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# IMAGING

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# Rapid Ultrasound for Shock and Hypotension

## A Clinical Update for the Advanced Practice Provider: Part 1

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**ABSTRACT**
The Rapid Ultrasound for Shock and Hypotension (RUSH) examination is used for patients with hypotension without clear cause or undifferentiated hypotension. In the emergency department setting, clinicians may perform the RUSH examination to supplement the physical assessment and differentiate the diagnosis of hypovolemic, obstructive, cardiogenic, and distributive forms of shock. The key elements of the RUSH examination are the pump, tank, and pipes, meaning potentially causes of the hypotension are examined within the heart, vascular volume and integrity, and the vessels themselves. Clinicians follow a systemic protocol to seeking evidence of specific conditions including heart failure exacerbation, cardiac tamponade, pleural effusion, pneumothorax, abdominal aortic aneurysm, and deep vein thrombosis. Because ultrasonography is a user-dependent skill, the advanced practice nurse in the emergency department should be educated regarding the RUSH protocol and prepared to implement the examination. **Key words:** emergency department, hypotension, shock, ultrasonography, ultrasound

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THE **R**APID **U**LTRASOUND FOR **S**HOCK AND **H**YPOTENSION (RUSH) examination was first described in February 2010 by Perera, Mailhot, Riley, and Mandavia for patients with hypotension without a clear cause or undifferentiated hypotension (Elbaih, Housseini, & Khalifa, 2018). Using three probes, the RUSH examines three areas, the pump, the tank, and the pipes (Elbaih et al., 2018; Perera et al., 2010; see Figure 1). Three areas are assessed during

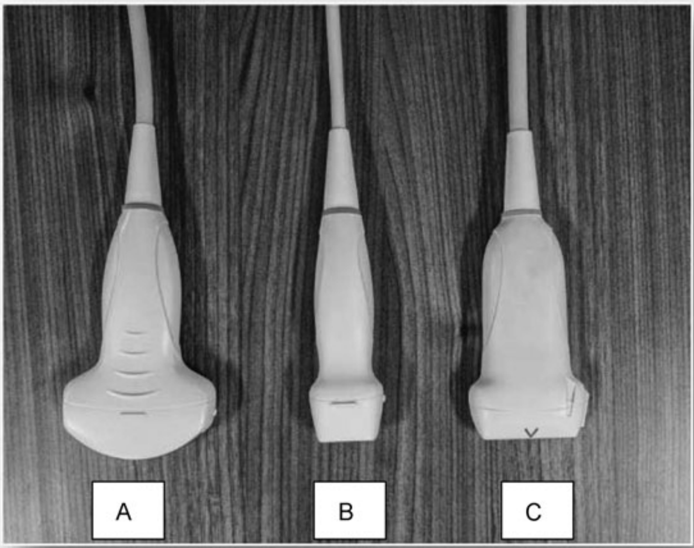


**Figure 1.** (A) Curvilinear, (B) phased array, and (C) linear probes. Photograph courtesy of Nichole Crenshaw.

this examination: the heart (referred as the pump), intravascular volume (the tank), and vessels (pipes). During assessment of the *pump*, the clinician focuses on the heart, how well it is contracting, and whether any excess fluid is present around it. The *tank* normally refers to evaluation of vascular volume or structural issues that could lead to loss of blood, meaning any interruption in vascular integrity allowing fluid to leak to other places, for example, a hemothorax. The last component of the examination is the *pipes*. In this portion of the protocol, the clinician focuses on finding a vascular conduction problem, such as deep vein thrombosis or an aortic aneurysm, to explain why the patient has hypotension (Perera et al., 2010).

When the clinician has limited time to correct hypotension, point-of-care ultrasonography (POCUS) proves to be a helpful tool in determining the cause of hypotension. The clinician is able to efficiently assess volume and other parameters such as heart contractility, intravascular volume, and aortic aneurysms that impact blood pressure in the critically ill patient (Perera et al., 2010; Stawicki et al., 2009). Some of the signs and symptoms of different types of shock may overlap, providing limited and conflicting data to the clinician. For example, patients with obstructive and cardiogenic shock may present with distention of the jugular vein, yet their treatments will be different (Perera et al., 2010). Having the ability to use POCUS and RUSH protocol for patients with hypotension can help the emergency department (ED) clinician categorize the shock state and subsequently improve the management of these critically ill adult patients (Shokoohi, Boniface, Zaragoza, Pourmand, & Earls, 2017).

Multiple studies have proved the sensitivity, specificity, and utility of RUSH examinations. The highest sensitivity and specificity were found in patients with hypovolemic shock (100% sensitivity and 100% negative predictive value; Bagheri-Hariri et al., 2015; Elbaih et al., 2018; Ghane et al., 2015).

Keikha, Salehi-Marzijarani, Soldoozi Nejat, Sheikh, and Mirrezaie (2018) found the RUSH examinations to have sensitivity of 95% and specificity of 95% for identifying the cause of undifferentiated hypotension. Another study supporting the use of the RUSH examination was a cross-sectional prospective study conducted by Elbaih et al. (2018). One hundred patients who had suffered polytrauma were evaluated using the RUSH examination, followed by chest and pelvic scans using pan-computed tomography. The mean age of the patients included was 27.5 years, with a range from 7 to 65 years. After the initial evaluation, 64% of patients were found to develop instability as a result of hypovolemic shock. The clinical predictors found for hypovolemia were respiratory rate, heart rate, systolic blood pressure, arterial blood pressure, and Glasgow Coma Scale score, $p < 0.01$. In this study, the RUSH examination was found to have a general accuracy of 95.2%, demonstrating a high level of precision for finding the reason for the patient's hemodynamic instability. The highest accuracy was among patients having cardiogenic shock. These findings were supported by sensitivity of 100%, specificity 98.9%, a positive predictive value of 90.9%, and negative predictive value of 100%.

Proficiency in performing this examination offers the advanced practice clinician targeted decision-making for treatment of patients with hypotension. Addressing the *tank* will require aggressive fluid resuscitation, whereas the *pump* requires inotropic support with careful administration of fluid (Perera et al., 2010; Shokoohi et al., 2017). Evidence shows that because POCUS is a user-driven skill, didactic education is required to provide training with simulation and in addition to clinical hours in conducting the examination (Jensen, Dyre, Jørgensen, Andreasen, & Tolsgaard, 2018; McConnaughey, Freeman, Kim, & Sheehan, 2018). Because bedside ultrasonography is a user-driven skill, didactic education, training with simulation, and clinical practice conducting the examination are essential (McConnaughey et al., 2018).

## DIFFERENT TYPES OF SHOCK (CARDIOGENIC, OBSTRUCTIVE, DISTRIBUTIVE, HYPOVOLEMIC, AND MIXED)

### Cardiogenic Shock

Cardiogenic shock usually happens because of an imbalance in oxygen delivery, blood pressure, and cardiac output, which occur as a result of a *pump* (heart) failure (Massaro, 2018). Patients frequently compensate with increased systemic vascular resistance and may have increased pulmonary wedge pressure, central venous pressure, and decreased stroke volumes. Some conditions associated with cardiogenic shock are myocardial infarctions, ischemic cardiomyopathies, myocarditis, and valvular insufficiencies (Massaro, 2018).

### Obstructive Shock

In obstructive shock, the patient has an imbalance in oxygen delivery and blood pressure as a result of an obstruction of blow flow outside the heart (Massaro, 2018). Conditions such as restrictive pericarditis, cardiac tamponade, tension pneumothorax, and pulmonary embolism (PE) are commonly associated with obstructive shock (Massaro, 2018).

### Distributive Shock

Distributive shock occurs as a result of decreased systemic vascular resistance and redistribution of blood volume (Massaro, 2018). This type of shock is usually associated with increased cardiac output to compensate for reduced vascular resistance. Both pulmonary wedge pressure and central venous pressure are decreased during this form of shock. Some diseases that cause this form of shock are sepsis, anaphylaxis, and adrenal insufficiency (Massaro, 2018). In conditions such as sepsis, the systemic vascular resistance may be increased earlier in the condition and normally decreases as the disease worsens (Abdalaziz, Algebaly, Ismail, El-Sherbini, & Behairy, 2018).

## Hypovolemic Shock

During hypovolemic shock, the cardiac output and the delivery of oxygenation to the tissues are diminished secondary to a decrease in preload (Massaro, 2018). Increase in systemic vascular resistance, drop in central venous pressure, and pulmonary wedge pressure are observed because of the low volume in the vascular system. The leading cause of this form of shock is hemorrhage from either internal or external causes. Gastrointestinal loss is another common cause for hypovolemic shock (Massaro, 2018).

## Mixed Forms of Shock

Clinicians must consider that hypotensive patients may have more than one form of shock. An example would be a patient who has developed an ischemic cardiomyopathy with components of cardiogenic shock and is also battling a severe infection causing distributive shock. This patient would be considered to have a mixed form of shock (Massaro, 2018). Patients with mixed forms of shock are more difficult for the advanced practice clinician to diagnose and also to manage, as the treatment of one type of shock may negatively affect the outcome of the other form (see Table 1).

When conducting a RUSH examination, it is vital for a clinician to understand how to operate the appropriate probes and corresponding transducers. The probes that will be necessary for this examination are the linear, curvilinear, and phased array probes. The phased array is low-frequency probe, usually ranging from 5 to 1 MHz. It generates a pie-shaped image that is able to assess deeper structures such as cardiac windows, abdominal aorta, inferior vena cava, and different quadrants from the abdomen. Because of efficient two-dimensional imaging and a smaller footprint, this probe is ideal for the thoracic cavity to view in between ribs and for moving organs such as the heart (Hsu & Menaker, 2016; Chiem, 2020). The curved array or curvilinear probe is a low-frequency probe, usually ranging from 5 to 2 MHz, with a wide field of view useful for deeper structures. Because of the larger footprint of the curved probe, rib shadowing may be a barrier to using this probe in the thoracic cavity and it is better suited for abdominal structures. In addition, it is not optimal for evaluation of the heart as it has a poor near-field resolution. The linear probe is a high-frequency probe, ranging from 10 to 5 MHz, that is used for evaluation more superficial structures such as peripheral vascular and sliding lung pleura (González, Ortega, Crenshaw, & de Tantillo, 2019; Chiem, 2020).

To obtain a clinically useful picture, the advanced practitioner must also be familiar with operation of the ultrasound machines and its settings. Important functions include the gain, which will change the brightness of the image, and the depth, which alters the penetration visible to the user. Brightness or B mode can use grayscale to display an image in two dimensions (see Figure 2), whereas Time-Motion or M mode examines a line of motion over time and it can document the motion of tissue in a still image (Saul et al., 2015). In the RUSH examination, it is most frequently used to examine the motion of the pleura (Gillman & Kirkpatrick, 2012; see Figure 3). In addition, an experienced clinician is able to freeze and save specific images during patient examination. The B and M modes are the two modes used in the RUSH examination.

When conducting a RUSH assessment, the advanced practitioner should also be prepared to differentiate reliable findings from visual artifacts (Hoskins, Martin, & Thrush, 2010). For example, a false image of the liver is expected to occur at the right upper quadrant in the area above the diaphragm. The presence of this mirror image assists the practitioner to exclude the possibility of fluid in the cavity (Rippey & Royse, 2009; Wongwaisayawan et al., 2015).

The phenomenon of acoustic shadowing must also be considered, especially when viewing the heart from the parasternal view or assessing the lung pleura (Hoskins et al., 2010). The practitioner will observe

**Table 1.** Type of shock and likely findings on RUSH protocol

| | Type of shock | | | |
|---|---|---|---|---|
| | **Hypovolemic** | **Cardiogenic** | **Obstructive** | **Distributive** |
| The pump | Hyperkinetic heart | Hypokinetic heart | Pericardial effusion | Hyperkinetic (early sepsis)<br>Hypokinetic (late sepsis) |
| | | Decreased motion of mitral valve | Right ventricular collapse in tamponade or straining (dilation) during pulmonary embolism | |
| The tank | Flat IVC | Distended IVC | Distended IVC | Normal to decreased IVC |
| | Free fluid (peritoneal, pleural) | Pleural effusions, lung rockets | Lack of lungs sliding in B mode and bar code sign in M mode if pneumothorax | Pleural effusion if empyema or |
| | | Ascites | | Ascites in bacterial peritonitis |
| The pipes | Aortic aneurysm dissection | Within normal limit | Deep vein thrombosis | Within normal limits |

*Note*. IVC = inferior vena cava.

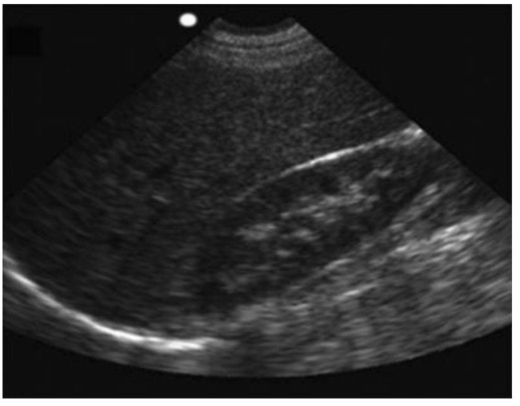

**Figure 2.** Brightness mode image. Photograph reproduced with permission from SonoSim, Inc.

a shadow from the ribs that appears to be dark vertical lines (see Figure 4). This normal finding results because the ultrasound waves do not penetrate bone (Wongwaisayawan et al., 2015).

## RUSH PROTOCOL

### The Heart (Pump)

See Figure 5.

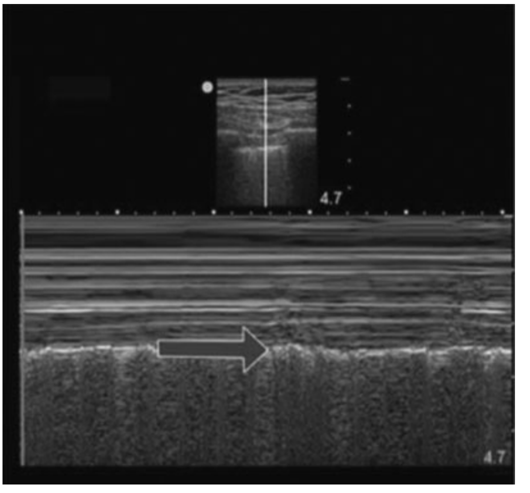

**Figure 3.** Motion mode image. Photograph reproduced with permission from SonoSim, Inc.

Evaluation of the pump includes the following:

a. Qualitative assessment of left ventricular function (indirect evaluation of ejection fraction and cardiac contractility)

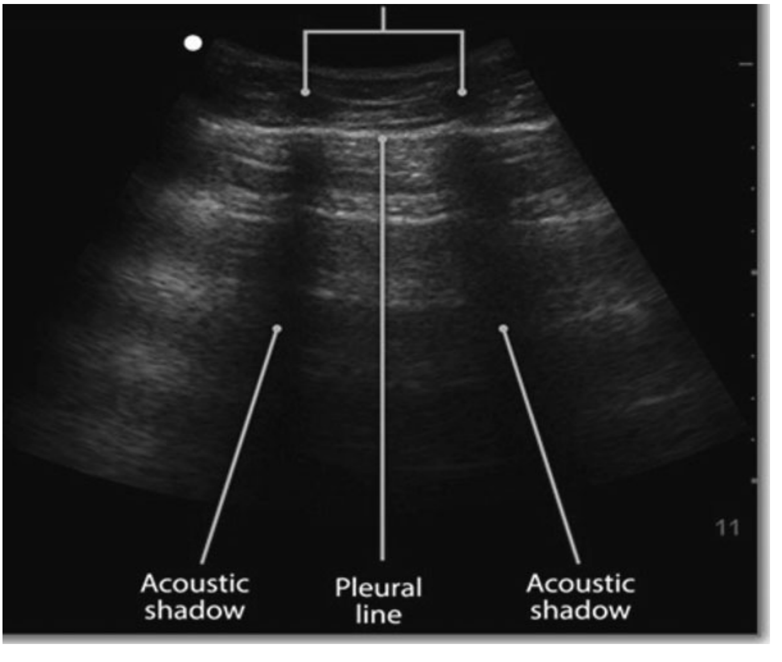


**Figure 4.** Acoustic shadowing artifact. Illustration reproduced with permission from SonoSim, Inc.

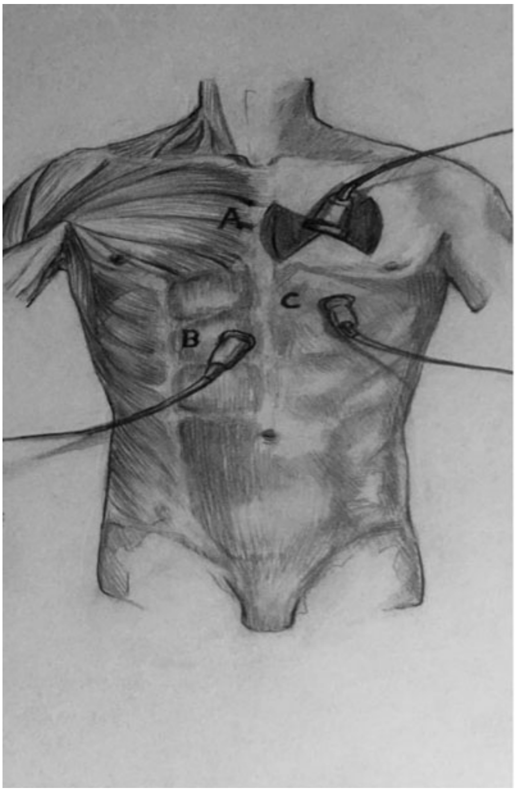


**Figure 5.** Cardiac windows. (A) Parasternal long- and short-axis views, (B) subxiphoid view, and (C) apical view. Illustration courtesy of Yusmel Jimenez. Reprinted with permission.

    i. Assess the anterior left leaflet of the mitral valve
    ii. Motion of the left ventricle
  b. Obstruction
    i. Pericardial effusion
    ii. Right ventricular strain secondary to a lung issue (i.e., PE)

The clinician begins the RUSH protocol by evaluating the *pump*, or the heart. To evaluate the pump, a clinician can use three main different anatomical windows. The probe or transducer used for these views would be low frequency, 1–5 MHz, such as the phased array. The first one is the parasternal long view (Perera et al., 2010; Wacker & Winters, 2014). Placing the low-frequency phased array transducer on the anatomical left sternal border fourth intercostal space, the indicator will point toward the patient's anatomical left, specifically the left elbow diagonally if the ultrasound machine is in general mode. If the ultrasound machine setting is in cardiac mode, then the indicator should point diagonally toward the right shoulder (Perera et al., 2010; Wacker & Winters, 2014; see Figures 6 and 7).

The second view of the heart can be obtained by placing the low-frequency phased array probe in the apical "four-chamber" view. The probe is placed in the transverse view, with the indicator to the patient's anatomical right toward the right iliac crest, just medially to the midclavicular line or left nipple, fifth intercostal space (Perera et al., 2010; Wacker & Winters, 2014; see Figure 8).

The last view is the subxiphoid view, in which the probe is placed in the transverse plane, with the indicator pointing toward the patient's anatomical right, using the liver as an acoustic window (González et al., 2019; Wacker & Winters, 2014). The probe is then tilted slightly to the left or subxiphoid area to visualize the heart (González et al., 2019; Perera et al., 2010; Wongwaisayawan et al., 2015; see Figure 9).

From the parasternal long axis (PSLA), the clinician can observe the right ventricular outflow track, the left ventricle, the ventricular septum, the posterior wall of the left ventricle, and the anterior and posterior mitral leaflets (Perera et al., 2010). Although from the PSLA, the ED clinician will be able to appreciate an enlarged right ventricle, the four-chamber view is the recommended window to assess difference in dimension between the right and left ventricles. In a normal clinical setting, the right ventricle is half or two third the size of the left ventricle (Perera et al., 2010; Perera, Lobo, Williams, & Gharahbaghian, 2014). Acute and chronic conditions that may cause alterations to this ratio are discussed later.

The next component of examining the *pump* includes assessing the contractility of the heart. This requires evaluation of the mitral valve and global left ventricular

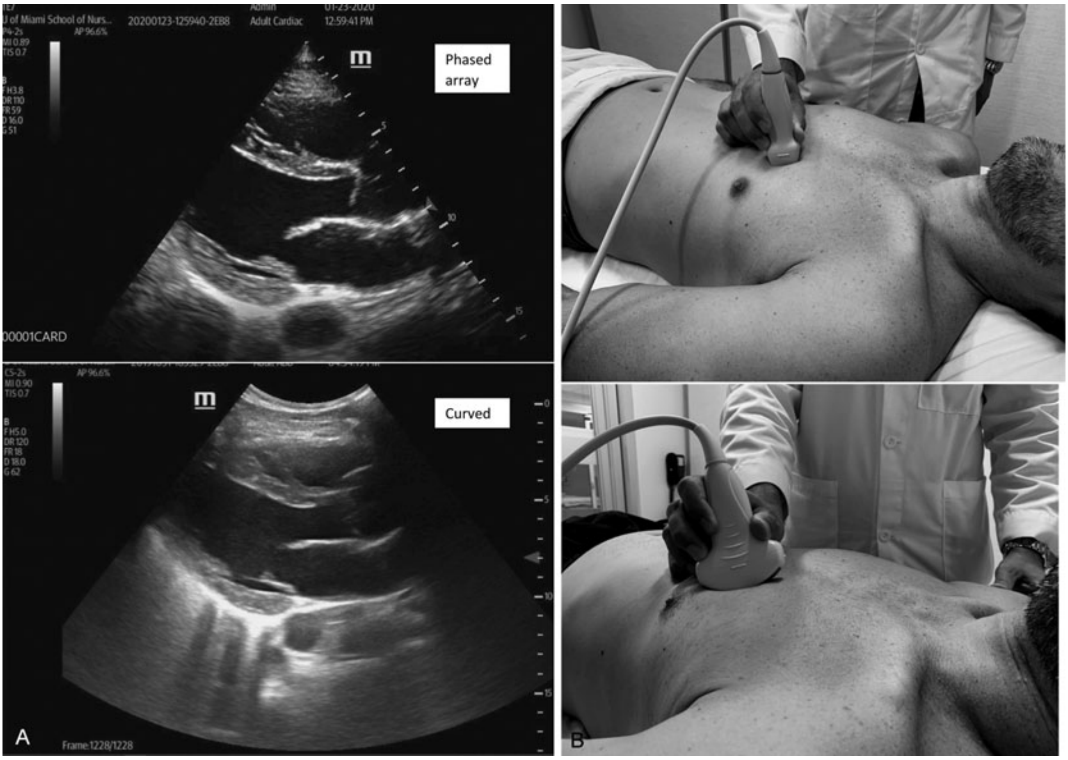


Figure 6. (A) Parasternal long axis of the heart phased array and curved probe. (B) Curved and phased array probe position for parasternal long axis. Photograph courtesy of Juan M. Gonzalez.

function (Wacker & Winters, 2014). The clinician should closely examine the motion of the anterior leaflet of the mitral valve to determine whether it is making contact or coming close to making contact with the interventricular septum of the heart (Perera et al., 2010; see Figure 10A). In a normal state of contractility, the anterior leaflet of the mitral valve is seen snapping or flipped open against the interventricular septum (Perera et al., 2014). In a patient with poor activity, the leaflet does not come into contact with the interventricular septum during systole (Perera et al., 2010; see Figure 10B).

The contractility of the heart is then assessed by observing the contraction and relaxation of the left ventricle. To do so, the clinician focuses on the tight opposition of the posterior wall of the left ventricle and the interventricular septum (Mcdonald,

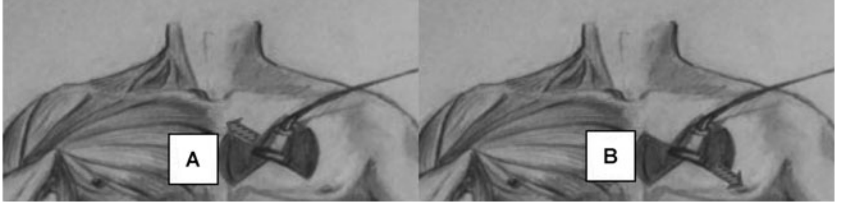


Figure 7. (A) Probe position for cardiac mode. (B) Probe position for general mode. Illustration courtesy of Yusmel Jimenez. Reprinted with permission.

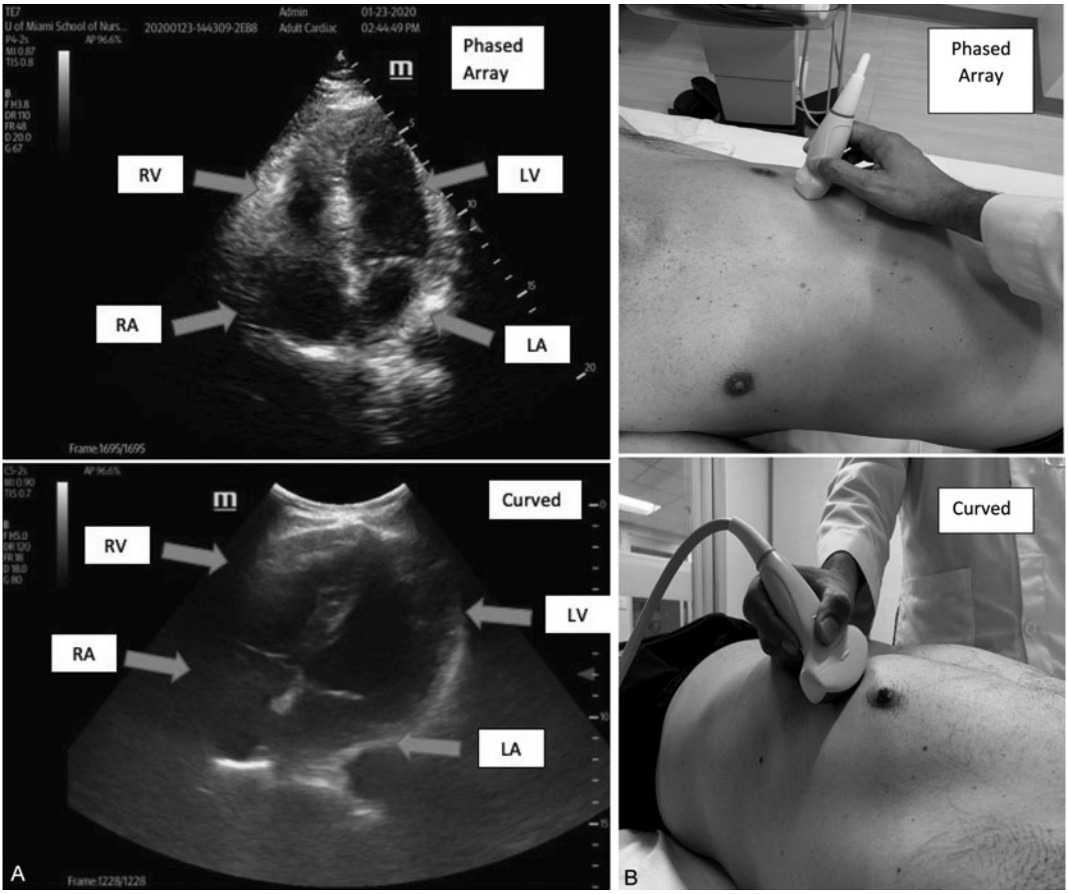


**Figure 8.** (A) Four-chamber view of the heart with phased array and with curved probe. (B) Probe position for four-chamber (apical) view of the heart with phased array and curved probe. LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle. Photograph courtesy of Juan M. Gonzalez.

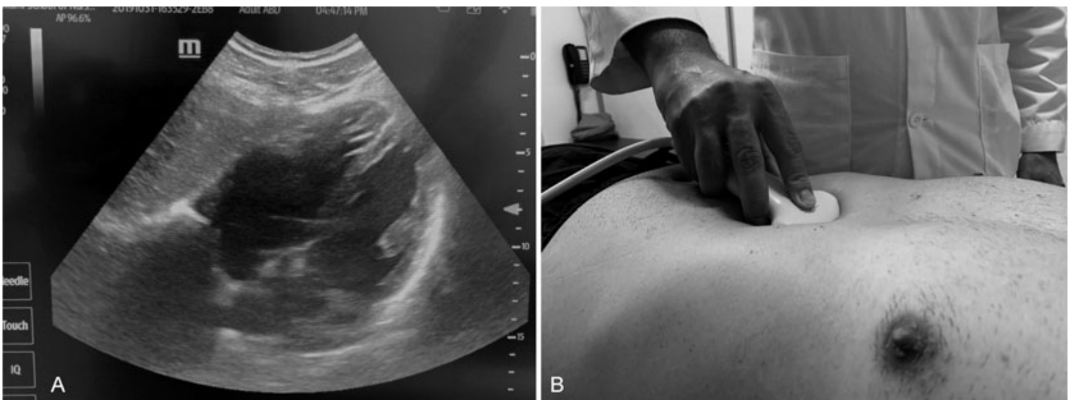


**Figure 9.** (A) Subxiphoid view of the heart. (B) Curved probe position of the probe for subxiphoid view of the heart. Photograph courtesy of Juan M. Gonzalez.

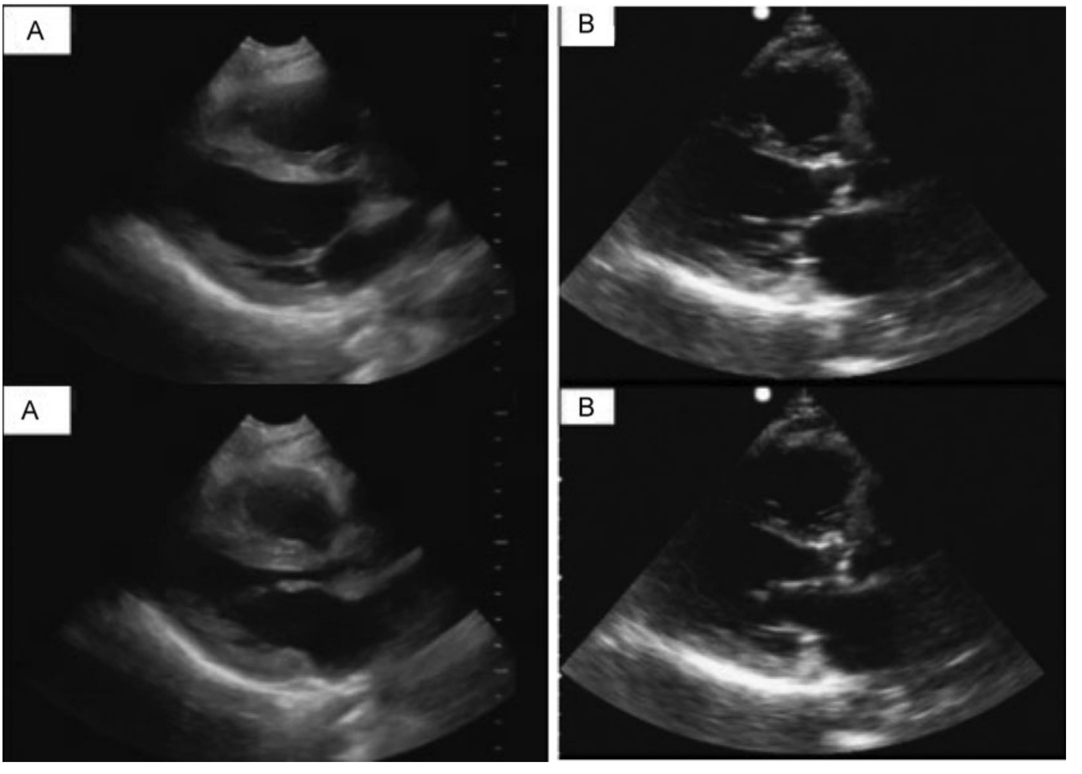


**Figure 10.** (A) Normal movement of the anterior leaflet of mitral valve. (B) Abnormal movement of the anterior leaflet of mitral valve. Photograph reproduced with permission from SonoSim, Inc.

Feigenbaum, & Chang, 1972; Perera et al., 2010). As the ventricle is going through systole, the clinician observes for approximation of the posterior wall of the left ventricle to the interventricular septum. A normal finding as the cardiac cycle goes through end diastole is for the posterior wall of the left ventricle and interventricular septum to separate from one other, allowing for blood filling (Mcdonald et al., 1972; Perera et al., 2010; see Figure 11A). However, in a patient with poor contractility, these two walls may not approximate one other or demonstrate this tight opposition (Perera et al., 2010; see Figure 11B). During this portion of the examination, heart contractility is categorized into one of four grades: normal; mild to moderately decreased; severely decreased; or hyperdynamic, which is more contractile than normal. The hyperdynamic state is an abnormal condition usually seen during compensation of distributive shock or hypovolemia (Perera et al., 2014).

After initial evaluation of cardiac function, the clinician assesses the ultrasound scan for any evidence of an obstruction as the cause for the hypotension. Obstructive processes associated with the heart frequently result from pericardial effusions. Common causes for pericardial effusions are cancer, infectious causes such as pericarditis, noninfectious sources such as renal failure, and trauma (Vakamudi, Ho, & Cremer, 2017). Patients experiencing acute processes generally demonstrate rapid onset of symptoms when compared with those with chronic processes, as the heart has less time to adapt to the compression (Vakamudi et al., 2017). In an acute pericardial effusion, fluid accumulation of 50 ml can lead to a tamponade. When an effusion develops due to a chronic condition, the pericardial sac stretches gradually and allows

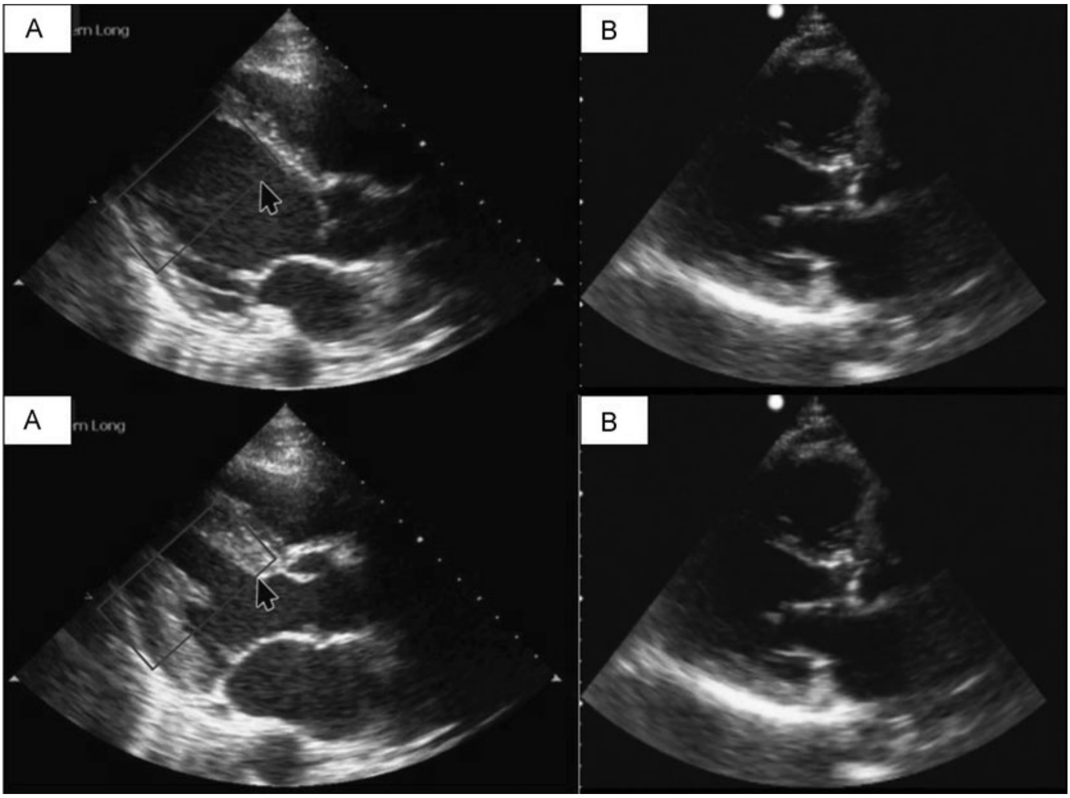


**Figure 11.** (A) Normal left ventricular wall motion. (B) Abnormal ventricular wall motion. Photograph reproduced with permission from SonoSim, Inc.

additional fluid to accumulate before symptoms develop (Perera et al., 2014).

A clinician should be especially alert for a pericardial effusion that leads to compression of the right ventricle. This finding is pathognomonic of a tamponade (González et al., 2019; Perera et al., 2010; Wacker & Winters, 2014). In this setting, the right ventricle has what is known as a paradoxical movement. The right ventricle appears contracted or collapsed rather than dilated during the diastolic phase of the cardiac cycle (Perera et al., 2014; (see Figure 12). Inversely, the right atrium of the patient with a tamponade will be collapsed during systole (Smith, Watnick, & Ferre, 2017). In addition, patients experiencing a pericardial tamponade commonly develop *plethoric inferior vena cava*, or little variation with the respiratory cycle. This finding is considered very sensitive (95%–97%)


**Figure 12.** Pericardial tamponade. Photograph reproduced with permission from SonoSim, Inc.

for the diagnosis of a tamponade (Alerhand & Carter, 2019).

Although estimating the amount of fluid in the sac is considered challenging, the advanced practice provider performing the ultrasound scan can describe the size of the pericardial effusion based on the measurement of the anechoic space in the pericardial sac (Alerhand & Carter, 2019). A measurement of less than 10 mm in diastole would be described as a small effusion and likely have 50–100 ml of fluid. A measurement of 10–20 mm would be considered a moderate-size effusion with 100–500 ml of fluid. Any measurement greater than 20 mm during diastole would be considered a large effusion with more than 500 ml of fluid (Alerhand & Carter, 2019). If enough fluid is present, the heart may even be seen swinging inside the sac (Alerhand & Carter, 2019).

The clinician may also use another method to categorize the size of the pericardial effusion (Perera et al., 2014). Utilizing the view from the parasternal long axis, effusions less than 1 cm in depth that are not circumferential around the heart would be considered small. Effusions less than 1 cm that are circumferential around the heart would be considered moderate. Finally, effusions greater than 1 cm and circumferential around the heart would be considered large (Perera et al., 2014). As there are variations in the literature regarding the categories of pericardial effusion, it is essential for the advanced practitioner to use ultrasound scan in conjunction with physical examination, history, and other findings to make a clinical determination. It is important for the ED clinician to remember that one cannot rule in or rule out a pericardial tamponade solely based on the size of the pericardial effusion.

When evaluating for obstructive conditions, the clinician must also assess for right ventricular strain. This problem is diagnosed by evaluating the overall size of the right ventricle (Wacker &Winters, 2014). As stated previously, the normal finding is for the right ventricle to be smaller than the left ventricle.

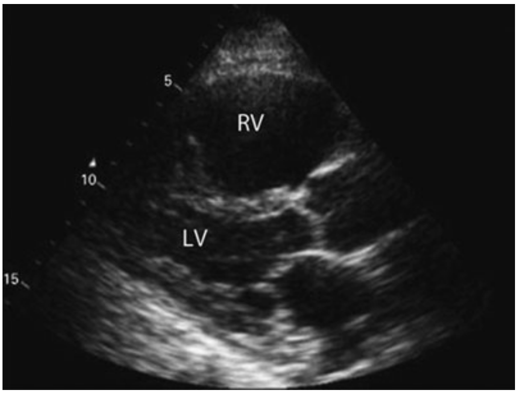


**Figure 13.** Right ventricle straining pattern. LV = RV = right ventricle. Photograph reproduced with permission from SonoSim, Inc.

In cases of pulmonary hypertension or a very large PE, the pulmonary arterial pressure increases, dilating the right ventricle. As a result, the right ventricle will appear larger than the left ventricle on the ultrasound scan (Perera et al., 2010, 2014; (see Figure 13). This right-sided ventricular overload caused by increased pulmonary pressures consequently decreases amount of blood arriving from the pulmonary vasculature to the left ventricle. In severe cases, the left ventricle may appear collapsed, demonstrating the decreased filling of this chamber. However, the clinician needs to be aware that some conditions can lead to chronic enlargement of the right ventricle and can be confused for ventricular straining. Conditions such as chronic obstructive pulmonary disease and chronic pulmonary hypertension can lead to these changes. Of note, in these cases, the clinician normally observes enlargement of the ventricle itself with dilation rather than dilation alone, which is more commonly seen in acute straining patterns, such as PE. The clinician should consider ventricular wall size as a point of differentiation: In acute conditions leading to straining, the wall will be less than 5 mm. In the case of chronic conditions, this measurement tends to be greater than 5 mm (Perera et al., 2010, 2014).

## IMPLICATIONS FOR ADVANCED PRACTICE CLINICIANS

The RUSH examination can help the clinician evaluate patients who are experiencing hypotension of unknown cause in the ED. In the first step of the RUSH protocol, evaluation of the *pump*, the advanced practice provider can quickly assess for potential causes of hypotension such as pericardial effusions, decreased left ventricular wall motion, and mitral valve problems. The emergency nurse practitioner can also assess for right ventricular straining patterns in the setting of a PE, another possible cause for hypotension.

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The authors and planners have disclosed that they have no financial relationships related to this article.