Chest Pain

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Introduction

The use of ultrasonography to diagnosis and manage emergent conditions in the hospital setting has been firmly established. In fact, within that setting its use is becoming more widespread, with a focus on the diagnosis of acute cardiac conditions because of the high associated morbidity and mortality. Because of the proven benefits of cardiac ultrasound, termed echocardiography, it is now being implemented in other areas including the prehospital and austere settings. The potential for early diagnosis, early intervention, and change in management through the use of echocardiography is clear.

Cardiac ultrasound is a very broad and technical field. It can take years to master the depth of knowledge within this extensive subject. However, echocardiography can be performed accurately by a novice sonographer with training focused on basic anatomy, basic cardiac function and image acquisition. Patients in any setting can benefit from point-of-care echocardiography to diagnose, guide management, and direct further care for their condition. This chapter will introduce the basic skills needed for obtaining standard echocardiographic views that can be used in the pre-hospital and austere settings. It will present diagnostic pathways and management considerations for common, critical diagnoses that can be made with echocardiography.

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Anatomy

The heart is a hollow muscular organ that serves as a circulatory pump for the body's blood. The heart works in close conjunction with the lungs to deliver oxygenated blood into systemic circulation. The heart is broadly divided into two sides, the right and the left, each containing one atrium and one ventricle. The right side of the heart receives deoxygenated blood from the systemic venous circulation and pumps it into the pulmonary circulation. The left side of the heart receives oxygenated blood from the pulmonary circulation, and distributes the blood into the high pressure systemic arterial system. The right side of the heart is a much lower pressure system than the left side under normal physiologic conditions, and the heart is structured to accommodate this. As such, the left ventricle (LV) is more muscular than the right and has a larger cavity size.

The pattern of blood flow during the process of central circulation is critical to understanding basic echocardiography. Blood enters the heart from the body through the inferior vena cava (IVC) and superior vena cava (SVC) and drains directly into the right atrium (RA). It then passes through the tricuspid valve and enters the right ventricle (RV). During systole, the ventricular contraction phase, blood is ejected from the right ventricle through the pulmonary valve and into the pulmonary arteries. Blood returns from the pulmonary circulation through the four pulmonary veins and drains directly into the left atrium (LA). During diastole, the ventricular filling phase, blood then flows through the mitral valve and enters the left ventricle. During systole, blood is ejected from the left ventricle through the aortic valve and into the proximal aorta. The aorta ascends posteriorly and then curves inferiorly, making the aortic arch, then descends through the thorax and abdomen. The portion of the aorta from the aortic valve through the branching of the left subclavian artery is known as the ascending aorta and aortic arch; anything distal to the left subclavian artery is known as the descending aorta.

Structurally, the heart is composed of three layers; from outer to inner: the epicardium, the muscular myocardium, and the endocardium. The heart is surrounded by a sac-like structure called the pericardium. The outer layer is the fibrous pericardium which is actually attached to various portions of the thorax by weak ligaments. The inner portion is the serous pericardium, and is further divided into parietal and visceral layers. The visceral layer is synonymous with the epicardium. There is a small amount of serous fluid between the visceral and parietal layers that serves as a lubricant for the heart as it moves through the cardiac cycle.

The heart's position in the thorax creates two important anatomic concepts to understand: its surfaces and its axes. Because of the heart's unique shape it has three surfaces: the inferior/diaphragmatic surface, the posterior surface/base, and the anterior/sternocostal surface. The diaphragmatic surface is formed mostly by the right and left ventricles, with a smaller portion of the right atrium. The posterior surface, also known as the base, is formed primarily by the left atrium. The anterior surface is formed mostly by the right ventricle and to a lesser degree the right atrium.

The long axis of the heart lies from its base to its apex. The terms base and apex are derived from the cone shape of the heart. It is important to note that the heart does not rest on its base, but rather on its diaphragmatic surface. The base of the heart is close to the midline, and the apex of the heart represents the ending point of the left ventricle, usually four centimeters inferolateral to the left nipple near the point of maximum impulse. This orientation of this long axis of the heart can change slightly depending on both anatomic and pathologic features of the patient in question. The short axis lies at a perpendicular angle to the long axis of the heart [1].

Image Acquisition and Interpretation

Probe Selection

For standard echocardiography the phased array probe should be used. This probe has several unique properties that make it ideal for imaging the heart. Primarily, the phased array probe has small face or "footprint", which is ideal for imaging the heart in between the limited space afforded by the ribs. Furthermore, it uses electronic beam steering to "widen out" the beam from the flat probe face, making the field of view larger so that more of the cardiac structure can be imaged. Lastly, the phased array probe uses a high pulsed repetition frequency (PRF), meaning more pulsed sound waves per second. This imaging parameter creates a higher temporal resolution, which is ideal for imaging the dynamic, ever-pumping heart [2].

By convention, when imaging most of the body, the marker dot on the probe is positioned towards the patient's right or towards the head, to correspond to the marker dot which is on the left side of the imaging screen. Because of the unique structure of the heart, and the various imaging axes as mentioned early, the convention is changed for echocardiography. When the ultrasound machine is changed to cardiac mode the marker dot moves to the right of the screen. And when imaging the patient, the marker dot on the phased array probe is moved through a series of positions that correspond to the axes of the heart rather than simply "towards the right" or "towards the head." These positions and the corresponding cardiac images that are obtained will be detailed further in this chapter.

Positioning and Anatomic Considerations

Most providers prefer to scan from the patient's left side, but this is purely operator-dependent. This may be impossible to achieve if working in a small transport vehicle, helicopter or other small working space. Positioning and anatomic considerations vary depending on the view you are attempting to obtain, but several broad parameters apply. The axis of the heart can vary depending on both a patient's overall phenotype and presence of chronic cardiac disease. Tall and thin people tend to have a more vertical long axis, whereas short and obese people tend to have a more horizontal long axis. Additionally, it is worth mentioning that some of the more common chronic cardiac diseases cause a more horizontal axis, such as those with left ventricular hypertrophy due to chronic hypertension. Feeling for the PMI can guide the practitioner in determining apex location and overall axis.

Various positioning methods can be used to increase the viewing window and bring the heart closer to the probe thereby improving image quality. Having a patient put their left arm over their head will broaden the rib spaces, and thus increase the size of several desired scanning windows. Placing the patient in the left lateral decubitus position will allow the heart to be in a more dependent position, which is closer to the chest wall and thus the probe. This can improve all of the cardiac views, but is best for the apical view in particular. Lastly, having a patient inhale or exhale while scanning can facilitate viewing. For instance, inhaling while attempting a subxiphoid view may allow for better alignment of the liver in front of the probe, thus allowing a clearer acoustic window through which to view the heart. In contrast, parasternal and apical views are often improved with exhalation. This can become more important in patients with certain pulmonary pathologies, such as COPD, where exhaling significantly decreases the amount of interference caused by air. These and more view-specific image optimization techniques will be reviewed within each section.

Standard Echocardiographic Views

Parasternal Views

In the two parasternal views, a rib space directly next to the patient's left sternal border is used as a window between bones to view the heart from its anterior surface. There is usually no lung parenchyma between the transducer and heart to cause interference or scattering in this area.

The patient can be supine or in left lateral decubitus position. It may be helpful to have the patient put their left arm behind their head in order to expand rib space and thus widen the window. In these views, respiratory variation will have minimal effect.

Long Axis

The parasternal long axis (PSLA) view is the workhorse for cardiac imaging. It is often the easiest view to obtain and is the view that offers the most diagnostic information. It is very good for evaluating global left ventricular contractility and estimating ejection fraction. It gives information on right ventricular size. This view is also good for obtaining measurements of the left atrium and aortic root. The left atrium may be enlarged in heart failure, mitral regurgitation, and other pathologies. The aortic root can become enlarged in aortic root aneurysm and in some aortic dissections. Evaluating presence of pericardial effusion can also be done in this view, with the presence of posterior fluid being much more sensitive for a true effusion.

To obtain the parasternal long axis view, the probe marker should be oriented towards the patient's right shoulder. The transducer should initially be placed in the

Fig. 1 Parasternal long transducer placement. The transducer is placed on the anterior chest wall at the second or third intercostal space, to the left of the sternum, with the transducer marker towards the patient's right shoulder

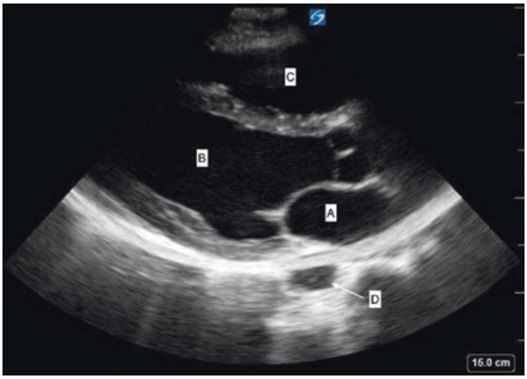

Fig. 2 Parasternal long view. Parasternal long cardiac view in between cardiac cycles with both mitral and aortic valves closed. Blood flows from the left atrium (**a**) through the mitral valve, into the left ventricle (**b**), and out to the body through the aortic valve. The right ventricle is can be see at the top of the screen (**c**). The descending thoracic aorta is posterior to the heart (**d**)

third or fourth intercostal space (Fig. 1). Depending on the patient, moving superiorly or inferiorly by 1–2 rib spaces will be necessary to find the optimal view. As its name suggests, this view is truly parasternal, as the probe should be a maximum of 2 cm from the left sternal border. The probe may need to be fanned or rocked in order to align the probe most closely with the long axis of the heart.

On the imaging display, the apex of the heart will be oriented towards the left side of the screen, and the base of the heart to the right (Fig. 2). The right ventricle will located at the top of the screen. Beneath it, and towards the left side of the screen will be the left ventricle. In a properly oriented image, the left ventricular outflow tract (LVOT), aortic valve, and aortic root should be visible. The left atrium will be beneath the aortic root and to the right of the left ventricle. The anterior and posterior leaflets of the mitral valve should be visible. The proper depth is achieved when a cross-sectional view of the descending aorta is visible posterior to the pericardium.

Once the parasternal long view is appropriately obtained, there are several pieces of information that can be quickly gathered to produce highly useful information about the functional status of the heart: global ventricular function or ejection fraction estimate, which includes mitral valve assessment; the presence of pericardial effusion; and the relative sizes of the RV, LVOT and LA as they relate to each other. When oriented appropriately the RV, ascending aorta, and LA should be approximately the same size in the PSLA. Any violation of this rule usually indicates a pathologic process, such as RV enlargement, aortic root aneurysm, or heart failure.

Short Axis

The parasternal short axis (PSSA) is particularly good at detecting localized wall abnormalities and relative ventricular sizes. The window used for the PSSA will be the same intercostal space location as PSLA, just lateral to left sternal border. The same patient positioning will apply for both parasternal views (supine or left lateral decubitus). In the short axis view, however, the probe marker points towards the patient's left shoulder (Fig. 3). This is most often obtained just after the PSLA, so rotating the transducer 90 degrees clockwise from right shoulder to left shoulder provides the starting point for obtaining this image.

Three distinct planes of the short axis are commonly used in cardiac ultrasound, each achieved by a different degree of fanning along the heart's long axis. In all views, the right side of the heart is at the top left of the screen and the left ventricle is more centrally located, and should appear circular in an appropriately oriented image. The views are discussed in order from base to apex. When fanned towards the base, a view at the level of the aortic valve can be achieved. In this view the aortic valve will be just to the right of the right atrium, centrally located. A normal tri-leaflet aortic valve will look like a "Mercedes Benz sign." At the deepest part of

Fig. 3 Parasternal short transducer placement. From the long axis position, the transducer is rotated approximately 90 degrees clockwise so the marker points towards the patient's left shoulder

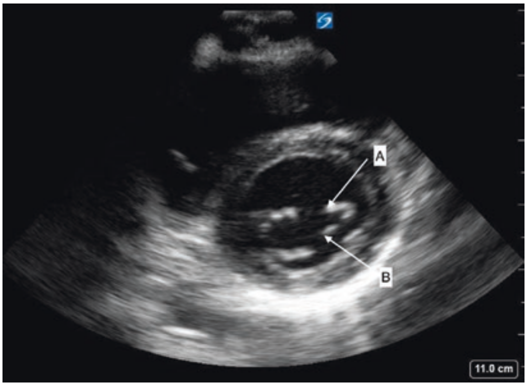

Fig. 4 Mitral valve "fish mouth" in parasternal short view. Mitral valve parasternal short view displaying the "fish mouth" of the mitral valve in short axis. The anterior leaflet (**a**) can be seen above the posterior leaflet (**b**)

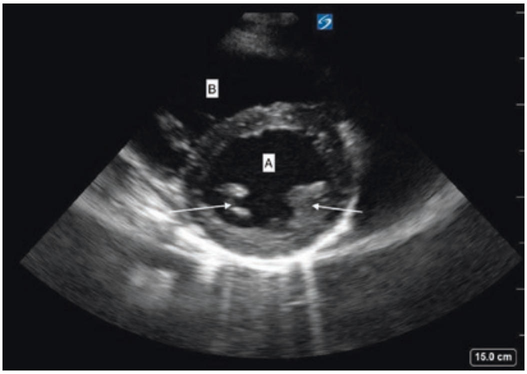

Fig. 5 Parasternal short view. Parasternal short cardiac view at the level of the papillary muscles (arrows). LV cavity (**a**) is circular, not elongated or ovoid. The RV cavity (**b**) can be seen in upper left

the screen, most posteriorly, the left ventricle should be visible. Moving towards the apex, the next view should be at the level of the mitral valve. In this view, the mitral valve is seen in the center of the LV (Fig. 4). The RV is anterior and slightly to the left on the screen. Lastly, when the probe is tilted slightly towards the apex, the LV is viewed in cross-section at the level of the papillary muscles, located at approximately 4 and 8 o'clock on the circular LV (Fig. 5).

The PSSA can be used to evaluate for global ventricular function as well as localized wall motion abnormalities. The LV should move in a concentric fashion during systole. Any gross deviation from that synchronized concentric contraction may represent acute ischemia, old infarct, or electrical rhythm abnormalities such as bundle branch blocks. The relative size of the ventricles is easily approximated in this view as well. The normal ratio of RV to LV is 0.6–1 [3]. When the RV starts to approach or exceed the size of the LV it is indicative of a pathologic process such as acute pulmonary embolism (PE) or chronic pulmonary hypertension (pHTN). If the right sided pressures are high enough, it may cause the septal wall to "bow" outward into the LV, causing the LV to transition from circular appearing to "D-shaped." Additionally, pericardial fluid will be apparent in this view, especially as the heart is fanned through apex to base.

Apical Four Chamber

The apical four chamber view (A4) of the heart images all four chambers of the heart at the same time, as viewed from the apex as its name suggests. It is ideal for directly comparing the right to left sides of the heart, evaluating both LV and RV systolic function, and evaluating for pericardial effusion and tamponade.

The apical four chamber view is the most technically difficult view to obtain, especially for novice providers. While this view can be obtained in a supine patient, the left lateral decubitus position typically will produce superior images as it brings the apex of the heart closer to the chest wall. This view can be obtained in several ways. Often, the probe can be placed in an intercostal space 1–2 cm inferior to the nipple near the PMI, and adjusted accordingly to optimize image (Fig. 6). The optimal position may be more medial in thinner patients, and more laterally located in obese patients or those with cardiomegaly.

This view can also be obtained starting from the PSSA. From the PSSA, the probe can be slid towards the apex, while rotating it slightly in a clockwise position, until the apex is reached. At this point, the probe is fanned to point back towards the base of the heart. This method keeps the heart in view during the transition from PSSA to A4 and may be easier for novice providers. Lastly, palpating for the point of maximal impulse will help guide probe placement, as this typically corresponds with the closest point the left ventricle is to the surface of the skin. In the apical four chamber view, the probe marker will be towards the patient's left side, usually aimed between posterior axilla and elbow.

The ideal apical 4-chamber view will have the apex pointing directly at the transducer, with the septum vertically-oriented, directly in the middle of the screen so that the right side of the heart is on the left side of the screen and vice versa (Fig. 7). The left ventricle will be on the right side of the screen with the left atrium located below it. The right atrium will be located below the right ventricle farther from the probe surface, and the left atrium in a similar position below the left ventricle.

Fig. 6 Apical four chamber transducer placement. The transducer is placed near the point of maximal impulse (PMI) with the marker pointed towards the patient's left elbow

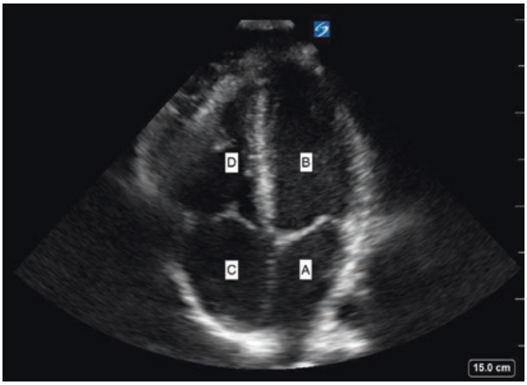

Fig. 7 Apical four chamber view. Apical four chamber view in systole, with apex of the heart located at the top of the screen, base located at the bottom. Ideal orientation is with septal wall (between **d** and **b**) located in vertical orientation, perpendicular to the face of the cardiac transducer. The cardiac chambers are as follows: left atrium (**a**), left ventricle (**b**), right atrium (**c**) and right ventricle (**d**)

Subxiphoid

The subxiphoid view takes a different approach from those previously discussed. In this view, the heart is viewed from the epigastrum, just below the xiphoid process. This approach uses the liver as an acoustic window through which to view the heart from its diaphragmatic surface. By using the liver, a large homogenously echogenic organ, the probe avoids interference from aerated lung and bowel gas. This is typically the view used to evaluated the heart during the eFAST exam. It is helpful in evaluating for pericardial effusion or tamponade and evaluating the inferior vena cava (IVC).

The patient should be supine. Flexing the knees will allow the abdominal musculature to relax and allow for more pressure to be applied with the probe, which may be necessary in more obese patients. Asking the patient to inhale may optimize view by bringing both the liver and the heart more inferior and therefore closer to the transducer.

The cardiac probe marker should be directed to the patient's left and the probe should angled such that it is pointed upward into the chest cavity (Fig. 8). It may be necessary to point the probe slightly towards the patient's left flank, or slide the probe to the patient's right in order to better utilize the liver as an acoustic window.

In this view, the liver will be anterior to the heart, at the top of the screen (Fig. 9). The apex of the heart will be up and to the right of the screen, in contrast to the apical views, in which the apex will be pointed directly at the transducer. The right ventricle will be closest to the transducer after the liver. The left ventricle and left atrium will then be more posterior to the right heart.

To view the IVC from this position, rotate the probe 90-degrees counterclockwise so that the marker dot is oriented cranially (Fig. 10). Then, slide the probe slightly to the right of the patient's midline. A sagittal view of IVC will be posterior to the liver at this angle, and will be seen entering the R atrium on the right side of the screen (Fig. 11). The IVC is usually 1.5–2 cm in anterior-posterior diameter at

Fig. 8 Subxiphoid transducer placement. The transducer is placed just below the xiphoid process with the marker pointed towards the patient's left

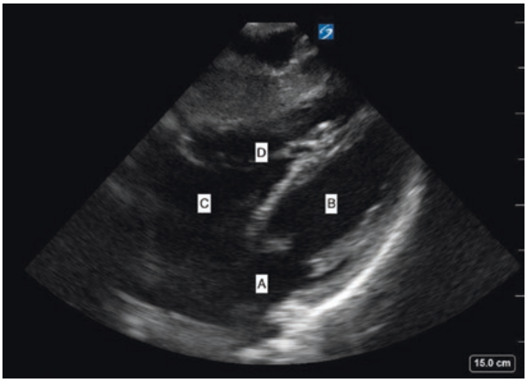

Fig. 9 Subxiphoid view. The subxiphoid cardiac view demonstrates the heart viewed through the acoustic window of the liver. Cardiac chambers are identified as follows: left atrium (**a**), left ventricle (**b**), right atrium (**c**), right ventricle (**d**)

Fig. 10 IVC transducer placement. The transducer is placed just below the xiphoid process, slightly to the right of midline, with the marker pointed towards the patient's head

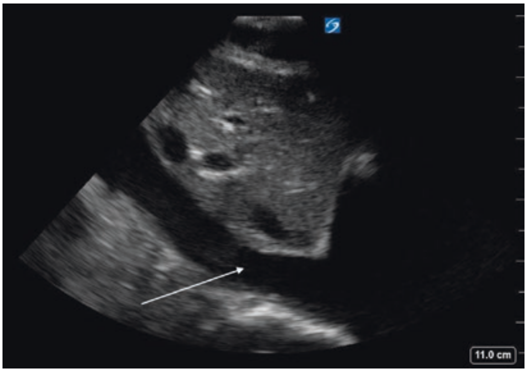

Fig. 11 IVC. The inferior vena cava is demonstrated in long axis passing through the liver and emptying into the right atrium

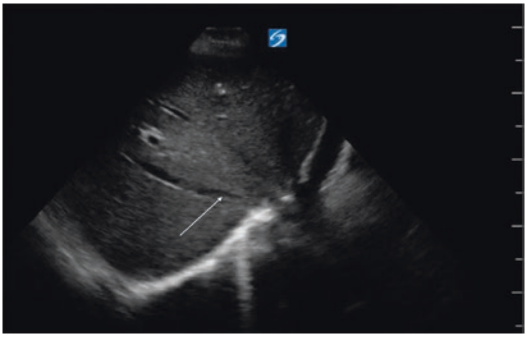

Fig. 12 Collapsed IVC. Collapsed IVC (arrow) passing through the liver on its course to the right atrium. At times, a collapsed IVC can be so small it can be difficult to identify

normal maximum dilation. This is measured 3–4 cm distal from its entrance to the R atrium [3].

The size of the thin-walled IVC usually varies with respirations, collapsing with inspiration and dilating with expiration. A quick visualization of the IVC can provide rapid information into both a patient's cardiac function and volume status. A patient who is hypovolemic may have a small or mostly collapsed IVC (Fig. 12). A patient with an obstructive pathology such as tamponade or pulmonary embolism may have a dilated IVC with minimal respiratory variation (Fig. 13).

Suprasternal

The suprasternal view is a quick and effective way to evaluate for evidence of an aortic dissection. It is fairly specific for this process if it is visualized, but not a sensitive test. Therefore, it should not be considered a "rule-out" examination. In this view, the probe is placed in the suprasternal notch with the probe marker facing towards the left and the probe face pointed downwards into the chest. The probe should be angled as anteriorly as possible. In order to accomplish this, it may be beneficial to tilt the head of the bed to 30 degrees, or even have the patient sit

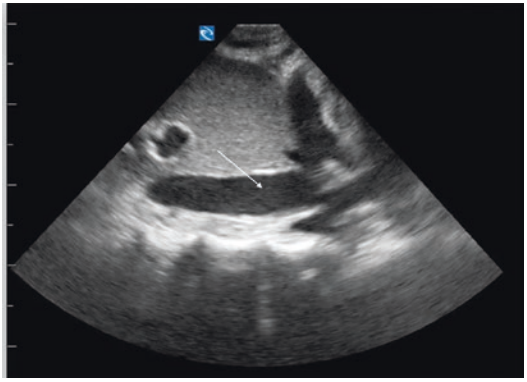

Fig. 13 Dilated IVC. Dilated IVC (arrow) passing through the liver and emptying into the right atrium

Fig. 14 Suprasternal Notch. The suprasternal notch view shows the ascending (**a**) and descending (**b**) thoracic aorta, with the aortic arch located in between. Also visible here are the brachiocephalic vein (**c**), left carotid artery (**d**), and right pulmonary vein (**e**)

upright and have them extend their neck. The depth of the image will need to be decreased significantly compared to all other cardiac windows.

The aortic arch will be visible with the ascending aorta on the left side of the screen and the descending aorta on the right side of the screen (Fig. 14). From screen left to right, the origins of the brachiocephalic artery, left carotid, and left subclavian arteries will be visible. Beneath the aortic arch, a cross section of the right pulmonary artery will be visible as well.

Pathology

Decreased Left Ventricular Ejection Fraction

Ejection fraction (EF) refers to the percentage of blood volume in the left ventricle that is forced out of the left ventricle into systemic circulation with each systolic contraction. This is the clinical index that is used to evaluate myocardial contractility, and thus offers clinical evidence regarding the overall function of the heart [4]. In general, an EF between 55–65% is considered normal, 45–55% is mildly reduced, 35–45% is moderately reduced, and severely reduced is less than

35%. Heart failure can be classified in several different ways, but the most common way is to dichotomize it into two categories: systolic heart failure or heart failure with reduced ejection fraction (HFrEF) and diastolic heart failure or heart failure with preserved ejection fraction (HFpEF). Systolic heart failure refers to the ability of the LV to contract and squeeze blood out of the heart. Diastolic heart failure refers to the ability for the LV to relax and fill with blood. Systolic heart failure can be related to several causes, including dilated cardiomyopathy (Fig. 15), hypertrophic cardiomyopathy (Fig. 16), severe hypertension and even myocardial infarction. Using ultrasound to evaluate diastolic heart failure is beyond the scope of this text.

The global left ventricular function can be easily assessed by simple visual estimation. In fact, this qualitative assessment has been shown to be as accurate in determining ejection fraction as formal measurements in studies comparing cardiologists to learners with basic training [5]. In order to make this qualitative assessment, three separate estimates should be assimilated. First, during systole the myocardium of the left ventricle should appear to thicken uniformly and the LV chamber size should decrease as blood is pumped out of the heart. If the chamber size appears to reduce by more than 50% then it can be considered normal. If the

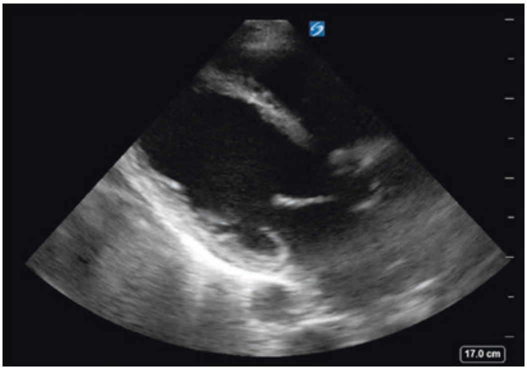

Fig. 15 Dilated cardiomyopathy. Parasternal long axis image demonstrating ballooning of the left ventricle typical of dilated cardiomyopathy

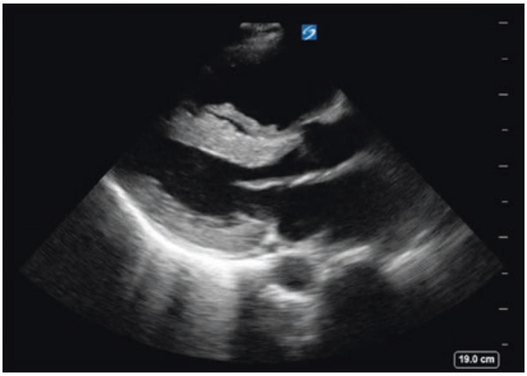

Fig. 16 Hypertrophic cardiomyopathy. Parasternal long axis image demonstrating uniform thickening of the left ventricular walls indicating hypertrophic cardiomyopathy

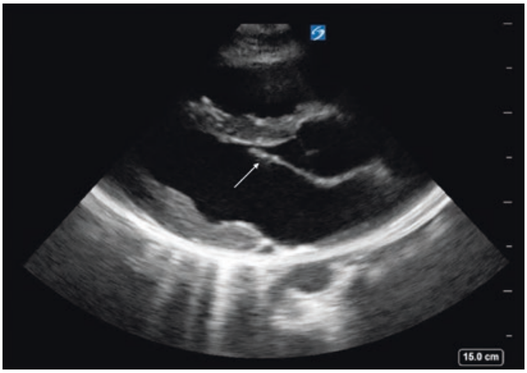

Fig. 17 Mitral valve leaflet touching septum. Parasternal long axis image showing the anterior leaflet of the mitral valve (arrow) touching septum during diastole, which is the common state associated with normal ejection fraction

LV is determined to be squeezing less than 50%, then it is helpful to determine which broad category of systolic heart failure is occurring: mildly reduced, moderately reduced or severely reduced [3]. This is especially critical in patients with no history of heart failure, or in those with severe symptoms who may be experiencing an acute change in heart function, as in a congestive heart failure (CHF) exacerbation. This takes some experience and more focused training, but the same principles apply: visually estimate the percentage change of the left ventricular size.

Next, the contractility and volume status of LV can be estimated by looking at the motion of the anterior mitral valve leaflet. In a healthy individual, the anterior leaflet should closely approach or even touch the septal wall during LV filling (Fig. 17). If there is limited motion of the anterior leaflet, it may indicate that the LV is "congested," i.e., the volume of the ventricle is abnormally high after systole. When this is visually difficult to determine, this motion can be easily mapped in M-mode by placing the scan line over the leaflet tip. Formally, this measurement is termed the end-point septal separation (EPSS). A measurement greater than 7 mm is indicative of moderate to severely reduced ejection fraction [3].

Finally, the mitral annulus at the posterior leaflet should be examined for motion. Normally, the leaflet should have vigorous right to left movement across the screen as the LV contracts during systole and pulls the mitral annulus towards the apex. Little or no movement can indicate poor contractility, and may be a further clue that systolic dysfunction is present.

Using these criteria, the practitioner can develop a qualitative sense of the overall systolic function of the left ventricle. This information is critical to the overall evaluation of the heart. In the setting of an unstable patient, including those with hypotension and/or dyspnea, this evaluation is a crucial first step in determining the root cause. Finding acute heart failure during prehospital evaluation may prompt the provider to escalate care, including the initiation of vasopressors for those with severe hypotension, or positive pressure ventilation for those in severe respiratory distress.

RV Enlargement

Pulmonary embolism causing shock, syncope or vital sign instability is a true emergency with high degree of mortality, yet prompt recognition can sometimes be difficult. The insidious nature of pulmonary embolisms are perhaps their most well-known feature. Dyspnea with normal breath sounds, no clearly defining EKG changes, and no obvious radiographic abnormalities make prompt diagnosis challenging. Only approximately 50% of patients with PE have any complaint of chest pain. In fact, 50% of patients with first time PE will have normal vital signs [6]. However, ultrasonographic detection of acute RV enlargement and strain is highly sensitive for detection of PEs that cause hemodynamic compromise. It is worth noting that chronic pulmonary hypertension can result in right heart strain, but this is typically associated with right ventricular remodeling and hypertrophy, distinguishing it from acute RV dysfunction related to embolism. This section focuses on acute right heart strain due to pulmonary embolism.

Normally, the pressure in the systemic circulatory system is much higher than that in the pulmonary system. Therefore, during systole, the pressure that the LV needs to generate to pump blood against that high systemic pressure is far greater than that in the RV. For example, normal peak systolic measurements of the left and right ventricles are approximately 120 mmHg and 25 mmHg respectively [1]. A similar relationship exists in the atria.

In the case of a pulmonary embolism, the normally low-resistance, high-flow pulmonary vasculature system suddenly becomes obstructed, increasing the RV afterload, or the pressure it has to pump against, significantly. As a result, the systolic and diastolic pressures of the in the right side of heart increase as well. The increased RV afterload can sometimes be so significant as to cause obstructive shock and cardiac arrest. This rise in pressure will manifest itself on echocardiography in several ways.

The relative size of the RV cavity compared to the LV cavity is readily obtained in several views discussed in this text including the parasternal short axis and apical four chamber. A normal ratio is 0.6–1 [3]. The RV can be considered enlarged anytime it starts to exceed this ratio, and certainly if it meets or exceeds the size of the LV. In the PSLA, an enlarged RV may be visible as an elongated RV with flattened interventricular septum (Fig. 18); however, relative ventricular cavity size comparisons are best performed in the PSSA and A4 views [3].

The elevated RV pressures seen in right heart strain can be very prominent during systole, and manifest in ventricular cavity size changes. This can be seen as a flattening of the interventricular septum, resulting in the LV appearing as D-shaped, rather than circular in the PSSA view (Fig. 19). If the relative pressure difference between the two ventricles is even more pronounced, there can even be a “bowing” of the interventricular septum into the LV cavity.

The apical four chamber view is the most accurate in determining the relative sizes of right and left ventricles. Occasionally, off-axis images taken in the other

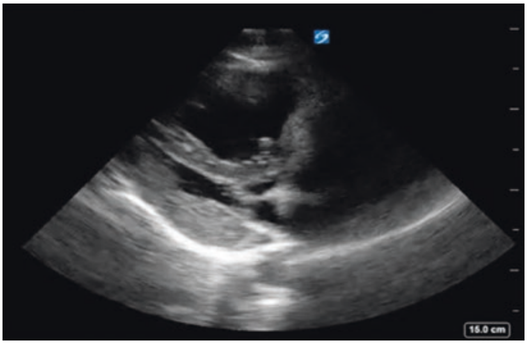

Fig. 18 Parasternal long axis, dilated right ventricle. Parasternal long axis image showing a severely dilated right ventricle with associated left ventricular collapse

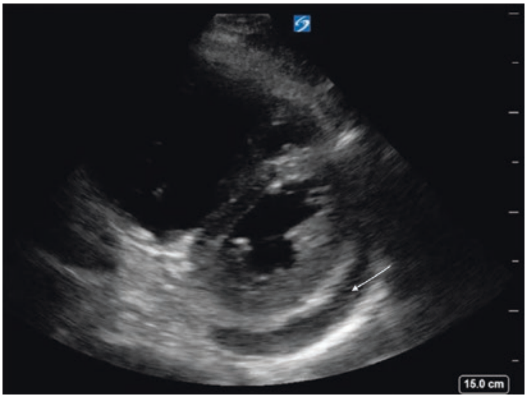

Fig. 19 Parasternal short axis – dilated right ventricle. Parasternal short axis image showing an enlarged right ventricle when compared to the left. This results in septal bowing towards the left ventricle that causes it to appear "D-shaped." Small effusion is denoted by an arrow

cardiac views may give the RV an enlarged appearance, wherein the apical four chamber view removes that potential deception. In this view, the LV should always appear larger than the RV under normal circumstances (Fig. 7). In the case of acute PE, the RV can appear enlarged, which typically indicates a sizable clot burden (Fig. 20). In addition to RV size and septal wall abnormalities, the free wall of the right ventricle may show little to no movement as it struggles to contract against the elevated pressure, best seen in the apical four chamber view. When this occurs the movement of the apex is often spared. This is termed McConnell's sign, and can be used to differentiate acute right heart strain from chronic changes. Chronic right heart strain will result in remodeling of the RV, and the free wall will become hypertrophied and relatively more mobile.

Evaluation of flow across the tricuspid valve is a more advanced mechanism to evaluate for elevated right ventricular systolic pressures (RVSP). When blood flow is obstructed from moving forward in the case of a large PE, not only does the RVSP increase but it causes backwards flow from the ventricle into the atrium, termed tricuspid regurgitation or insufficiency. This can be detected by placing a Doppler color box in the right atrium and looking for flow jets. Qualitatively, a jet flowing from the ventricle into the atrium that reaches the opposite atrial wall is considered severe regurgitation. The quantitative method then requires the continuous wave

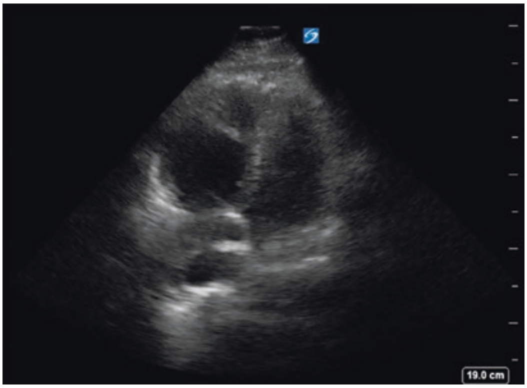

Fig. 20 Apical four chamber – dilated right ventricle. Apical four chamber image showing RV:LV ratio of greater than 1:1, indicating severe RV dilation

Doppler gate be placed in that regurgitant jet to determine actual flow velocities, a more advanced step.

Pericardial Effusion & Cardiac Tamponade

The space between the pericardium and epicardium usually has a very small amount of physiologic fluid that acts to lubricate the heart as it contracts. Normally, that small amount of fluid is less than 50 ml and is undetectable by ultrasound [3]. However, there are many different pathologic conditions that can cause the amount of fluid to build up. When the amount of fluid is significant enough to restrict the physiologic function of the heart, the terminology changes from simple pericardial effusion to cardiac tamponade.

There are many widely varying conditions that can result in a pericardial effusion. The more commonly encountered causes include pericarditis (which itself has many potential causes including infectious and autoimmune), direct injury to the heart in the form of trauma, neoplastic disease, myocardial infarction, many rheumatologic conditions, and renal disease. Depending on the source, pericardial fluid can be hyperechoic, such as in the case of clotted blood or purulence; or it can be hypoechoic, such as most uremic or malignant effusions.

The size of a pericardial effusion is graded by measuring the separation between the epicardium and pericardium. A small effusion is less than 0.5 cm (Fig. 21), a moderate effusion measures between 0.5 and 2 cm (Fig. 22), and a large effusion is greater than 2 cm (Fig. 23) [7, 8]. Two centimeters of separation corresponds to approximately 500 mL of fluid [3].

The heart may have a prominent anterior fat pad located in the anterior precordial space of the right ventricle that is often mistaken for fluid in the PSLA view (Fig. 24). If there is no anechoic substance in the posterior or dependent portion of the pericardial space, or if the anterior anechoic substance appears heterogenous, this is most likely fat [3]. This epicardial fat pad is most common in females, elderly, obese people and diabetics [1].

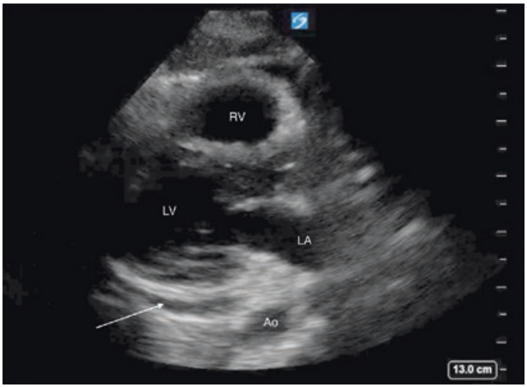

Fig. 21 Small pericardial effusion. Small pericardial effusion (arrow) seen in parasternal long view during diastole. Note the fluid extending anterior to the descending thoracic aorta, differentiating it from pleural effusion. Small effusions typically measure less than 0.5 cm

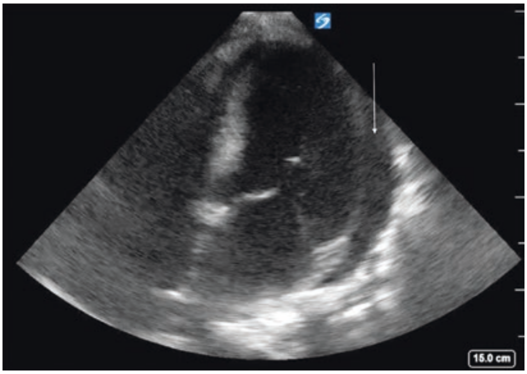

Fig. 22 Moderate pericardial effusion. Moderate sized pericardial effusion (arrow) seen in an apical four chamber view

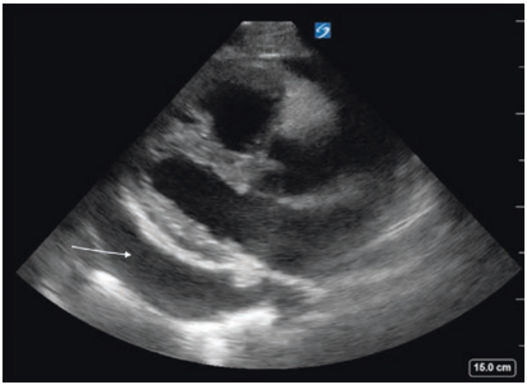

Fig. 23 Large pericardial effusion. A large-sized pericardial effusion is noted here in this parasternal long view. Large pericardial effusions typically measure greater than 2 cm

The pericardium is a semi-flexible sac. It can stretch to accommodate a large amount of fluid if it accumulates at a slow rate, over weeks to months. However, an effusion that accumulates rapidly can cause acute hemodynamic compromise with a much lower fluid burden. Cardiac tamponade occurs when the amount of fluid in the pericardium creates pressure that compromises the ability for the heart to fill with blood. This is a form of obstructive shock.

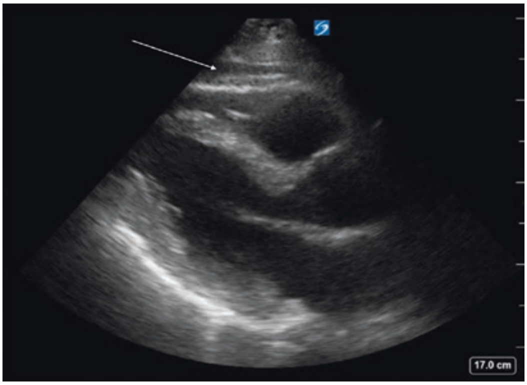

Fig. 24 Epicardial fat pad. An epicardial fat pad may be present anterior to the right ventricle and can be very similar in appearance to a small pericardial effusion in a parasternal long view, often they can be indistinguishable. However, small pericardial effusions will typically be seen posterior to the left ventricle and an epicardial fat pad will be seen anterior to the right ventricle

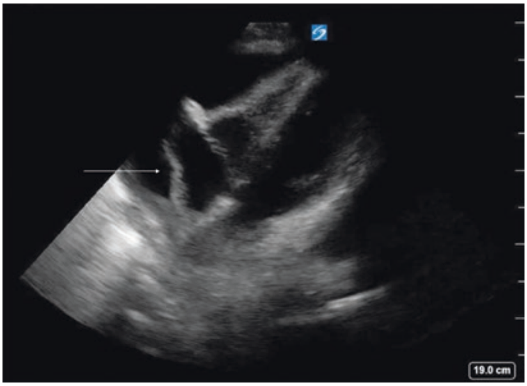

Fig. 25 Right atrial collapse in tamponade. Right atrial collapse (arrow) in pericardial tamponade, demonstrated in the subxiphoid view. This is the most sensitive sign for pericardial tamponade

Because the right side of the heart typically operates under lower pressures, it is susceptible to the inward force of the pericardial fluid before the left side of the heart. Therefore, we use the apical four chamber and subxiphoid views to evaluate for tamponade as they give the best visualization of the right heart. In echocardiography, tamponade is defined as RA collapse during systole and RV collapse during diastole. Right atrial collapse during systole, when it should be filling with blood, is the most sensitive sign for cardiac tamponade as it will usually occur first (Fig. 25) [8]. Diastolic collapse of the RV, its filling phase, is the more specific sign for tamponade and can be easier to detect (Fig. 26).

The IVC should also be evaluated in suspected tamponade. Similar to PE, another common form of obstructive shock, the IVC will be dilated and lack respiratory variation as forward flow of blood is compromised (Fig. 13).

When imaging the heart in PSLA, one common pitfall is to mistake a left-sided pleural effusion for a pericardial effusion. The key distinguishing factor in this view is the relationship of the fluid to the descending thoracic aorta. In both cases, fluid will be posterior to the left ventricle, but a pericardial effusion will track anterior to the descending aorta, whereas a left-sided pleural effusion will stop abruptly at the aorta (Fig. 27).

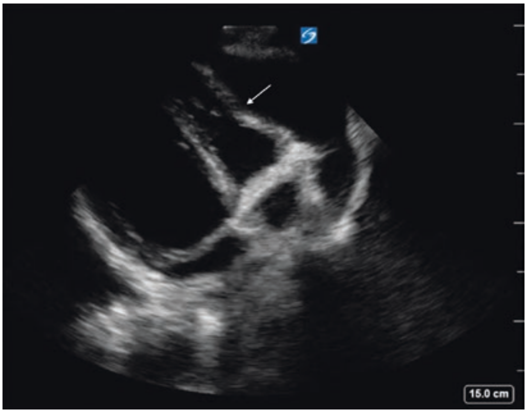

Fig. 26 Right ventricular collapse in tamponade. Right ventricular collapse (arrow) during ventricular filling is seen in this subxiphoid view of pericardial tamponade. This is the most specific sign for pericardial tamponade

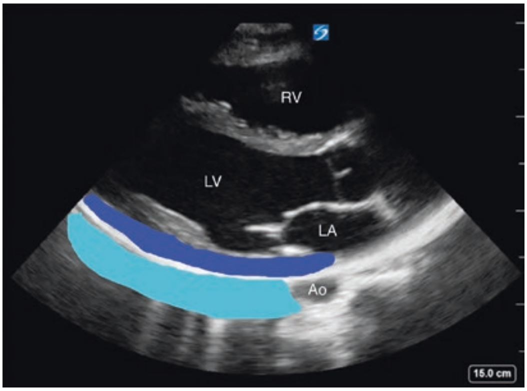

Fig. 27 Pericardial effusion vs. left sided pleural effusion. This parasternal long view demonstrates the distinguishing features of the relative locations where pericardial effusions (dark blue) and pleural effusions (light blue) would appear. Notice the pericardial effusion will travel anterior to the descending aorta, whereas the pleural effusion will not

Pericardiocentesis, draining of the pericardial effusion, should be done emergently in those patients with severe hemodynamic compromise or arrest. Ultrasound can be used to located the largest pocket of fluid to make drainage safer. This may be in the subxiphoid location, as is most commonly taught for this procedure, but an intercostal approach can be considered as well.

Regional Wall Motion Abnormality

Both acute and chronic myocardial ischemia and infarction can cause localized wall motion abnormalities in the region supplied by the affected coronary artery. The area of severely ischemic or infarcted myocardium will not contract, and therefore will appear as asymmetrical or lacking movement during systole. Such asymmetries may be visible in any view, but is most apparent using the PSSA, as this transverse view of the ventricles allows for evaluation of concentric movements almost continuously from base to apex. Areas of chronic ischemia or old infarctions will usually be thinner compared to neighboring regions, due to replacement of myocardium

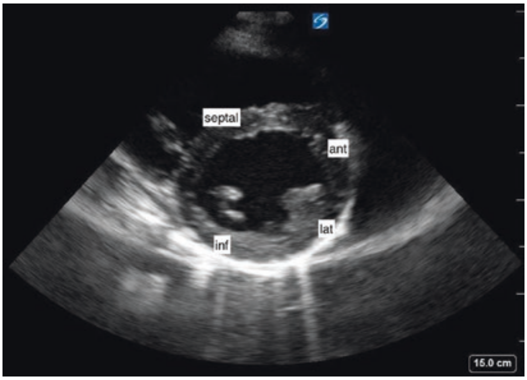

Fig. 28 Walls of LV labeled in parasternal short. Parasternal short cardiac view at the level of the papillary muscles showing the relative wall sections

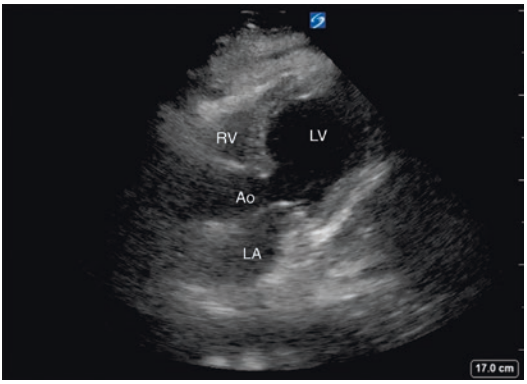

Fig. 29 Takotsubo Cardiomyopathy. Note the isolated apical dilation of the left ventricle (LV) in this subxiphoid view of Takotsubo cardiomyopathy, named after the Japanese word for octopus trap

by fibrotic scar tissue. In contrast, with acute infarctions there will be no difference in thickness of the myocardium at rest, though it will not contract and thicken during systole. EKG is the gold standard for evaluating for myocardial infarction, but in an austere environment in which EKGs or cardiac biomarker testing is not readily available, ultrasound may be the only diagnostic tool. Classically, EKG leads I, aVL, V5, and V6 refer to the lateral wall; leads II, III, and aVF refer to the inferior wall; leads V1-V2 refer to the septal wall; and leads V2-V4 refer to the anterior wall (Fig. 28). In patients in whom EKG findings are difficult to interpret, echocardiography may be useful in confirming suspected infarction. In other environments, ultrasound may be the only diagnostic tool for diagnosing acute myocardial ischemia in those patients with concerning chest pain or similar symptoms.

A rare condition called Takotsubo cardiomyopathy causes acute reversible apical or mid-chamber hypokinesis of the left ventricle. Takotsubo presents with similar symptoms to ACS. EKG findings typically include significant ST elevation of lateral leads, although without reciprocal depression. Otherwise known as stress cardiomyopathy, the ultrasonographic hallmark of this disorder is wall motion abnormalities that do not follow the distribution of any one coronary artery, making the left ventricle appear to balloon out at its apex (Fig. 29). While early recognition is helpful, this condition is treated as a STEMI until proven otherwise by cardiologists.

Aortic Dissection

An aortic dissection occurs when severely elevated blood pressure creates a tear in the arterial wall into which high pressure blood flows, creating a channel between the layers of the arterial wall known as a false lumen. This false passageway can obstruct arterial flow to branches off the aorta, extend into branches off the aorta, obstruct flow to the distal aorta, and even rupture. Aortic dissections are most commonly classified into Stanford Type A and Type B based on the origin of the false lumen. Type A dissections originate in the ascending aorta and involve the aortic arch and its branches. Type B dissections involve the descending aorta distal to the left subclavian. Type A is a true surgical emergency, with a 1–2% increase in mortality with each hour that passes until treatment is achieved [9]. Aortic dissections can have a variety of presentations, but most commonly patient's describe a ripping or tearing sensation in the chest or abdomen that radiates to the back. Other presenting complaints include syncope, new neurological symptoms, and hypotension, and therefore can be difficult to diagnose [9]. Imaging is absolutely crucial to early identification of this potentially fatal pathology, and using ultrasound has been proven to significantly improve time to diagnosis and mortality in suspected aortic dissection [10].

Ultrasonographic evidence of dissection can be difficult to detect. Therefore multiple views should be attempted in order obtain the most information. Evidence includes visualization of the dissection flap, aortic root dilatation, aortic regurgitation and pericardial effusion. A dissection flap will not be visible on ultrasound in the classic fashion that it would be on a CT scan. Often, a flap will be dynamic in position due to differences in blood pressure throughout the cycle. It will appear similar to a valve, moving in and out of the plane of the ultrasound image.

The parasternal long axis and the suprasternal view are best at identifying a type A dissection. The PSLA may show a dilated aortic root that is greater than 3.5 cm, aortic regurgitation using color Doppler, pericardial effusion if the dissection is contiguous with the pericardium, and sometimes a dissection flap. Evidence of acute pericardial effusion should always prompt investigation into the size of the aortic root. The suprasternal view is best at visualizing a type A dissection flap itself. The abdominal aorta should be scanned as well to evaluate for type B dissections. This is a similar scan to aortic aneursym screening, with less emphasis on specific landmarks, and more on scanning through the length of the abdominal aorta. Longitudinal views of the abdominal aorta are more useful for confirming a dissection flap than for screening.

It is important to remember that ultrasound is not a sensitive test for dissection, and should never be used to rule out this condition. However, in the right clinical scenario, visualization of a dissection flap should prompt aggressive blood pressure and heart rate control and evacuation or transport to a center with cardiothoracic surgery capabilities.

Pearls and Pitfalls

Echocardiography is one of the most difficult ultrasound skills to acquire, but perhaps the most critical regarding the management of acutely ill patients. It requires time and practice to master the ultrasonographic anatomy of the heart, the multiple different views, how to adapt these views to different body habitus, and finally to determine pathology. Despite these barriers, it is important to be mindful of that fact that the cardiac views obtained do not have to be perfect to learn useful clinical information. For example, if you wanted to evaluate the source of a patients hypotension, even limited views of the heart can determine if there is a pericardial effusion, enlarged RV, or fulminant heart failure. So, the bottom line is that you do not have to be an echocardiographic master to use ultrasound in the pre-hospital evaluation of a sick patient.

To build on that, the parasternal long axis view of the heart can help you evaluate for most of the pathology that is discussed in this chapter. Typically, it is the easiest to obtain. Remember to use the tips previously discussed to help you obtain this view: move up or down a rib space if the initial attempt is unsuccessful, bring the left arm up, roll the patient toward their left to bring the heart closer to the chest wall, and have the patient expire.

Despite best efforts at optimization, some patients will simply not have diagnostic cardiac views. The types of patients that tend to have very limited cardiac views include those with a history of midline sternotomy, are morbidly obese, have subcutaneous emphysema, have COPD, or are getting positive pressure ventilation. If this type of pathology is encountered, the cardiac exam may be non-diagnostic even under otherwise ideal or optimized conditions.

Finally, the ultrasound machine should be placed in the cardiac mode when imaging the heart. Failure to do so will result in reversed images that may confuse the novice provider. In the apical four chamber view, this will result in the left ventricle appearing where the right ventricle would be in standard imaging, and could result in false diagnosis of enlarged RV or other RV pathology.

Future Opportunities for Research

Cardiac ultrasound in the pre-hospital and austere settings is still an emerging field, with its potential applications yet to be fully realized. Currently, research has focused on examining its current use patterns and feasibility [11–13]. Because ultrasound has the potential to increase diagnostic certainty and allow for therapeutic interventions in the pre-hospital settings, its potential is dramatic. In more austere settings, it may be the only imaging modality available.

Future directions for cardiac ultrasonography in these environments are emerging in several different areas including advanced triage, telemedicine, and early interventions. Regarding advanced triage, especially in the setting of mass casualty events, the use of cardiac ultrasound to identify potentially life threatening conditions that can be intervened upon early can change a victim's status and identify those in whom that early intervention can be life saving [14]. In less acute settings, such as remote villages or other austere settings, cardiac ultrasonography can assist in the decision making to escalate treatment, marshal resources or even transfer a patient to get more advanced care. For example, a patient in whom a large pericardial effusion with evidence of tamponade was identified as the source of hypotension should have a pericardiocentesis performed, but it would not be advisable for the patient to remain in an austere setting if transfer was an option.

Through the use of increasingly advanced ultrasound, wireless technology, and ever-present cell phones, it is easier than ever to transmit ultrasound images in real time. This opens up several different avenues for which ultrasound can be useful in these prehospital or remote settings [15]. First, experts that are physically in a different location from the patient and provider can direct that provider, in real time, in order to assist in obtaining cardiac images, which can be especially useful for less experienced providers. Furthermore, images transmitted in real-time can be used to make early, critical diagnoses that can then direct downstream resource utilization and patient management.

Finally, in a more extreme situation, ultrasound is being used to assist in ECMO cannulization in the prehospital setting in several European countries with promise [16]. This intervention and use of ultrasound requires advanced knowledge and practical expertise, so it is currently limited to only select physician and paramedic teams, but represents another potential for the use of ultrasound in the pre-hospital environment.

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