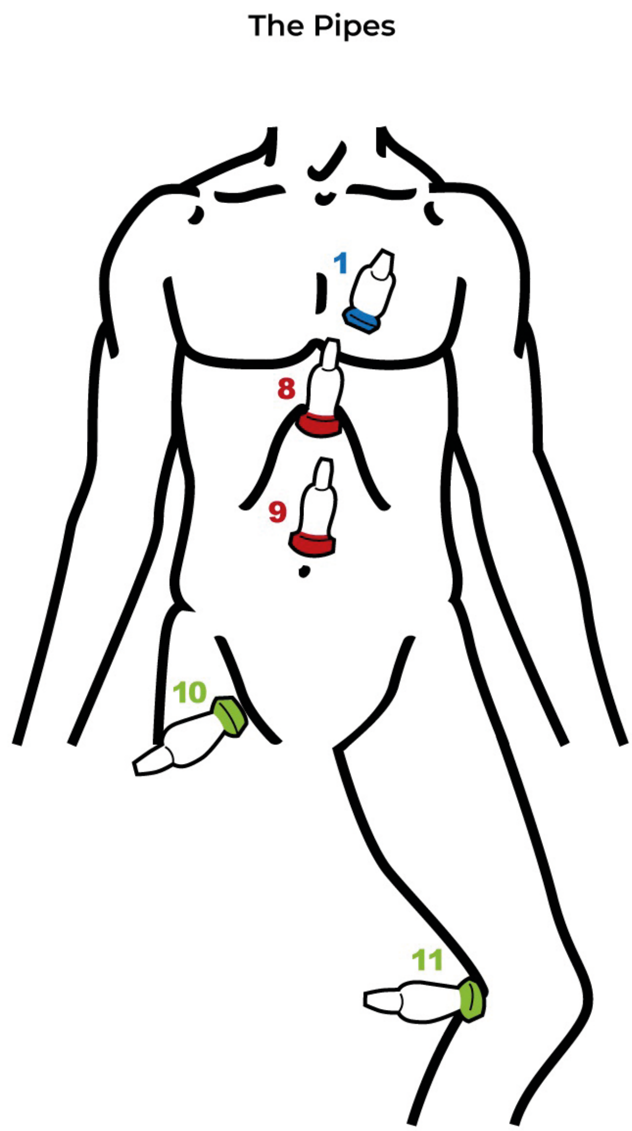

Figure 3. For examination of the pipes, the phased array probe (blue), the low-frequency curvilinear probe (red) and the high-frequency linear probe (green) are used. 1: parasternal long axis view; 8: the epigastric aortic view; 9: supraumbilical aortic view; 10: femoral view; 10: popliteal views

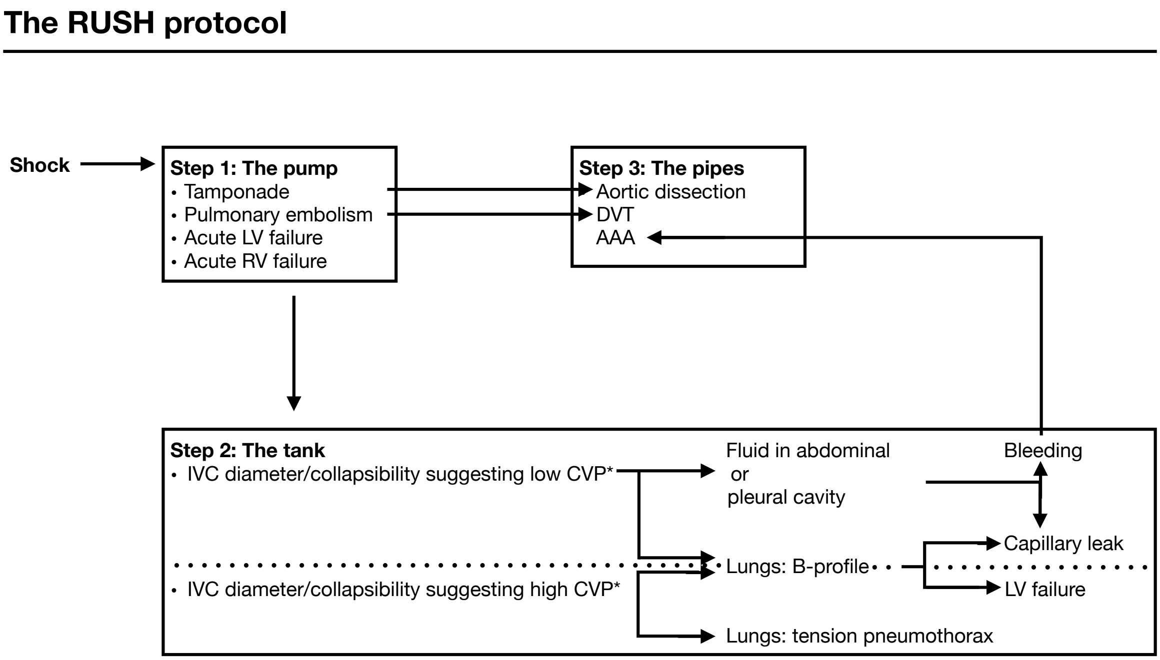

Figure 4. Flowchart of the RUSH protocol. Based on the findings, parts of the protocol may be left out; * factors that might influence IVC dynamics should be considered before drawing conclusions based on measurements; AAA = abdominal aortic aneurysm; DVT = deep venous thrombosis; CVP = central venous pressure; IVC = inferior vena cava; LV = left ventricle; RV = right ventricles

Type A aortic dissection was already covered in the cardiac examination. With the low-frequency curvilinear probe the rest of the aorta can be scanned for either dissection or abdominal aortic aneurysm (AAA, diameter >3 cm) *(figure 3).* The windows are the epigastric space and supraumbilical area, which can be extended towards the femoral artery in a case of dissection to search for the extend of it. AAA has an increased risk of rupture when the diameter exceeds 5 cm. Most AAAs are located inferior of the renal arteries and rupture typically occurs in the retroperitoneal space, which is hard to visualise by ultrasound examination. When, based on the cardiac images, a thromboembolic cause of shock is suspected, the high-frequency linear probe can be used to visualise the venous side of the circulatory system for obstruction by deep venous thrombosis (DVT) to support the diagnosis of pulmonary embolism. In the lower extremities the probe is placed on the common femoral vein and the popliteal vein *(figure 3)*. In case of DVT, the vessel cannot be compressed completely with direct pressure in these two locations and this two-point compression technique is enough to quickly screen for DVT.[7]

Discussion

The RUSH protocol is an extensive protocol, which incorporates the use of different probes for multiple ultrasound elements. While extensive, an experienced ultrasound operator may easily complete the entire protocol in 5-10 minutes. The mnemonic of dividing the exam into pump, tank and pipes helps to remember the sequence of ultrasound elements. The clinician should start with the heart and IVC to determine the subtype of shock, followed by a tailored selection of the other components of the protocol to help find the cause *(figure 4)*. In a recent prospective study, the conclusion of the RUSH exam was compared with the diagnosis that was made by standard departmental practices. They found an excellent accuracy for hypovolaemic, cardiogenic and obstructive shock with sensitivities of 94%, 96% and 99%, respectively. In distributive and mixed-type shock the sensitivity was slightly lower, 75% and 81%, respectively; the latter may be explained by the limitations of IVC measurements. Specificity was up to 95% or higher for all subtypes.[14] Comparable results with a slighter lower sensitivity for distributive and mixed shock were found in two recent meta-analyses.[15,16] Of note, these studies only included patients breathing spontaneously.[14-16] Sensitivity and specificity may drop in mechanically ventilated patients because of the effects on IVC compliance and respiratory dynamics, which might be the biggest pitfall of using the RUSH protocol on mechanically ventilated patients in the ICU. In addition, IVC dimension and dynamics can only give an estimation of the CVP in spontaneously breathing patients. Therefore, IVC measurements should be interpreted with caution and should always be related to findings in the other components of the protocol.

Another pitfall is when too much time is spent searching for signs of a type A dissection of the ascending aorta when a tamponade is found on cardiac imaging, since this is easily missed. When symptoms of acute aortic dissection are present, CT angiography should not be delayed. A limitation of the protocol might be that it is more extensive than most bedside resuscitation ultrasound protocols, but in most cases the exam can, if needed, be abbreviated when the subtype of shock is identified with heart and IVC ultrasound.[2] Of course, the protocol should not be used in isolation and the patient's history and clinical course should be considered when drawing conclusions.

Disclosures

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