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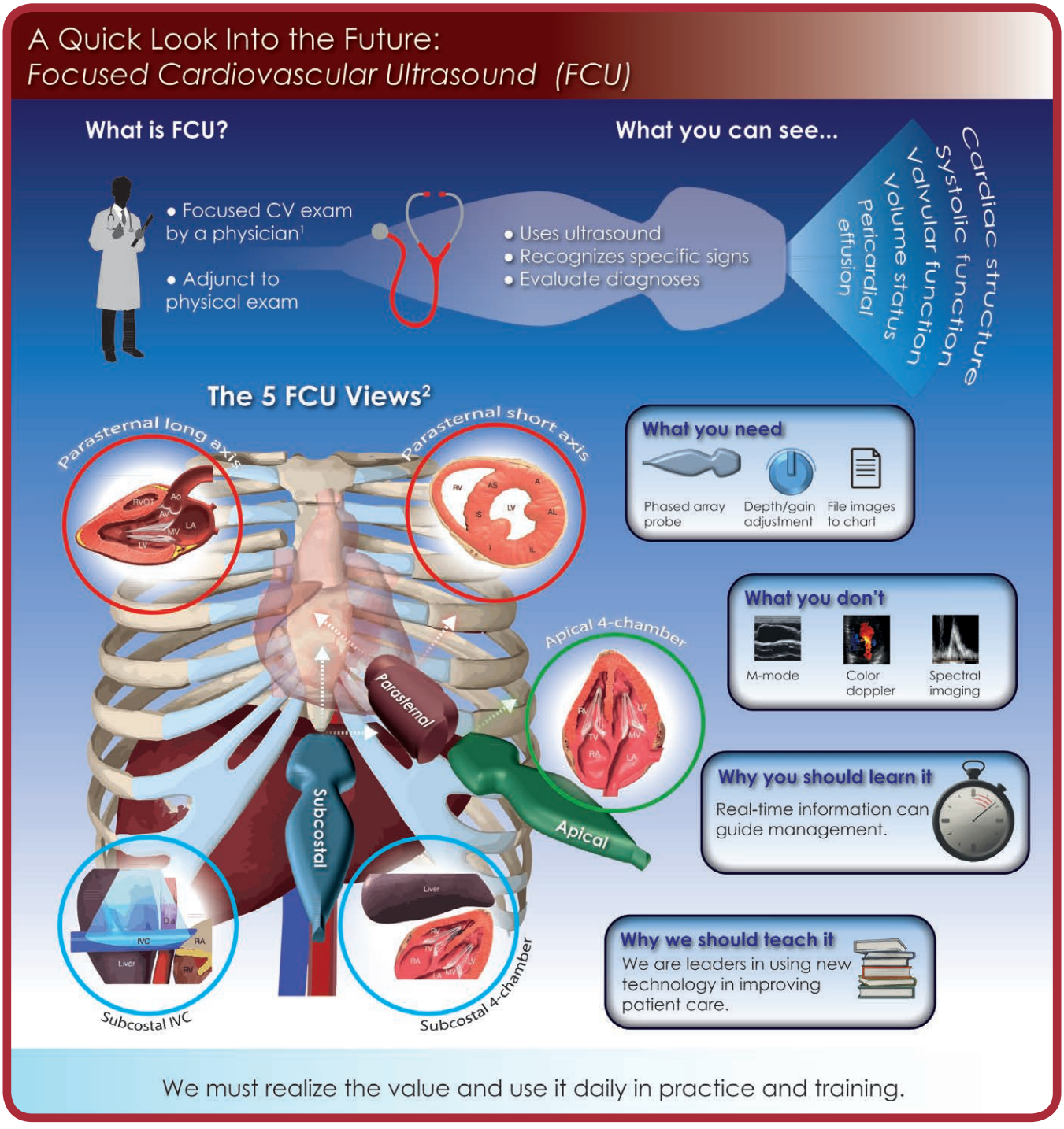

Focused cardiovascular ultrasound has been made feasible by recent technological advances in ultrasound that have reduced the cost, size and complexity of performing point-of-care ultrasound examinations. In this infographic, we describe the key functions of ultrasound necessary to perform focused cardiovascular ultrasound, the core ultrasound views needed, and the factors that are influencing its adoption.[1,2]

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IARS International Anesthesia Research Society

The authors declare no conflicts of interest.

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2. Zimmerman JM, Coker BJ. The nuts and bolts of performing focused cardiovascular ultrasound (FoCUS). *Anesth Analg* 2017; 124:753–760.

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SPECIAL ARTICLE

CME

The Nuts and Bolts of Performing Focused Cardiovascular Ultrasound (FoCUS)

Josh M. Zimmerman, MD, FASE,* and Bradley J. Coker, MD†

The benefit of focused cardiovascular ultrasound as an adjunct to physical examination has been shown in numerous specialties and in diverse clinical settings. Although the value of these techniques to the practice of anesthesiology is substantial, they have only begun to be incorporated. This article reviews the basic techniques required to perform a bedside focused cardiovascular ultrasound (ie, FoCUS examination). This includes a discussion of patient positioning, breath control, probe position, and manipulation and was supplemented by normal and abnormal examples for review. (Anesth Analg 2017;124:753–60)

This article reviews the basic techniques required to perform a focused cardiovascular ultrasound (FoCUS) examination at the bedside. It begins with indications, limitations, and equipment, then describes in detail the nuts and bolts of physically performing the examination. For each of the views, there is a discussion of patient positioning and technique, a brief review of anatomy, and examples of normal and abnormal images. This article is also accompanied by a Supplemental Video tutorial that demonstrates the techniques described herein (Supplemental Digital Content, http://links.lww.com/AA/B686). Obviously, no article is adequate to train a provider without a background in cardiovascular ultrasound. The goal of this article is not to provide comprehensive education but rather a solid introduction and reference for further practice. A broader description of the history, application, value, and training required for anesthesiologists to perform these techniques has been published separately.

FoCUS should be seen as an extension of the physical examination rather than as a limited version of a comprehensive echocardiogram. When viewed in this light, ultrasound can expand dramatically the diagnostic potential of the bedside evaluation. Although there are numerous potential reasons to perform FoCUS, the most common indications in the perioperative period include signs or symptoms of heart failure and hemodynamic instability. The diagnostic targets of FoCUS include evaluation of cardiac structure, biventricular systolic function, valvular function, pericardial effusion, and volume status.

It is important that physicians performing FoCUS have a clear understanding of the limitations inherent to the techniques, as well as the limitations of their individual level of skill, training, and experience. Furthermore, the pocket-sized devices often used for FoCUS cannot be expected to have the same image quality and resolution of a full-service platform. The FoCUS examination is neither comprehensive nor designed to make quantitative assessments.[1] Subtle abnormalities may be overlooked, and there may be uncertainty regarding the severity of abnormalities that are identified. There is a natural tendency to place a high value on what can be seen, and the practitioner of FoCUS needs to be careful to neither lock in nor exclude diagnoses based on limited ultrasound information. The findings of an examination always should be taken in context, with a healthy suspicion that the interpretation could be flawed or incomplete and with a low threshold to request a second opinion or a formal echocardiogram to confirm findings.

EQUIPMENT AND ULTRASOUND PROBE SELECTION

Focused ultrasound can be performed with any of a variety of ultrasound machines, from the stand-alone full-service echocardiography platforms, to smaller portable machines, to the smallest pocket-sized ultrasound devices. It is not the type of machine that defines focused ultrasound but the training of the provider and the scope of the clinical questions being addressed. Any ultrasound system can be used so long as it meets the following requirements: availability of a 2-dimensional phased array (cardiac) probe of appropriate frequency for adult patients; the ability to record date, time, and patient identifiers with the images; and the ability to adjust gain and depth. The availability of M-mode, color flow Doppler, spectral Doppler imaging, and measurement tools are not required for a FoCUS examination.[1,2] Electrocardiogram (ECG) capability is not required for FoCUS, and some machines may not be able to display ECG. When machines with this capability are used, however, ECG leads should be connected to ensure that images are acquired appropriately.

ULTRASOUND PROBE TERMINOLOGY

Because the language used to describe ultrasound probe manipulation is not standardized, the terminology used in this article needs to be defined. For cardiac ultrasound, the probe is held in the left hand so that the right hand can be used to manipulate the machine. All probes will have an indicator, generally a light or a notch, that corresponds to an orientation marker, usually a dot, on the ultrasound image. For cardiac ultrasound, the orientation marker is on

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the right of the ultrasound image. Although probe orientation can be confusing for new bedside ultrasonographers, it need not be. The ultimate goal is to create the correct orientation on the screen. If the image appears reversed, simply rotate the probe 180°. When describing probe motion, the authors will use the following terminology:

Sliding. Motion of the probe to a different position on the body. This will also be described as "window shopping." This is done to find the optimal position from which to image, particularly when trying to scan between ribs. The sliding motion can be done to move from one interspace to another (larger motions), or to optimize imaging at a given interspace (small motions).

Tilting. With the probe kept at the same location on the body, a rocking motion is applied to the probe to image different structures within the same plane (Figure 1). This is done most commonly to center an image on the screen and represents a motion of the "tail" or cord of the transducer toward or away from the probe's indicator.

Angulation. With the probe kept at the same location on the body, the transducer is moved side-to-side to create new imaging planes relatively parallel to the original plane. This motion will be at angles perpendicular to the tilting motion.

Rotation. With the probe otherwise held still, it is turned around its central axis similar to turning a key in a lock.

ULTRASOUND IMAGE TERMINOLOGY

Window. The term window is used to describe the location of the ultrasound probe. Just like a window in a house, this is what the transducer transducer looks through to see the heart. The 3 windows described in FoCUS are parasternal, apical, and subcostal (Figure 2).

Plane. This is the anatomic plane or cross section of the heart that is made by the ultrasound beam. The 3 planes used for the FoCUS examination are the long axis, short axis, and 4 chamber.

1. Long axis: Parallel to the long axis of the left ventricle (LV), simultaneously intersecting the apex of the LV, the center of the aortic valve (AV), and the center of the mitral valve in the anterior–posterior dimension.
2. Short axis: Perpendicular to the long axis of the ventricle, showing a circular cross section of the ventricle. In the case of FoCUS, the LV short axis will be at the level of the papillary muscles.
3. Four chamber: Perpendicular to the short axis, this plane simultaneously transects the apex of the LV, both ventricles and atria, and the mitral and tricuspid valves.

View. A combination of window and plane used to describe a particular image. For instance, the parasternal long-axis (PLAX) view is made from the parasternal window and transects the heart in the long axis plane.

KNOBOLOGY AND IMAGE OPTIMIZATION

A detailed understanding of ultrasound physics is not necessary for the practitioner of FoCUS; however, some understanding of image optimization will prove useful. The following settings are available on many of the simplest ultrasound devices.

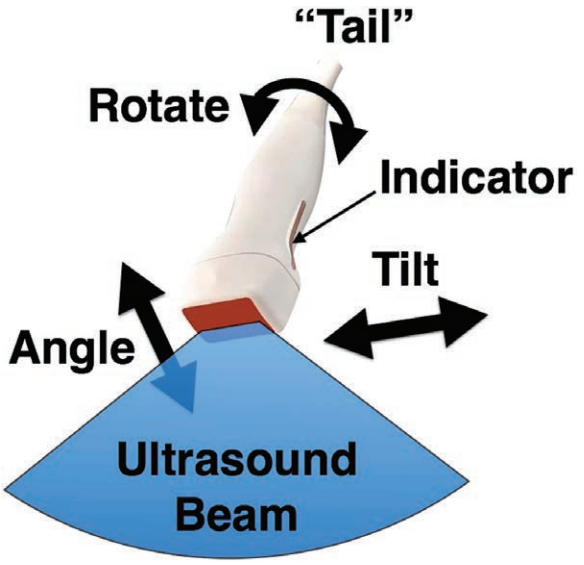


Figure 1. Ultrasound probe manipulation nomenclature. Tilt moves the probe in the plane of the ultrasound beam, angle moves the probe perpendicular to the beam (creating new planes parallel to the original), and rotate turns the probe like a key in a lock.

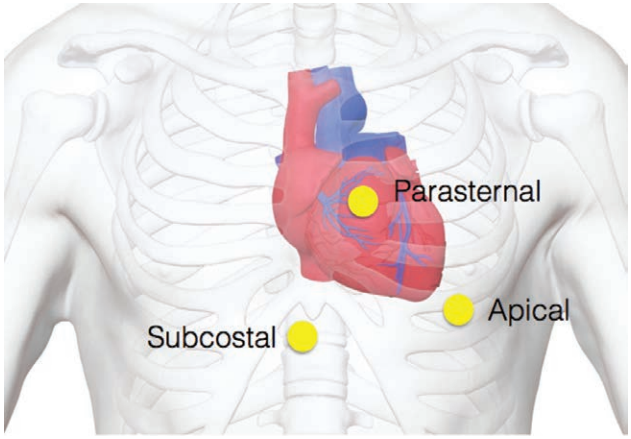


Figure 2. The heart in the chest, with the sternum and ribs to provide orientation. The 3 windows are indicated by the yellow dots.

Depth. The depth of scanning for each image should be set to include the structures of interest and nothing else (as shown in the video examples). Inappropriately increasing the depth of scanning both makes relevant structures appear smaller and results in an image that is refreshed less frequently with less temporal resolution and quality.

Gain. This setting affects the displayed brightness of the ultrasound image. Gain should be set so that blood appears black rather than gray. A reasonable setting could be achieved by turning gain up until blood appears gray, then decreasing it slightly.

Time-Gain Compensation. Some ultrasound systems offer the ability to automatically adjust gain to optimize the display and to provide uniform brightness throughout the image rather than an image that becomes darker at increasing depth due to the lower strength of the returned signal. Sometimes

referred to as the "make it better button," it can be a quick way to improve the gain and image display settings.

PARASTERNAL WINDOW

Patient Positioning. A complete FoCUS examination often can be performed in the supine patient, and clinical situations in which patients cannot be turned will be encountered frequently. Parasternal imaging, however, would ideally be performed in the full left-lateral decubitus position, with the patient's left arm extended. It is often comfortable for patient to rest their left forearms under their head (Figure 3). For all FoCUS imaging, the ultrasonographer should be positioned on the patient's left side with the probe held in the left hand, leaving the right hand free to manipulate the ultrasound machine.

Breath Control. Imaging from every window is better if patients can breathe shallowly. In spontaneously ventilating patients, parasternal images are often best at end-exhalation when there is less lung interposed between the probe and the heart. If possible, having patients briefly hold their breath at a low lung volume can improve imaging from the parasternal window. The authors' technique is to instruct the patient to "Take a deep breath in, now breathe all the way out and hold it…hold it…hold it…now breathe." This reminds the patient not to begin breathing in until adequate images have been obtained. In intubated patients, it can help to briefly pause the ventilator to allow a passive exhalation.

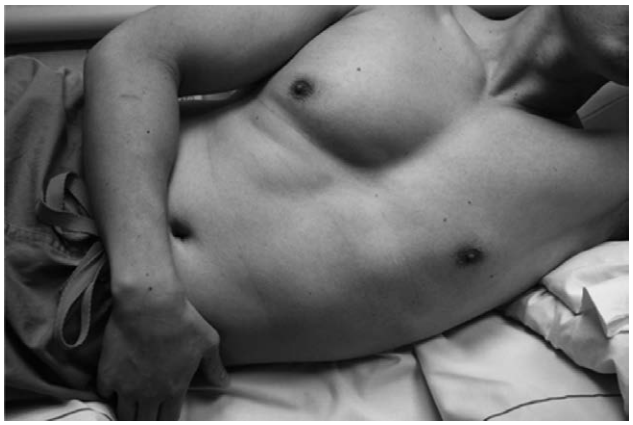


Figure 3. Optimal patient positioning for the parasternal window. The patient is in the left lateral decubitus position with his left arm extended.

Parasternal Long Axis (Supplemental Digital Content, Video 1, http://links.lww.com/AA/B611)

Probe Position and Manipulation. The PLAX image is made with the probe placed just to the left of the sternum in the third to fifth intercostal space with the indicator pointed toward the patient's right shoulder (Figure 4). The technique referred to by the authors as "window shopping" should be used. This entails moving the probe briefly across the left parasternal interspaces to select the one that provides the best image. After identifying the best window, small changes in rotation, tilt, and angle should be made to optimize the image.

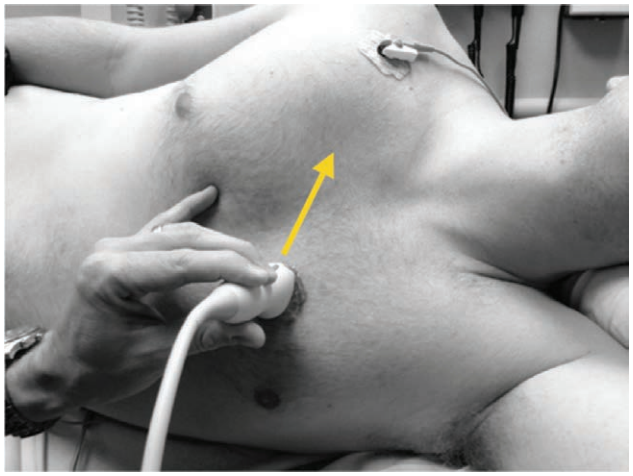


Figure 4. Probe position for the parasternal long axis (PLAX.) The probe is just to the left of the sternum, in the fourth intercostal space (though this location will vary), with the indicator pointing toward the patient's right shoulder. The indicator location and direction is shown by the yellow arrow.

Anatomy. The PLAX shows the right ventricular outflow tract (RVOT), the AV and proximal ascending aorta, the left atrium, mitral valve, and the basal and mid segments of the anteroseptal and inferolateral walls of the LV (Supplemental Digital Content, Video 1, http://links.lww.com/AA/B611; Figure 5).

Assessment. A great deal of valuable information is available from the PLAX image. The authors recommend a consistent approach to evaluating this image, starting with the RVOT and moving clockwise.

1. Right ventricle (RV): Although this image is not the best to quantify the size or function of the RV, the sonographer can get a sense of significant RV enlargement or dysfunction. The RVOT should appear similar in size to the aortic root in this view. As discussed previously, all assessment of chamber size with FoCUS is qualitative but nonetheless valuable.
2. AV: The structure and opening of the AV can be assessed. A valve that opens well, even if calcified, is not likely to have clinically significant stenosis. An AV

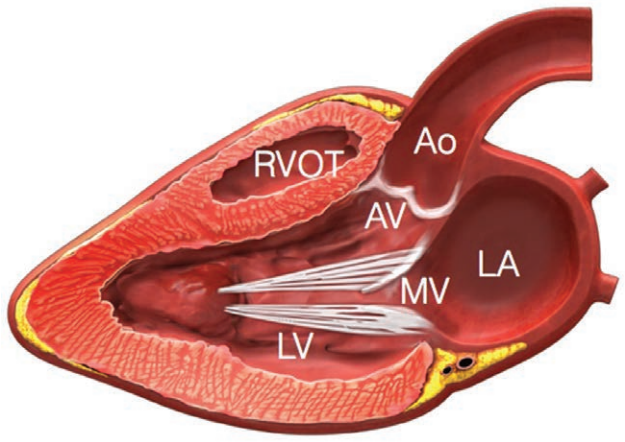
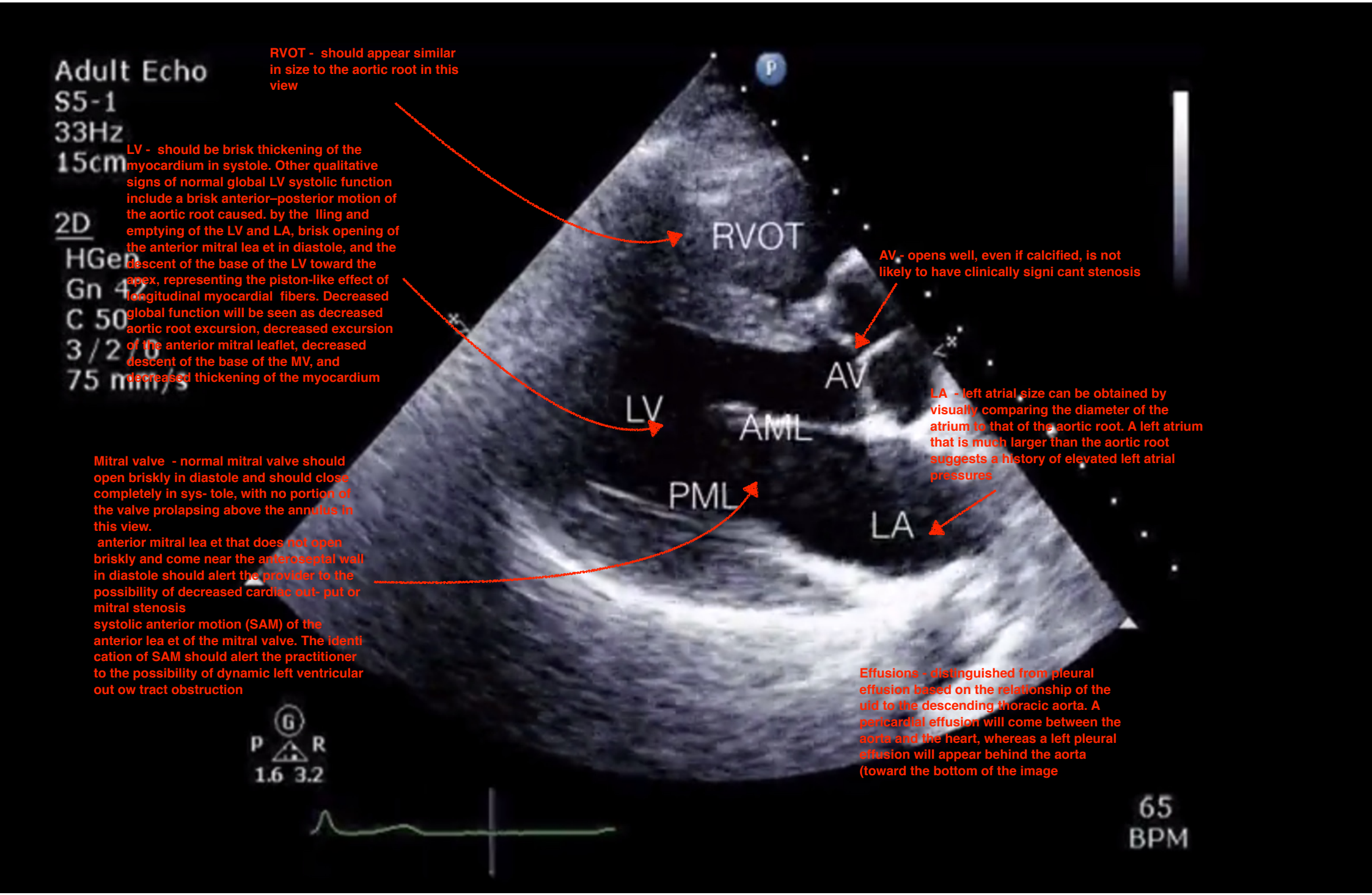


Figure 5. Anatomy of the PLAX. At the top of the screen, closest to the ultrasound probe, is the right ventricular outflow tract (RVOT). Moving clockwise, the aortic valve (AV) and proximal ascending aorta (Ao) are seen, then the left atrium (LA), mitral valve (MV) and left ventricle (LV). PLAX indicates parasternal long axis.


Adult Echo
S5-1
33Hz
15cm
2D
HGen
Gn 4
C 50
3/2
75 mm/s
RVOT - should appear similar in size to the aortic root in this view
LV - should be brisk thickening of the myocardium in systole. Other qualitative signs of normal global LV systolic function include a brisk anterior–posterior motion of the aortic root caused. by the lling and emptying of the LV and LA, brisk opening of the anterior mitral lea et in diastole, and the descent of the base of the LV toward the apex, representing the piston-like effect of longitudinal myocardial fibers. Decreased global function will be seen as decreased aortic root excursion, decreased excursion of the anterior mitral leaflet, decreased descent of the base of the MV, and decreased thickening of the myocardium
RVOT
AV - opens well, even if calcified, is not likely to have clinically signi cant stenosis
AV
LV
AML
LA - left atrial size can be obtained by visually comparing the diameter of the atrium to that of the aortic root. A left atrium that is much larger than the aortic root suggests a history of elevated left atrial pressures
PML
LA
Mitral valve - normal mitral valve should open briskly in diastole and should close completely in sys- tole, with no portion of the valve prolapsing above the annulus in this view.
anterior mitral lea et that does not open briskly and come near the anteroseptal wall in diastole should alert the provider to the possibility of decreased cardiac out- put or mitral stenosis
systolic anterior motion (SAM) of the anterior lea et of the mitral valve. The identi cation of SAM should alert the practitioner to the possibility of dynamic left ventricular out ow tract obstruction
Effusions - distinguished from pleural effusion based on the relationship of the uid to the descending thoracic aorta. A pericardial effusion will come between the aorta and the heart, whereas a left pleural effusion will appear behind the aorta (toward the bottom of the image
P
R
1.6 3.2
65
BPM

that is heavily calcified and opens poorly should alert the provider to the possibility of significant aortic stenosis (Supplemental Digital Content, Video 2, http://links.lww.com/AA/B612).

3. Left atrium: A qualitative assessment of left atrial size can be obtained by visually comparing the diameter of the atrium to that of the aortic root. A left atrium that is much larger than the aortic root suggests a history of elevated left atrial pressures (from diastolic dysfunction, mitral valve disease, or atrial fibrillation). (Supplemental Digital Content, Video 2, http://links.lww.com/AA/B612).
4. Mitral valve: A normal mitral valve should open briskly in diastole and should close completely in systole, with no portion of the valve prolapsing above the annulus in this view. Leaflet tissue that extends above the annulus in systole suggests mitral valve prolapse or flail (Supplemental Digital Content, Video 3, http://links.lww.com/AA/B613). An anterior mitral leaflet that does not open briskly and come near the anteroseptal wall in diastole should alert the provider to the possibility of decreased cardiac output or mitral stenosis (Supplemental Digital Content, Video 4, http://links.lww.com/AA/B614). Mitral annular calcification (MAC), particularly at the base of the posterior leaflet, is a common finding in patients with hypertension, vascular disease, and renal failure (Supplemental Digital Content, Video 2, http://links.lww.com/AA/B612). Because MAC affects the base of the valve rather than the coaptation, it is a rare cause of hemodynamically significant stenosis. Rheumatic mitral valve disease, on the other hand, affects the subvalvular apparatus, commissures, and coaptation early in the disease process and creates what is described as a "hockey stick" deformity with stenosis resulting from a much smaller degree of leaflet thickening (Supplemental Digital Content, Video 5, http://links.lww.com/AA/B615). Another important abnormality that can be identified from the PLAX is systolic anterior motion (SAM) of the anterior leaflet of the mitral valve. The identification of SAM should alert the practitioner to the possibility of dynamic left ventricular outflow tract obstruction. This pathology can be seen in hypertrophic cardiomyopathy but also can be seen in patients with small, thick ventricles and abnormal mitral leaflet tissue. The findings can be subtle but should be sought when patients present with hemodynamic instability, syncope, or heart failure symptoms. It should be suspected when a portion of the mitral valve appears to be drawn into the left ventricular outflow tract during late systole (Supplemental Digital Content, Video 6, http://links.lww.com/AA/B616).
5. LV: Although only a portion of the anteroseptal and inferolateral walls are viewed in this image, a good sense of global and regional function can be obtained in the PLAX. There should be brisk thickening of the myocardium in systole. Other qualitative signs of normal global LV systolic function include a brisk anterior–posterior motion of the aortic root caused by the filling and emptying of the LV and LA, brisk opening of the anterior mitral leaflet in diastole, and the descent of the base of the LV toward the apex, representing the piston-like effect of longitudinal myocardial fibers. Decreased global function will be seen as decreased aortic root excursion, decreased excursion of the anterior mitral leaflet, decreased descent of the base of the MV, and decreased thickening of the myocardium (Supplemental Digital Content, Video 4, http://links.lww.com/AA/B614).
6. Effusions: Pericardial effusion can sometimes be identified in this view and can be distinguished from pleural effusion based on the relationship of the fluid to the descending thoracic aorta. A pericardial effusion will come between the aorta and the heart, whereas a left pleural effusion will appear behind the aorta (toward the bottom of the image) (Supplemental Digital Content, Video 7, http://links.lww.com/AA/B617). To ensure that effusion is not overlooked, the sonographer should begin imaging the PLAX with adequate depth to visualize at least 5 cm beyond the descending aorta.

Parasternal Short Axis (PSAX) (Supplemental Digital Content, Video 8, http://links.lww.com/AA/B618)

Probe Position and Manipulation. Starting with the PLAX view, the short-axis image is made by keeping the probe in the same location and rotating 90° clockwise so the indicator points toward the patients left shoulder (Figure 6).

Anatomy. The PSAX view transects the left and right ventricles at the level of the papillary muscles (the mid-portion of the LV). The short-axis section is like slices in a loaf of bread. The mid-segments of each of the 6 ventricular walls can be seen, representing myocardial territories perfused by each of the 3 main coronary arteries (Figure 7).

Assessment. The PSAX gives important information about global and regional ventricular function and filling and is useful particularly in the hemodynamically unstable patient.

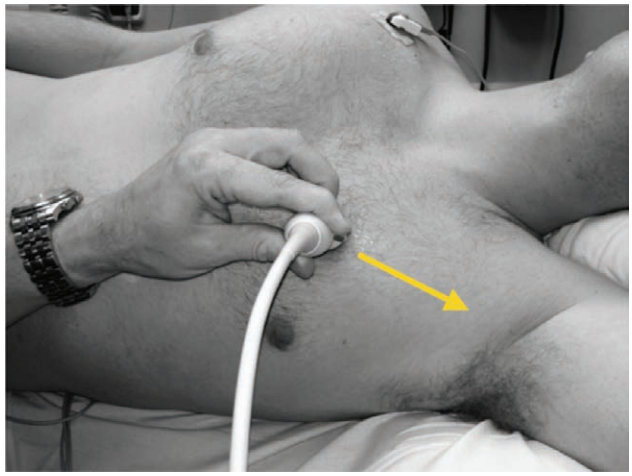
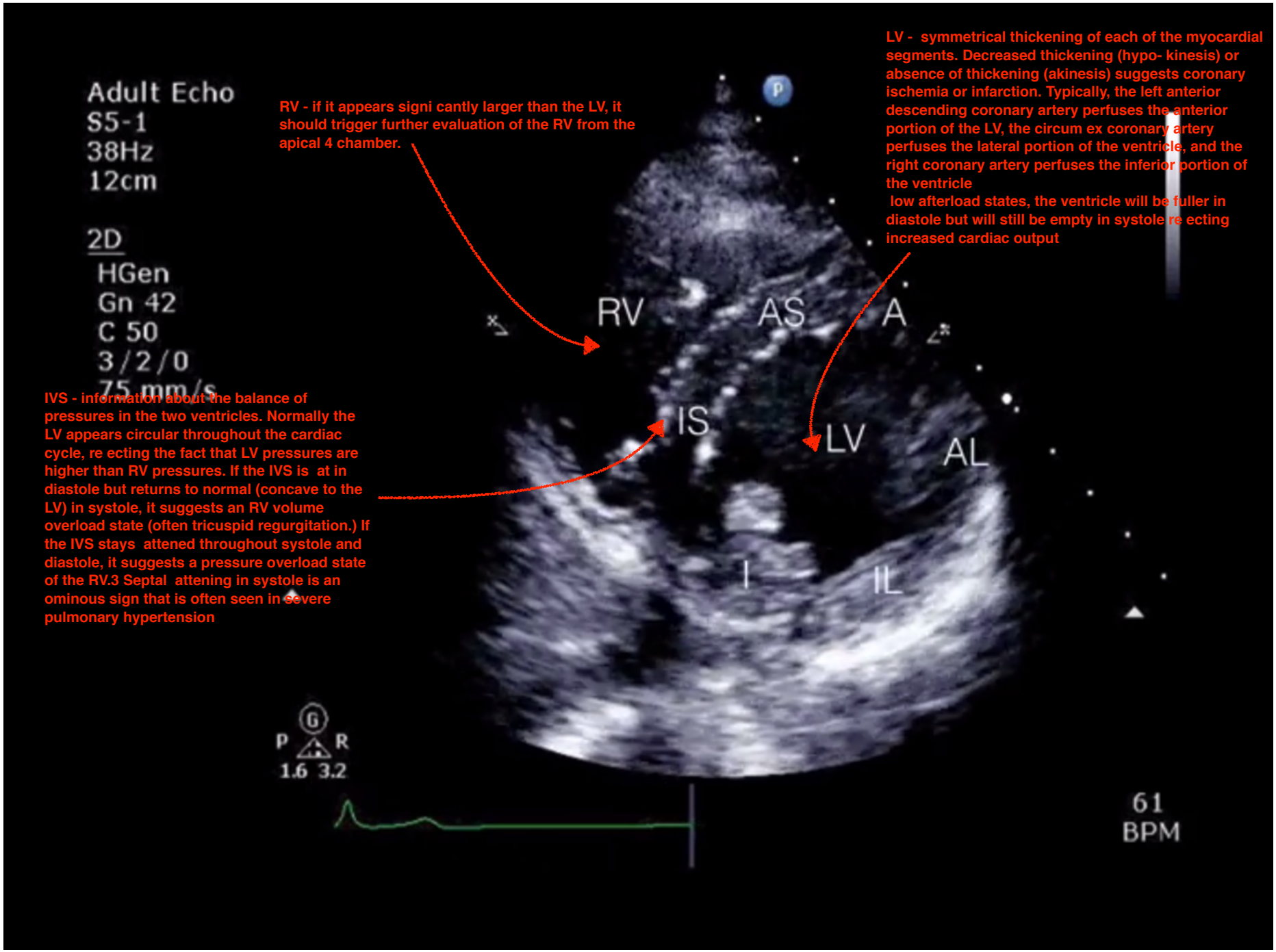


Figure 6. Probe position for the parasternal short axis (PSAX.) The probe is just to the left of the sternum, in the fourth intercostal space (though this location will vary), with the indicator pointing toward the patient's left shoulder. The indicator location and direction is shown by the yellow arrow.


Adult Echo
S5-1
38Hz
12cm
2D
HGen
Gn 42
C 50
3/2/0
75 mm/s
RV - if it appears signi cantly larger than the LV, it should trigger further evaluation of the RV from the apical 4 chamber.
LV - symmetrical thickening of each of the myocardial segments. Decreased thickening (hypo- kinesis) or absence of thickening (akinesis) suggests coronary ischemia or infarction. Typically, the left anterior descending coronary artery perfuses the anterior portion of the LV, the circum ex coronary artery perfuses the lateral portion of the ventricle, and the right coronary artery perfuses the inferior portion of the ventricle
low afterload states, the ventricle will be fuller in diastole but will still be empty in systole re ecting increased cardiac output
IVS - information about the balance of pressures in the two ventricles. Normally the LV appears circular throughout the cardiac cycle, re ecting the fact that LV pressures are higher than RV pressures. If the IVS is at in diastole but returns to normal (concave to the LV) in systole, it suggests an RV volume overload state (often tricuspid regurgitation.) If the IVS stays attened throughout systole and diastole, it suggests a pressure overload state of the RV.3 Septal attening in systole is an ominous sign that is often seen in severe pulmonary hypertension
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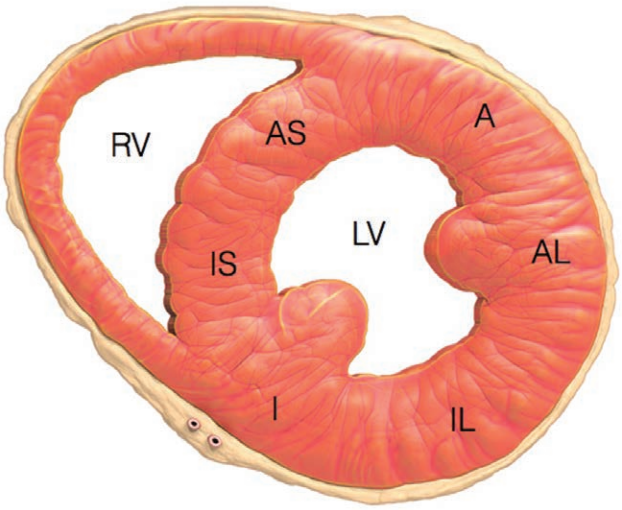


Figure 7. Anatomy of the PSAX. The right ventricle is seen on the left side of the screen and defines the 2 septal walls of the left ventricle. The papillary muscles are seen, identifying this as the midportion of the ventricle. Six segments of the ventricle are shown, representing distributions of all 3 coronary arteries. A, mid-anterior segment of the LV; AL indicates mid-anterolateral segment of the LV; AS, mid-anteroseptal segment of the LV; I, mid-inferior segment of the LV; IL, mid-inferolateral segment of the LV; IS, mid-inferoseptal segment of the LV; LV, left ventricle; PSAX, parasternal short axis; RV, right ventricle.

1. LV: In a ventricle with normal regional function, the PSAX will have symmetrical thickening of each of the myocardial segments. Decreased thickening (hypokinesis) or absence of thickening (akinesis) suggests coronary ischemia or infarction. Typically, the left anterior descending coronary artery perfuses the anterior portion of the LV, the circumflex coronary artery perfuses the lateral portion of the ventricle, and the right coronary artery perfuses the inferior portion of the ventricle (Supplemental Digital Content, Video 9, http://links.lww.com/AA/B619). In hypovolemic states, the LV will appear relatively small in diastole with hyperdynamic systolic function (Supplemental Digital Content, Video 10, http://links.lww.com/AA/B620). In low afterload states, the ventricle will be fuller in diastole but will still be empty in systole reflecting increased cardiac output (Supplemental Digital Content, Video 11, http://links.lww.com/AA/B621).
2. Right ventricle: The right ventricle is not the focus of the PSAX, but if it appears significantly larger than the LV, it should trigger further evaluation of the RV from the apical 4 chamber.
3. Interventricular septum (IVS): The behavior and position of the IVS can give important information about the balance of pressures in the two ventricles. Normally the LV appears circular throughout the cardiac cycle, reflecting the fact that LV pressures are higher than RV pressures. If the IVS is flat in diastole but returns to normal (concave to the LV) in systole, it suggests an RV volume overload state (often tricuspid regurgitation.) If the IVS stays flattened throughout systole and diastole, it suggests a pressure overload state of the RV.[3] Septal flattening in systole is an ominous sign that is often seen in severe pulmonary hypertension (Supplemental Digital Content, Video 12, http://links.lww.com/AA/B622).

APICAL WINDOW

Patient Positioning. Like the parasternal window, the apical window is best imaged with the patient in the left lateral decubitus position. Apical images are often more challenging than parasternal images when performed in the supine position and even a small amount of left tilt of the patient can improve the images. This can be achieved in some cases by a towel or pillow bump under the right side of the patient. With the patient in the full left-lateral decubitus position, it can be challenging to place the ultrasound probe at the true apex. This problem can result in an image with the right ventricle at the apex of the screen, giving the false impression of RV enlargement. This can be overcome either by moving the patient all the way to the edge of the bed or by tipping the patient slightly back from a true left lateral position.

Breath Control. Unlike the parasternal window, the optimal lung volume for apical images is less predictable. The LV apex generally moves slightly caudally as the patient inhales. After finding a reasonable window, the patient can be asked to breathe in or out slowly until the best apical image is achieved. They can then be asked to hold their breath using the same "hold it…hold it…hold it, now breathe" technique described earlier.

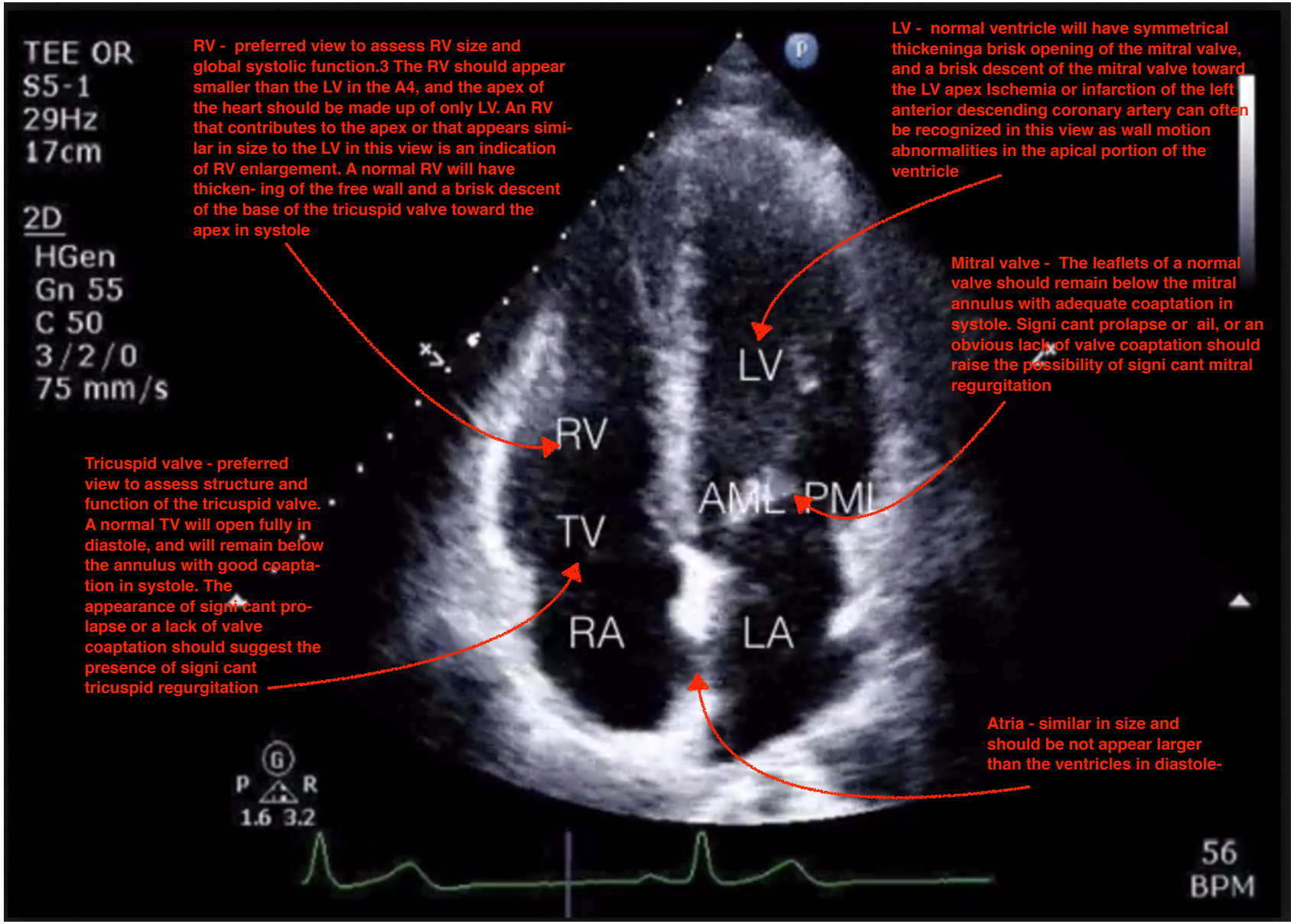
Apical 4-Chamber (A4) (Supplemental Digital Content, Video 13, http://links.lww.com/AA/B623)

Probe Position and Manipulation. The A4 image generally is more challenging than the parasternal or subcostal images. The first step is to identify the correct window for imaging. Again, this will involve a degree of window shopping. In some cases, palpation of the point of maximal impulse can be useful, though the authors generally identify the apex with ultrasound alone. The apex is usually just inferior and lateral to the nipple in men, and under the inferolateral quadrant of the left breast in women. Starting slightly medial to the expected location and moving the probe cephalad and caudad over several interspaces while slowly sliding laterally can help identify the apex. For the 4-chamber plane, the probe indicator will be often be pointed to the 5 o'clock position when viewed from above (Figure 8).

Anatomy. The apex of the LV should be at the top of the screen. The inferoseptal and anterolateral walls of the LV can be seen, and 6 myocardial segments (basal, mid-, and apical) can be identified. The longer anterior mitral leaflet can be seen medially with the shorter posterior leaflet laterally. The right ventricle can be seen as well, with the tricuspid valve displaced slightly toward the apex relative to the mitral valve. The left and right atrial should be visualized at the bottom of the image (Figure 9).

Assessment.

1. Left ventricle: This is another excellent view to assess global and regional left ventricular systolic function. A normal ventricle will have symmetrical thickening,


TEE OR
S5-1
29Hz
17cm
2D
HGen
Gn 55
C 50
3/2/0
75 mm/s
RV - preferred view to assess RV size and global systolic function.3 The RV should appear smaller than the LV in the A4, and the apex of the heart should be made up of only LV. An RV that contributes to the apex or that appears simi- lar in size to the LV in this view is an indication of RV enlargement. A normal RV will have thicken- ing of the free wall and a brisk descent of the base of the tricuspid valve toward the apex in systole
LV - normal ventricle will have symmetrical thickeninga brisk opening of the mitral valve, and a brisk descent of the mitral valve toward the LV apex Ischemia or infarction of the left anterior descending coronary artery can often be recognized in this view as wall motion abnormalities in the apical portion of the ventricle
Mitral valve - The leaflets of a normal valve should remain below the mitral annulus with adequate coaptation in systole. Signi cant prolapse or ail, or an obvious lack of valve coaptation should raise the possibility of signi cant mitral regurgitation
Tricuspid valve - preferred view to assess structure and function of the tricuspid valve. A normal TV will open fully in diastole, and will remain below the annulus with good coapta- tion in systole. The appearance of signi cant pro- lapse or a lack of valve coaptation should suggest the presence of signi cant tricuspid regurgitation
Atria - similar in size and should be not appear larger than the ventricles in diastole-
LV
RV
AML
PMI
TV
RA
LA
P
R
1.6
3.2
56
BPM

a brisk opening of the mitral valve, and a brisk descent of the mitral valve toward the LV apex (Supplemental Digital Content, Video 13, http://links.lww.com/AA/B623). Ischemia or infarction of the left anterior descending coronary artery can often be recognized in this view as wall motion abnormalities in the apical portion of the ventricle (Supplemental Digital Content, Video 14, http://links.lww.com/AA/B624).

2. Mitral valve: The leaflets of a normal valve should remain below the mitral annulus with adequate coaptation in systole. Significant prolapse or flail, or an obvious lack of valve coaptation should raise the possibility of significant mitral regurgitation (Supplemental Digital Content, Video 15, http://links.lww.com/AA/B625). MAC and rheumatic valve changes can also be identified, as described in the PLAX assessment (Supplemental Digital Content, Video 2, http://links.lww.com/AA/B612; and Supplemental Digital Content, Video 16, http://links.lww.com/AA/B626).
3. Atria: The relative sizes of the atria can be assessed qualitatively in this view. They should be similar in size and should be not appear larger than the ventricles in diastole (Supplemental Digital Content, Video 16, http://links.lww.com/AA/B626).
4. Right ventricle: This is the preferred view to assess RV size and global systolic function.[3] The RV should appear smaller than the LV in the A4, and the apex of the heart should be made up of only LV. An RV that contributes to the apex or that appears similar in size to the LV in this view is an indication of RV enlargement. A normal RV will have thickening of the free wall and a brisk descent of the base of the tricuspid valve toward the apex in systole (Supplemental Digital Content, Video 17, http://links.lww.com/AA/B627).
5. Tricuspid valve: This is also the preferred view to assess structure and function of the tricuspid valve. A normal TV will open fully in diastole, and will remain below the annulus with good coaptation in systole. The appearance of significant prolapse or a lack of valve coaptation should suggest the presence of significant tricuspid regurgitation (Supplemental Digital Content, Video 18, http://links.lww.com/AA/B628).

SUBCOSTAL WINDOW

Patient Positioning. Subcostal images are obtained with the patient in the supine position. In patients who are awake, the tone of the abdominal muscles can occasionally make imaging difficult. In these cases, the patient should place a pillow behind his/her knees or rest his/her feet on the bed.

Subcostal 4-Chamber (SC4) (Supplemental Digital Content, Video 19, http://links.lww.com/AA/B629)

Probe Position and Manipulation. The subcostal window is usually found 1 to 2 cm below the xiphoid process or slightly to the right of midline. There is a tendency for the probe to drift toward the patients left because this is where the heart is known to be, but to make the best subcostal images the liver needs to be used as the window rather than the stomach or spleen. To create the SC4 image, the probe is placed on the abdomen nearly horizontally with the indicator pointing directly to the patient's left (Figure 10). The technique of creating the subcostal window

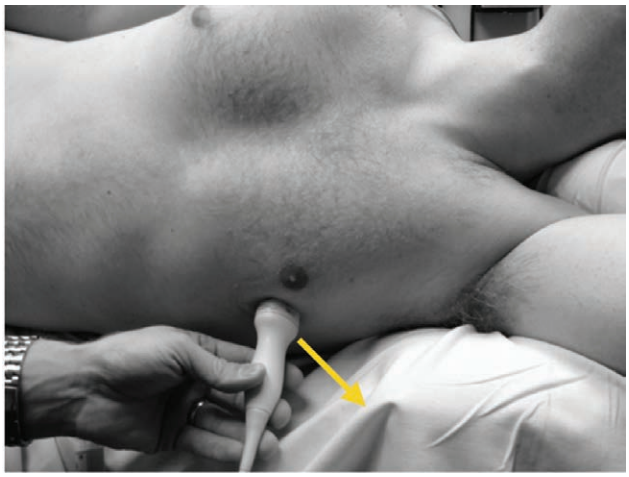


Figure 8. Probe position for the apical 4 chamber. The patient is in the left lateral decubitus position with their left arm extended. The probe is located just inferior and lateral to the left nipple, with the indicator pointed toward 5 o'clock (as viewed from above.) The indicator location and direction is shown by the yellow arrow.

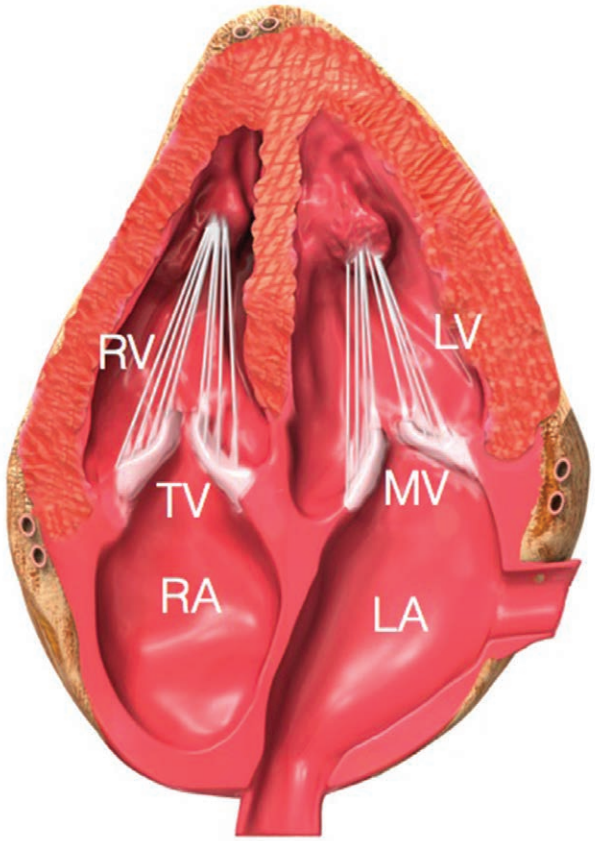


Figure 9. Anatomy of the apical 4 chamber. The apex of the LV should be under the probe, and the right and left atria and ventricles should be seen as well as the mitral and tricuspid valves. LA indicates left atrium; LV, left ventricle; MV, mitral valve; RA, right atrium; RV, right ventricle; TV, tricuspid valve.

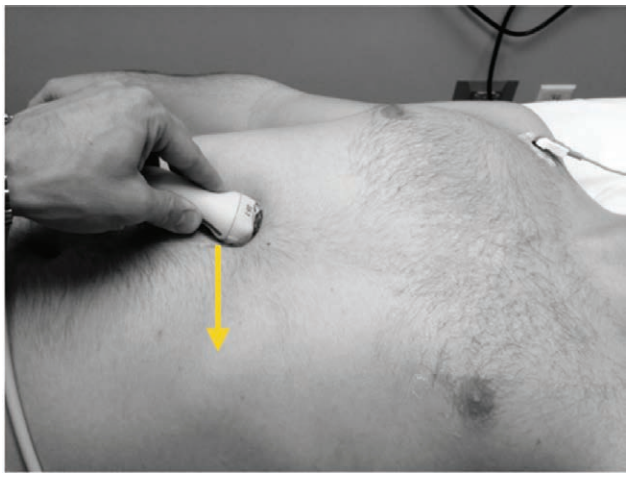


Figure 10. Probe position for the subcostal 4 chamber. The patient is supine with a pillow under his/her knees to relax the abdominal muscles. The probe is 1 to 2 cm below the xiphoid process with the indicator pointing directly toward the patient's left (toward the sonographer.) The indicator location and direction is shown by the yellow arrow.

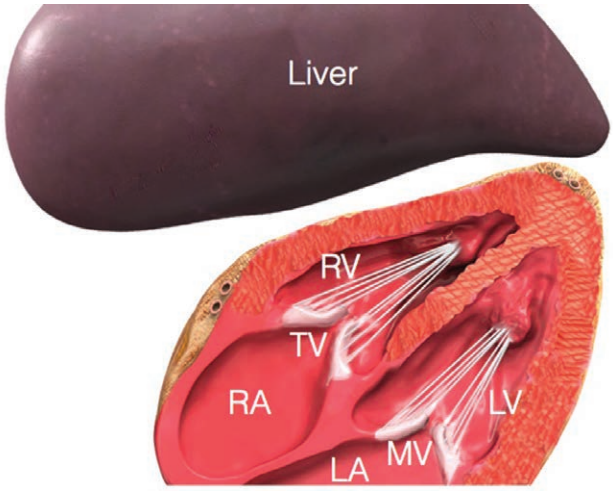


Figure 11. Anatomy of the subcostal 4 chamber. The liver is at the top of the screen. The right and left atria and ventricles can be visualized, along with the mitral and tricuspid valves. It should be noted that this is not the same cross-section as the apical 4 chamber. LA indicates left atrium; LV, left ventricle; MV, mitral valve; RA, right atrium; RV, right ventricle; TV, tricuspid valve.

for this image is reminiscent of placing a subclavian central line. The probe is pushed down into the abdomen and forward to create a window that looks toward the heart (located directly under the ribs) rather than a window that looks down into the abdomen. Slight changes in angulation and rotation are then used to create an appropriate SC4.

Breath Control. The subcostal 4 chamber can be improved in some cases by having the patient take a partial or full breath in and hold it. As the diaphragm falls, the probe comes closer to the heart.

Anatomy. Although the view is called the subcostal 4 chamber, and it may indeed show all 4 chambers of the heart, the cross section is not identical to that obtained from the apical window (Figure 11). This view transects a more inferior

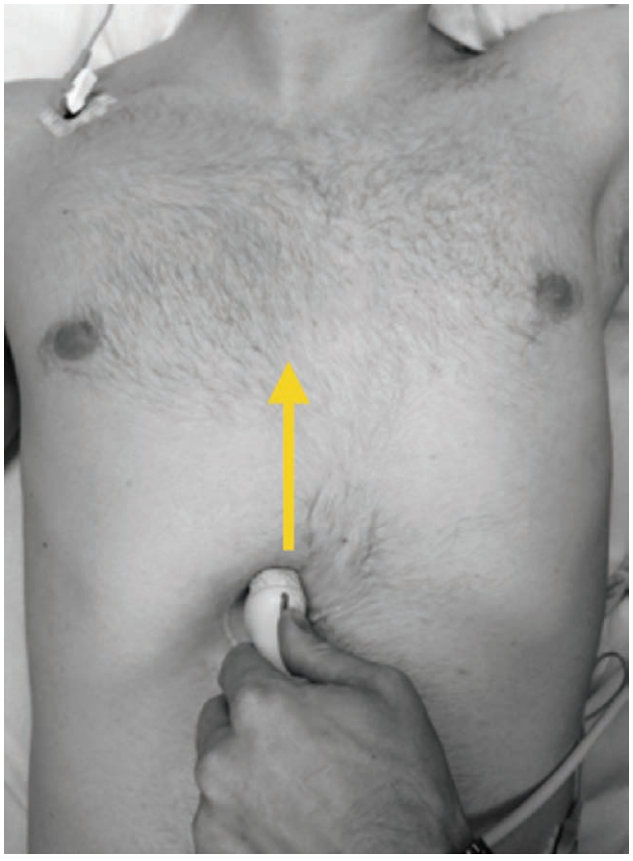
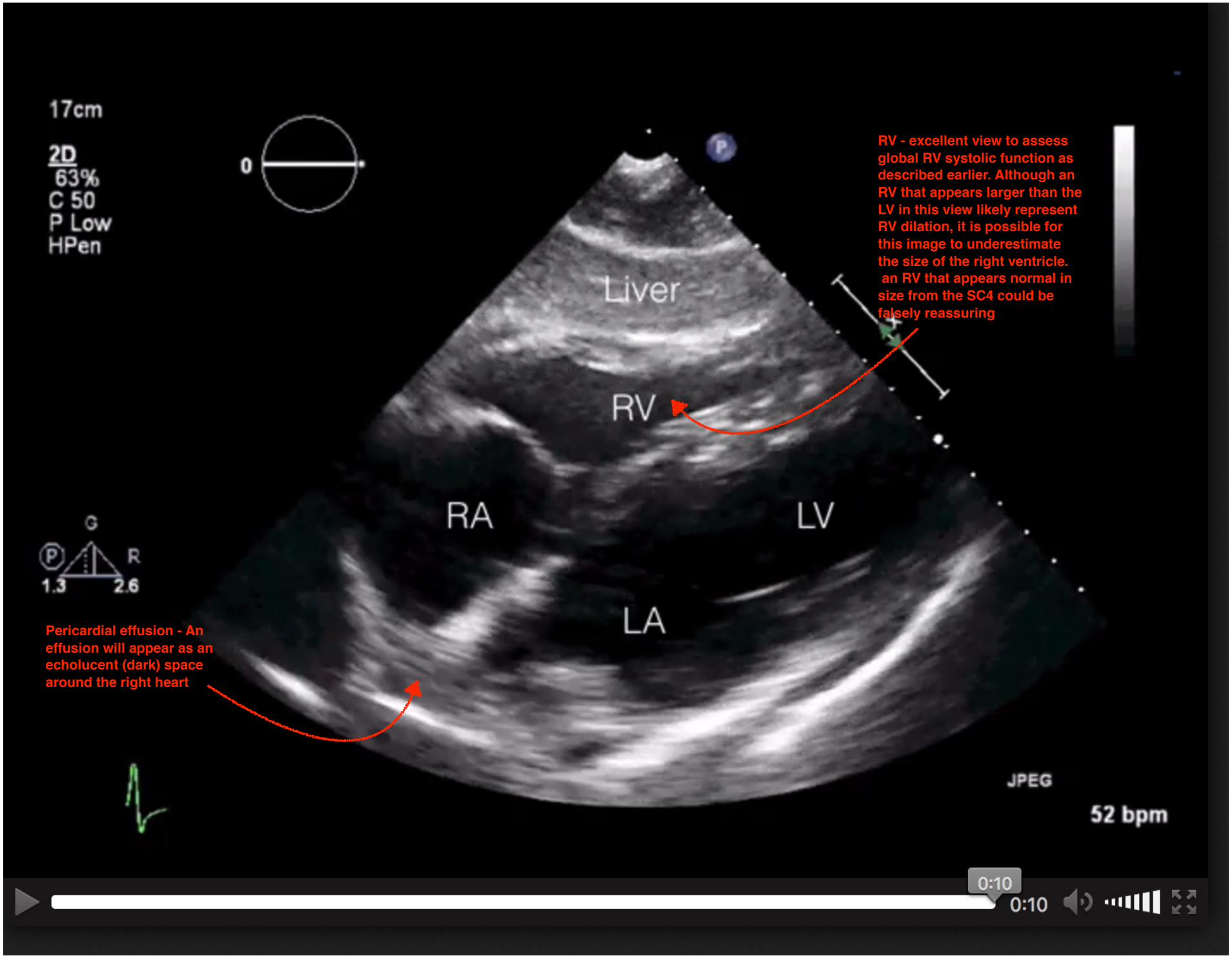


Figure 12. Probe position for the subcostal IVC image. The probe is 1–2 cm below the xiphoid process with the indicator pointing toward the patient's head. The indicator location and direction is shown by the yellow arrow. IVC indicates inferior vena cava.

portion of the right ventricle, and although it may show the inferoseptal and anterolateral walls of the LV, this is less predictable. The benefit of this view is that it shows the free wall of the right ventricle very well. It is a view that complements the information obtained from the other windows. For some patients, particularly those with tubes and drains or those with severe chronic obstructive pulmonary disease, the subcostal window may be the only one that provides adequate imaging, and a detailed 2D assessment of the cardiac structures can often be obtained from this window alone.

Assessment.

1. Right ventricle: The SC4 is an excellent view to assess global RV systolic function as described earlier. Although an RV that appears larger than the LV in this view likely represent RV dilation, it is possible for this image to underestimate the size of the right ventricle (Supplemental Digital Content, Video 20, http://links.lww.com/AA/B630). That means an RV that appears normal in size from the SC4 could be falsely reassuring.
2. Pericardial effusion: This is an excellent view to identify the presence of a pericardial effusion. An effusion will appear as an echolucent (dark) space around the right heart (Supplemental Digital Content, Video 21, http://links.lww.com/AA/B631). Findings of tamponade physiology may include right atrial inversion


17cm
2D
63%
C 50
P Low
HPen
0
Liver
RV
RA
LV
LA
G
P
R
1.3
2.6
RV - excellent view to assess global RV systolic function as described earlier. Although an RV that appears larger than the LV in this view likely represent RV dilation, it is possible for this image to underestimate the size of the right ventricle. an RV that appears normal in size from the SC4 could be falsely reassuring
Pericardial effusion - An effusion will appear as an echolucent (dark) space around the right heart
JPEG
52 bpm
0:10
0:10

during ventricular systole, right ventricular compression during diastole, and inferior vena cava (IVC) dilation (see next section.) As with other complex clinical scenarios, findings of effusion and tamponade should be evaluated within the clinical context.

Subcostal IVC Long Axis (Supplemental Digital Content, Video 22, http://links.lww.com/AA/B632)

Probe Position and Manipulation. Starting from the SC4, the probe should be tilted to center the right atrium in the screen. Then a slow counterclockwise rotation of the probe by 60 to 90° should show the IVC entering the right atrium. (Figure 12).

Anatomy. At the top of the image is the liver, with the IVC appearing near-horizontal on the screen as it enters the right atrium. It is important to distinguish the IVC from the abdominal aorta in this view. The aorta is thick-walled and will often have obviously systolic pulsatility. The IVC is thin-walled, can be seen to enter the right atrium, and has hepatic veins draining into it. The left hepatic vein can often be identified entering the IVC at the 12-o'clock position near the right atrium (Figure 13).

Assessment. The utility of this view is to evaluate the relative size and behavior of the IVC to aid in the assessment of volume status and fluid responsiveness.[3] An IVC that appears large with minimal change in diameter with ventilation (spontaneous or controlled) suggests relatively greater right atrial pressures and a lower likelihood of volume responsiveness (Supplemental Digital Content, Video 23, http://links.lww.com/AA/B633). A very small appearing IVC suggests a patient that is likely volume responsive (Supplemental Digital Content, Video 24, http://links.lww.com/AA/B634). Because assessment of volume status is one of the more complex aspects of cardiac ultrasound, it is important to view this information in the broader clinical context and not to use IVC assessment as the sole determinant.

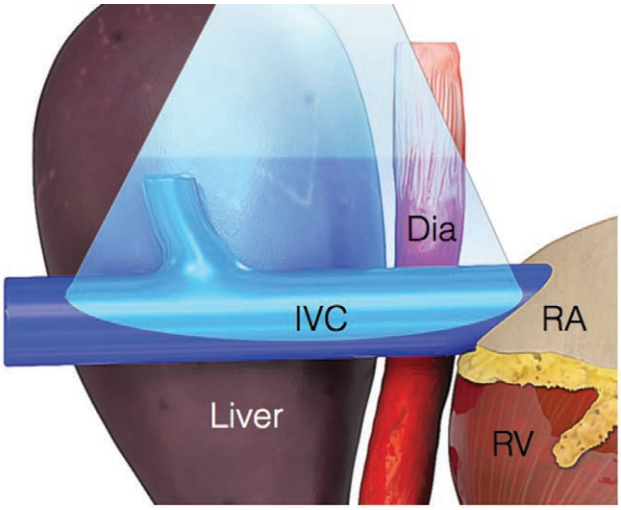


Figure 13. Anatomy of the subcostal IVC. At the top of the image is the liver. The IVC can be seen entering the right atrium. The left hepatic vein is seen entering the IVC near the right atrium. Dia indicates diaphragm; IVC, inferior vena cava; RA, right atrium; RV, right ventricle.

IMAGE STORAGE AND REPORTING

The days when perioperative echocardiographers could make images, act on the findings, store no images, and report no findings are gone. At this early stage of the adoption of point-of-care ultrasound, the authors recommend applying the current standards for medical imaging to all forms of point-of-care ultrasound and to FoCUS in particular. That means images should always be archived, either on an imaging server or on disks, for review and quality assurance. Every currently available ultrasound device has some mechanism for image storage. Likewise, there should be some mechanism for reporting the findings of each FoCUS examination. Paper forms can be used (an example used by the authors is included in the Supplemental Digital Content, http://links.lww.com/AA/B687), electronic forms can be created, or information can be reported in the anesthetic record.

CONCLUSIONS

The field of perioperative echocardiography is broad, complex, and takes years to master. FoCUS, on the other hand, can provide significant value in the care of complex patients with substantially less time and experience. This article provides a brief introduction to the techniques of FoCUS and the reader with further interest is strongly encouraged to seek further instruction.

DISCLOSURES

Name: Josh M. Zimmerman, MD, FASE.
Contribution: This author was the primary author, and was responsible for writing and editing this article.
Name: Bradley J. Coker, MD.
Contribution: This author helped with the writing and editing of the article.
This article was handled by: Nikolaos J. Skubas, MD, DSc, FACC, FASE.

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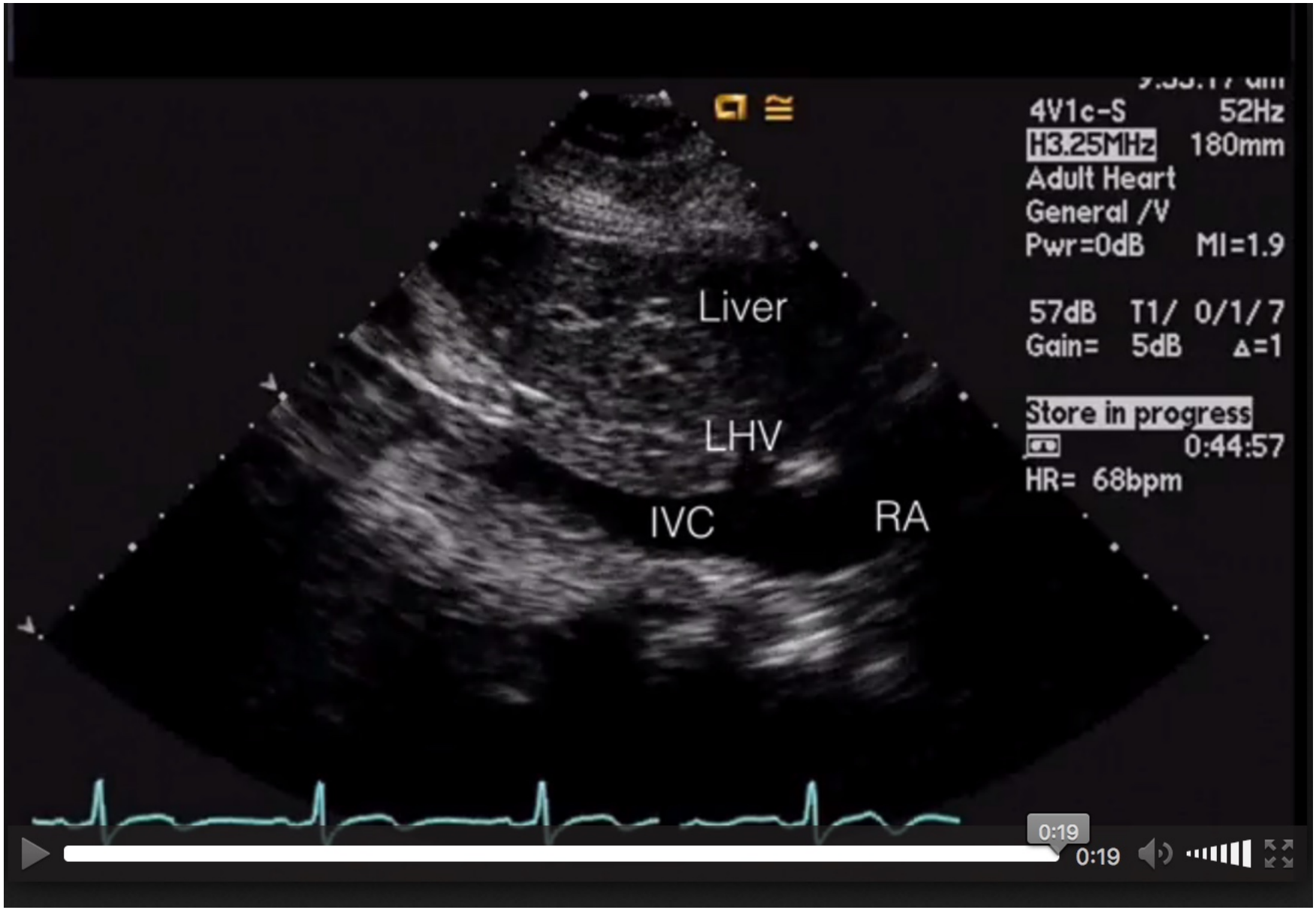
Liver
LHV
IVC
RA
4V1c-S
52Hz
H3.25MHz
180mm
Adult Heart
General /V
Pwr=0dB
MI=1.9
57dB
T1/ 0/1/7
Gain= 5dB
Δ=1
Store in progress
0:44:57
HR= 68bpm
0:19
0:19

Focused Cardiovascular Ultrasound (FoCUS)

Reporting Form

Patient name: _____ Patient MRN: _____

Sonographer: _____ Date of study: _____/_____/_____

Indication: ☐Murmur ☐Heart failure ☐Hemodynamic instability ☐Other:_____

Location of study: ☐Preop clinic ☐Same day surgery ☐OR ☐PACU ☐Other:_____

Quality of study: ☐Adequate ☐Indaequate Second Opinion Requested: ☐No ☐Yes

Left Heart

Size: ☐Small ☐Normal ☐Enlarged **Wall thickness**: ☐Normal ☐Significant hypertrophy

Global Function: ☐ Normal ☐Moderate dysfunction ☐Severe dysfunction

Regional wall motion abnormalities: ☐Absent ☐Present **Left atrium**: ☐Not enlarged ☐Enlarged

Right Heart

Size: ☐Small ☐Normal ☐Enlarged **Wall thickness**: ☐Normal ☐Significant hypertrophy

Global Function: ☐Normal ☐Moderate dysfunction ☐Severe dysfunction

Vent Septum: ☐Normal ☐Flat in diastole ☐Flat in systole **Right atrium**: ☐Not enlarged ☐Enlarged

IVC Size: ☐Normal ☐Flat ☐Enlarged **IVC Collapse (Sniff):** ☐NA ☐< 50% ☐> 50%

Pericardial Effusion: ☐Absent ☐Small ☐Large ☐RA syst collapse ☐RV diast collapse

Valves, Masses, Etc.

Aortic Valve: ☐Normal ☐Significant stenosis ☐Coapt defect/significant regurg

Mitral Valve: ☐Normal ☐Significant thickening ☐Coapt defect/significant regurg ☐Large EPSS

Systolic Anterior Motion of MV: ☐Absent ☐Present ☐Present with Obstruction

Tricuspid Valve: ☐Normal ☐Significant thickening ☐Coapt defect/significant regurg

Masses: ☐None ☐On AV ☐On MV ☐Cavitary **Lung Sliding**: ☐Bilat ☐Absent R ☐Absent L

Other pertinent findings: _____

Conclusions: _____

Created by Josh Zimmerman, MD, FASE and Bradley Coker, MD

Why Anesthesiologists Must Incorporate Focused Cardiac Ultrasound Into Daily Practice

Bradley J. Coker, MD,* and Josh M. Zimmerman, MD, FASE†

The size, availability, cost, and quality of modern ultrasound devices have, for the first time in modern medicine, enabled point-of-care ultrasound by the noncardiologist physician. The appropriate application of focused cardiac ultrasound (FoCUS) by anesthesiologists has the potential to alter management and affect outcomes for a wide range of patients. In this article, the indications, benefits, and limitations of FoCUS are described. The training and equipment required to perform FoCUS are also discussed. (Anesth Analg 2017;124:761–5)

The modern era of ultrasound was ushered into the scientific community during the late 1930s with the advent of metal flaw detectors and World War II, when interest in advanced detection technology such as sound navigation and ranging and radio detection and ranging peaked.[1] Later, application of ultrasound to medicine led to greater understanding of human anatomy, physiology, and pathology.[2] In the past 20 years, evolution of the microprocessors enabled the miniaturization of large cumbersome ultrasound devices to hand-held, even pocket-sized instruments. The size, cost, availability, and quality of these smaller ultrasound devices have placed point-of-care ultrasound in the noncardiologist physician's armamentarium. The purpose of this article is to describe the concept of focused cardiac ultrasound (FoCUS), its diagnostic targets, indications, benefits, and limitations. Training and equipment required to perform FoCUS are also discussed.

WHAT IS FOCUSED CARDIAC ULTRASOUND?

Many terms are used to describe a narrowed ultrasound examination of the cardiovascular system including, but not limited to, hand-held, point-of-care, bedside, quick-look cardiac ultrasound, or ultrasound stethoscope. These multiple synonyms are compounded by the variety of acronyms applied to bedside ultrasound protocols, such as FAST, FATE, FEEL, and RUSH, which are defined and described in Table 1.[3] To avoid any confusion, the term FoCUS will be used for the remainder of this article.

FoCUS, as defined by the American Society of Echocardiography, is a "focused examination of the cardiovascular system performed by a physician using ultrasound as an adjunct to the physical examination to recognize specific ultrasonic signs that represent a narrow list of potential diagnoses in specific clinical settings."[4] The essential features of FoCUS are summarized in Table 2.[4]

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FoCUS is used as an adjunct to the physical examination when a patient's symptoms suggest an abnormality of cardiovascular structure or function. It is important to note that FoCUS is not comprehensive, but is instead concentrated on improving the understanding of the underlying cardiovascular pathophysiology. Making a definitive diagnosis is not the objective of FoCUS. With FoCUS, the bedside physician is gathering crucial information to assess the patient's physiologic status, refine the differential diagnoses, and choose interventions that can change the course of management.[5] FoCUS is used to facilitate point-of-care decisions by answering critical questions in a binary fashion, that is, yes/present or no/absent. This simplifies the cardiac ultrasound examination because neither measurements nor quantifications are performed.[6] The agreement between qualitative data obtained by FoCUS and comprehensive standard echocardiography is good.[6–8] The simplicity of the FoCUS examination also lends itself to point-of-care application. The equipment used is usually portable, and the examination is quick and noninvasive and performed by the physician responsible for making real-time clinical decisions that may change management strategies.

The clinical indications to perform a FoCUS examination are shown in Table 3.[4,9] The ability of the physician to make timely and appropriate medical decisions when using FoCUS is increased.[10–17] Kanji et al[17] found that 28-day survival was improved in patients suffering from subacute shock whose management was guided by "limited" transthoracic echocardiography (TTE). Of note, their echocardiographic examination was comprised of the exact same views as the FoCUS examination.

Cardiovascular data that can be obtained from a FoCUS examination are summarized in Table 4.[9] Because of the limited diagnostic targets, only a select number of views are acquired during a FoCUS examination. The FoCUS examination typically comprises (1) parasternal long axis, (2) parasternal short axis, (3) apical 4-chamber, (4) subcostal 4-chamber, and (5) subcostal inferior vena cava views[18] (Figure 1). With the FoCUS examination, each cardiac structure is imaged in more than one view, to avoid errors of omission, validate findings, and ensure that ultrasound artifacts are not mistaken for abnormalities. However, in critical or life-threatening situations, that is, cardiac arrest, critical clinical decisions can be made with data obtained from a single view.[10]

Despite its potential, FoCUS, as any diagnostic tool, has important limitations (Table 5). The most important of

Table 1. Surface/Transthoracic Echocardiographic Examination Protocols

TTE Scan	Modalities	Views	Scope	Disadvantages
FAST Focused assessment with sonography in trauma	2-D, M-Mode	S4CH, right upper quadrant, left upper quadrant, and pelvis	Identifies intraperitoneal, pericardial, or pleural fluid	Does not evaluate any cardiac function/anatomy other than the presence or absence of pericardial fluid
FATE Focus assessed transthoracic echo	2-D, M-Mode	PLAX, PSAX, A4CH, S4CH, pleura	Excludes obvious pathology, evaluates ventricular size and systolic function, & visualizes pleura	More extensive image acquisition, requires larger depth of knowledge in image interpretation and analysis
FEEL Focused echocardiography in life support	2-D	PLAX, PSAX, A4CH, and S4CH	Evaluates for reversible causes of pulseless electrical activity	No valve assessment
RUSH Rapid ultrasound in shock	2-D	PLAX, PSAX, A4CH, S4CH, SIVC, right & left upper quadrants, pelvis, and thorax	Evaluates for pericardial fluid, ventricular systolic function, volume status, pleural and intraperitoneal fluid, pulmonary embolism, abdominal aortic aneurysm, & deep vein thrombosis	No valve assessment
FoCUS Focused cardiac ultrasound	2-D, Color Flow Doppler	PLAX, PSAX, A4CH, S4CH, and SIVC	Evaluates ventricular systolic function, volume status, pericardial effusion/tamponade, signs of chronic heart disease	No quantitative measurements obtained

Abbreviations: 2-D, 2-dimensional; A2CH, apical 2 chamber; A4CH, apical 4 chamber; PLAX, parasternal long axis; PSAX, parasternal short axis; S4CH, subcostal 4 chamber; SCSAX, subcostal short axis; SIVC, subcostal inferior vena cava; TTE, transthoracic echocardiography.
Adapted from Royse et al, 2012.[3]

Table 2. Essential Features of FoCUS

1. Simplified, limited in scope
2. Goal- and problem-oriented
3. Time sensitive and repeatable
4. Qualitative
5. Performed by physician at the point of care

Table 3. Indications to Perform FoCUS

1. Hemodynamic instability or undifferentiated shock
2. Cardiac arrest
3. Pericardial effusion/tamponade: signs and symptoms
4. Heart failure: signs and symptoms
5. High cardiac risk patients
6. Adjunct to physical examination

Table 4. Cardiac Data Obtained by FoCUS[a]

1. Ventricular dimensions and systolic function
2. Volume status/responsiveness
3. Pericardial effusion/tamponade
4. Gross anatomical abnormalities
5. Gross signs of chronic heart disease

[a]Adapted from Via et al, 2014.[9]

those is the experience and skill set of the physician performing the examination.[3] If the images acquired during the FoCUS examination are of poor quality or cluttered with artifact, little actionable information can be gleaned. It is paramount that the physician performing the FoCUS examination realizes the difference between a "good" image and an image that contains insufficient information to make sound clinical decisions. The onus is on the performing physician to understand his limitations and to recognize when consultation with a more experienced colleague is required. Second, FoCUS is a qualitative examination and the grading of the severity of disease processes, such as aortic stenosis, is not its scope. Third, FoCUS is limited by the type of ultrasound equipment used to perform the examination. Although FoCUS can be performed with high-end ultrasound machines with full capabilities, it is much more likely that it will be performed on machines that have fewer modalities, that is, 2 dimensional, M-mode, and basic color flow Doppler only. However, the small size of these ultrasound systems provides for increased portability and real-time use by the bedside, thus outweighing their limited functionality.

FOCUS VERSUS LIMITED TRANSTHORACIC ECHOCARDIOGRAPHY

Because of the heterogeneity of terms used to describe FoCUS, there may be confusion regarding how FoCUS differs from limited TTE. These differences can be pared down to one word, scope. Limited TTE requires ultrasound equipment with full functionality, training for image acquisition, obligatory knowledge for image analysis and interpretation, as well as accreditation for the safe and appropriate use of echocardiography in a broad scope of practice. FoCUS, on the other hand, has a narrower scope of practice and is restricted by the equipment used and the skill set of the physician performing the examination. The scope of practice of FoCUS may vary from a specific patient population (intensive care unit patients) to a clinical setting (preoperative assessment clinic). A limited TTE examination refers to a small number of images that are obtained by an expert echocardiographer (registered ultrasound technician or physician), which enable the physician to evaluate and discriminate between disease processes and severities. On the other hand, the FoCUS examination has a narrowed scope and can only address specific clinical questions[4,9] (Table 6).

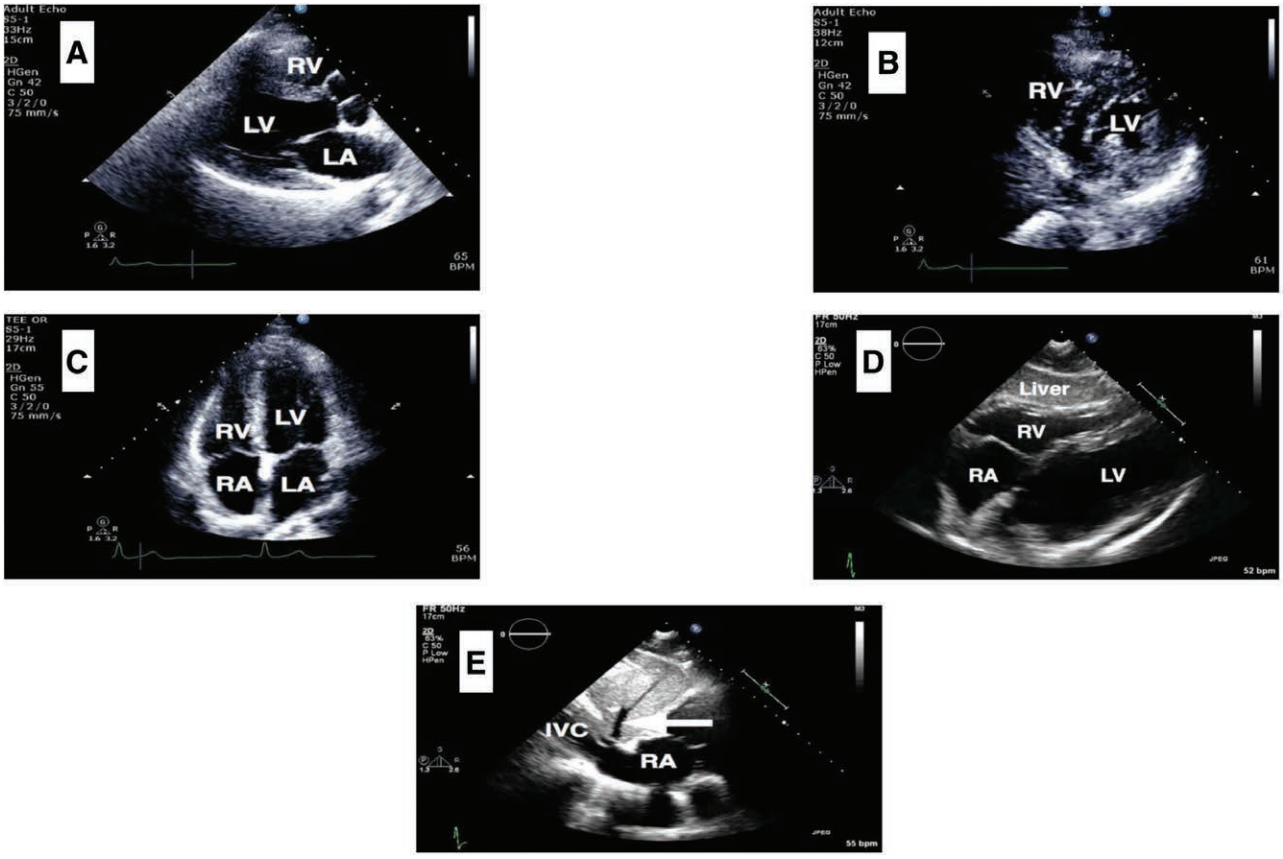

Figure. Composition of FoCUS examination. A, Parasternal long axis view. B, Parasternal short axis view. C, Apical 4-chamber view. D, Subcostal 4-chamber view. E, Subcostal inferior vena cava view.

Table 5. Limitations of FoCUS

1. Experience & skill set of performing physician
2. No quantifiable data
3. Functionality of equipment

Table 6. Limited TTE Versus FoCUS[a]

Limited TTE	
No restriction on exam capabilities	
Can rule out diagnoses	
Large knowledge base required	
Advanced level of ultrasound expertise required	
Billable	
FoCUS	
Narrowed scope	
Addresses specific clinical question	
Limited knowledge base necessary	

Abbreviation: TTE, transthoracic echocardiography.
[a]Adapted from Spencer et al, 2013.[4]

Table 7. Ultrasound Equipment for FoCUS

Type of Ultrasound Equipment	Modalities
Full functional ultrasound platforms	2D, 3D, M-mode, Doppler (PW, CW, CFD), Deformation
• GE – E95	
• Philips – EPIQ, iE33	
• Siemens – SC 2000	
Small ultrasound platforms	2D, M-mode, Doppler (PW, CW, CFD)
• GE – Vivid S7	
• Philips – Sparq	
• Sonosite – VEVO MD	
Hand-carried ultrasound devices	2D, M-mode, Doppler (PW, CW, CFD)
• GE – Vivid I	
• Philips – CX50	
• Sonosite – M-Turbo	
Pocket-sized ultrasound devices	2D & CFD
• GE – V scan	
• Philips – Lumify	

Examples of available systems. The list is not comprehensive.
Abbreviations: 2D, 2 dimensional echocardiography; 3D, 3 dimensional echocardiography; CFD, color flow Doppler; CW, continuous-wave Doppler; PW, pulsed-wave Doppler

THE ANESTHESIOLOGIST AND FOCUS

FoCUS is simply the application of a common technology in a new and innovative way. Much like the electrocardiogram may be considered a narrowly focused cardiac electrophysiologic technique, FoCUS may provide the anesthesiologist with timely data on the patient's anatomy and physiology, allowing him/her to construct more precise differential diagnoses and management strategies. The value of point-of-care ultrasound in comparison with or as an adjunct to the physical examination has been investigated.[19–23] Kobal et al[19] found that the accuracy of cardiovascular diagnoses by medical students, who had limited echocardiographic training and used a small hand-carried ultrasound device, was superior to that of experienced board-certified cardiologist using standard physical examinations. Patients with high cardiac risk who had surgery for hip fracture had lower mortality when treated by anesthesiologists who used a point-of-care, "focused" TTE.[24]

TRAINING REQUIREMENTS/RECOMMENDATIONS

Several specialties such as Trauma Surgery, Emergency Medicine, and Critical Care Medicine[25] have already embraced the use of ultrasound, including FoCUS, and have incorporated ultrasound education into formal training programs. The skills required to perform FoCUS can be obtained by noncardiology physicians with limited training. Cowie et al[26] demonstrated that echocardiography-naive anesthesiology trainees could rapidly and successfully be trained to recognize clinically significant aortic stenosis by using TTE.

There is scant information regarding the appropriate training for FoCUS in anesthesiology. The Society of Critical Care Anesthesiologists has suggested learning goals for critical care basic ultrasound, which are, however, broader than what is needed for FoCUS.[25] Ramsingh et al[27] developed a point-of-care ultrasound curriculum for general anesthesiology residents that blended traditional didactic lectures with hands-on model and simulation experience. Ideally, a curriculum for FoCUS designed for board-certified anesthesiologists would consist of (1) a core didactic curriculum, (2) access to an archive of images and clinical cases, and (3) hands-on model and simulation workshops supervised by expert teachers. Once the teaching sessions have been completed, the trainees would perform, capture, and interpret independent studies, which also need evaluation and validation. Finally, the trainees should prove and maintain competency.

EQUIPMENT

The various ultrasound platforms used to perform echocardiography include: (1) large, fully functional systems, (2) small platforms with basic functions, (3) hand-carried, and (4) pocket-sized systems (Table 7). Full functional systems are used in echocardiography laboratories and in the cardiac operating theater. They are bulky in size, difficult to maneuver, and expensive, thus less than ideal for the performance of FoCUS examination. Small ultrasound platforms typically retain much of the functionality, are cart-based, easier to maneuver, and less expensive. Hand-carried devices are typically the size of a laptop computer, readily carried to the bedside, and have standard ultrasound modalities only. Pocket platforms are small enough to fit in a laboratory coat pocket, but their functionality is restricted.[4,9]

Although implementation of FoCUS in daily practice is with hand-carried or pocket-sized platforms, it can be performed with any ultrasound machine. The recommendations from the American Society of Echocardiography are that ultrasound equipment used for FoCUS examinations meet 5 basic criteria: (1) a transducer with frequency appropriate for adult patients (typically 2–6 MHz), (2) minimal display requirements that include the ability to label images with at least 2 patient identifiers, as well as the date and time the examination was performed, (3) markers to indicate scale or image depth, (4) 2-dimensional gray-scale imaging and ability to adjust depth and gain, and (5) the ability to store images in a retrievable location in the Digital Imaging and Communications in Medicine format.[4,9] (Table 8)

Table 8. Criteria for Basic Ultrasound Equipment Functionality

1. Transducer with proper frequency
2. Labeling of images
3. Indicators of depth within imaging sector
4. Adjustable gain and depth
5. Image storage

BILLING

In the United States, billing is based on Current Procedural Terminology codes. Currently, although there is a Current Procedural Terminology code for limited TTE, no such code exists for FoCUS. It is inappropriate to bill a FoCUS examination as a limited TTE.[4,9]

CONCLUSIONS

The appropriate application of FoCUS by anesthesiologists may potentially alter management and affect outcomes for a wide range of patients. FoCUS and point-of-care ultrasound should be incorporated into our skills set and everyday practice.[28] Training for FoCUS should be ideally based on a national curriculum.

DISCLOSURES

Name: Bradley J. Coker, MD.
Contribution: This author is the primary author and corresponding author of the manuscript.
Name: Josh M. Zimmerman, MD, FASE.
Contribution: This author was involved in writing and editing the manuscript.
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A Pilot Assessment of 3 Point-of-Care Strategies for Diagnosis of Perioperative Lung Pathology

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BACKGROUND: Lung ultrasonography is superior to clinical examination and chest X-ray (CXR) in diagnosis of acute respiratory pathology in the emergency and critical care setting and after cardiothoracic surgery in intensive care. Lung ultrasound may be useful before cardiothoracic surgery and after discharge from intensive care, but the proportion of significant respiratory pathology in this setting is unknown and may be too low to justify its routine use. The aim of this study was to determine the proportion of clinically significant respiratory pathology detectable with CXR, clinical examination, and lung ultrasound in patients on the ward before and after cardiothoracic surgery.
METHODS: In this prospective observational study, patients undergoing elective cardiothoracic surgery who received a CXR as part of standard care preoperatively or after discharge from the intensive care unit received a standardized clinical assessment and then a lung ultrasound examination within 24 hours of the CXR by 2 clinicians. The incidence of collapse/atelectasis, consolidation, alveolar-interstitial syndrome, pleural effusion, and pneumothorax were compared between clinical examination, CXR, and lung ultrasound (reference method) based on predefined diagnostic criteria in 3 zones of each lung.
RESULTS: In 78 participants included, presence of any pathology was detected in 56% of the cohort by lung ultrasound; 24% preoperatively and 94% postoperatively. With lung ultrasound as a reference, the sensitivity of the 5 different pathologies ranged from 7% to 69% (CXR), 7% to 76% (clinical examination), and 14% to 94% (combined); the specificity of the 5 different pathologies ranged from 91% to 98% (CXR), from 90% to 99% (clinical examination), and from 82% to 97% (combined). For clinical examination and lung ultrasound, intraobserver agreements beyond chance ranged from 0.28 to 0.70 and from 0.84 to 0.97, respectively. The agreements beyond chance of pathologic diagnoses between modalities ranged from 0.11 to 0.64 (CXR and lung ultrasound), from 0.08 to 0.7 (CXR and lung ultrasound), and from 0 to 0.58 (clinical examination and CXR).
CONCLUSIONS: Clinically important respiratory pathology is detectable by lung ultrasound in a substantial number of noncritically ill, pre or postoperative cardiothoracic surgery participants with high estimate of interobserver agreement beyond that expected by chance, and we showed clinically significant diagnoses may be missed by the contemporary practice of clinical examination and CXR. (Anesth Analg 2017;124:734–42)

Lung ultrasonography is an emerging tool in emergency and critical care medicine to guide decision-making in real time. In broad terms, lung ultrasound is performed by the treating physician at the time and place of the clinical assessment and often is limited in scope, being confined to an assessment relevant to the clinical situation.[1] Thereby, lung ultrasound can provide a rapid, noninvasive assessment of the respiratory state without exposing patient or staff to ionizing radiation and without requiring transportation of the patient.[1–3]

In critical care, the use of lung ultrasound has been shown to decrease the number of chest X-rays (CXRs) and computed tomography (CT) scans, reducing radiation exposure as well as the cost of care,[4] and despite percussion note and auscultation forming key components of clinical examination, poor reliability has been described.[5,6] Generally, the diagnostic performance of lung ultrasound has been shown to approach CT scans and to be superior to clinical examination and CXR.[7] Nevertheless, in perioperative care, clinical examination and CXR have remained the modalities of choice for routine assessment of respiratory pathology, although missed pathology can result in poor outcomes and delayed recovery.[2] Importantly, however, because these patients are rarely in a critical state, the proportion of clinically meaningful respiratory pathology may be too low to justify the cost of implementing lung ultrasound into routine clinical practice.

Therefore, the primary aim of this prospective observational study was to assess the proportion of clinically important respiratory pathology detectable with CXR, clinical examination, and lung ultrasound in patients undergoing cardiac surgery. Secondary end points included the evaluation of the sensitivity and specificity of CXR and clinical

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examination of clinically significant respiratory pathology compared with lung ultrasound as the reference method.

METHODS

The local institutional ethical review board from the Melbourne Health Human Research Ethics Committee approved the study, which conforms to the ethical guidelines of the 1975 Declaration of Helsinki. Written informed consent was obtained from all patients. This manuscript adheres to the applicable Equator guidelines.

Design and Study Participants

In a prospective, observational pilot study, patients were enrolled at the Royal Melbourne Hospital, Melbourne, Australia. The study was conducted as a pilot study to evaluate feasibility before performance of a full-scaled, randomized trial to investigate whether lung ultrasound can improve clinical outcomes. Inclusion criteria were patients aged 18 years or older undergoing cardiac or thoracic surgery who received a CXR as part of standard care either preoperatively or postoperatively after discharge from the intensive care unit. Clinical examination and lung ultrasound were performed after and within 24 hours of the CXR.

Within 24 hours of the CXR, a standardized focused clinical examination and a lung ultrasound examination were performed by 2 independent observers. With respect to lung ultrasound, the observers were novice examiners with approximately 25 hours of training experience, but, if necessary, the scan was reviewed by an expert as per the observer's discretion. Observers were blinded to all radiologic findings but otherwise aware of the patient's previous medical history.

For comparison between ultrasound and clinical assessment, the lung was divided into 3 anatomical zones: (1) the anterior zone, defined by the sternum anteriorly and the mid-axillary line posteriorly; (2) the upper posterior zone, defined by the mid-axillary line anteriorly, the spinous processes of the thoracic spine posteriorly, and the inferior tip of the scapular inferiorly; and (3) the lower posterior zone, defined by the mid-axillary line anteriorly, the spinous processes of the thoracic spine posteriorly, and the inferior tip of the scapula superiorly.[8] On CXR, the lung was divided into 2 anatomical zones: an upper and a lower zone defined by the reporting radiologist.

Five common pathological entities were explored for each of the 3 methods: (1) collapse/atelectasis, (2) consolidation, (3) alveolar-interstitial syndrome, (4) pleural effusion, and (5) pneumothorax. The definitions for these are explained in the sections to follow.

Chest X-Ray

A CXR was performed only when ordered by the treating team in accordance with therapeutic local guidelines. The examinations were either erect posterior-anterior and lateral studies, or supine, semi-erect or erect anterior-posterior mobile studies for patients unable to be transported to the radiology department.

The consult radiologist was blinded to any lung ultrasound findings, and the results were reported electronically. Findings suggestive of pulmonary edema or interstitial disease were recorded as alveolar-interstitial syndrome, and if pleural effusion was reported, its corresponding size estimation was recorded as small, moderate, or large. The terminology used in reports was interpreted using the recommendations made by the Nomenclature Committee of the Fleischner Society.[9]

Clinical Examination

A comprehensive clinical examination, which followed standard local protocols and teaching, was performed in a systematic manner, and comprised inspection, percussion, and auscultation. The patient was examined in a seated position, and the examination was performed on all 3 anatomical zones as defined previously. Results for each observer were recorded on a standardized form.

A normal lung was defined as standard percussion note, vesicular breath sounds, no added sounds, and normal vocal resonance in the and absence of any of the 4 specified lung pathologies: *Collapse/atelectasis* was defined as a dulled percussion note, absent or reduced breath sounds, no added sounds, and decreased or increased vocal resonance. *Consolidation* was defined as a dulled percussion note, bronchial breath sounds, presence of crackles, and increased vocal resonance. *Alveolar-interstitial syndrome* was defined as the presence of fine pan-inspiratory crackles. *Pleural effusion* was defined as stony dulled percussion note and absent breath sounds over the effusion. Additional supporting signs included bronchial breathing at upper border of effusion, possible pleural rub, and reduced vocal resonance. When detected, the size of the effusion was estimated based on the clinical reasoning and categorized as small, moderate, or large. *Pneumothorax* was defined as hyper-resonant percussion note, absent or reduced breath sounds, no added sounds, and decreased vocal resonance.

Lung Ultrasound

A lung ultrasound was performed immediately after the clinical examination with a Sonosite X-PORTE portable ultrasound device (Fujifilm, Bothell, WA), with a 1–5 MHz transthoracic and a 6–13 MHz linear array of transducers. The procedure was standardized and followed the iLungScan protocol as established by The University of Melbourne, Ultrasound Education Group.[10] Patients were in a supine position for the examination, which was performed on all 3 anatomical zones. All images were stored and the results for each observer were recorded on a standardized form. See online complemental digital content for example of a lung ultrasound examination (https://s3.amazonaws.com/iTU/iTeachU/LU+chapter/Supine+lungscan.mp4) (video is reproduced with permission of the University of Melbourne).

A normal lung pattern was identified by the presence of normal lung sliding or lung pulse, reverberation artifacts from the pleura, and absence of any of the following pathologies (Figure 1)[8]: Collapse or atelectasis pattern was defined as a loss of lung volume, increased tissue density, and hyperechoic static air bronchograms.[11] Consolidation was defined as a tissue-like pattern or "hepatization" with minimal volume loss and the presence of dynamic

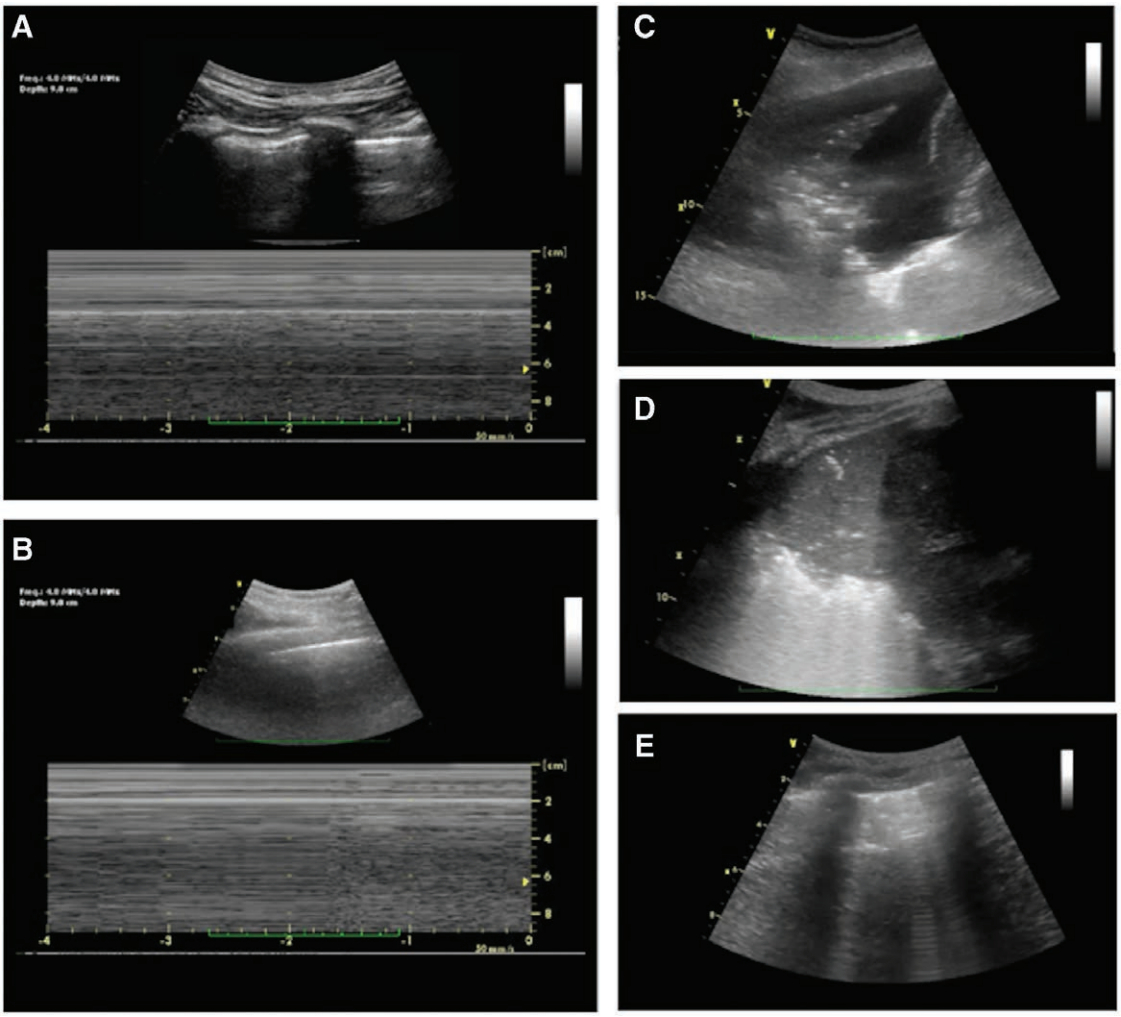

Figure 1. Ultrasound images of normal lung and the defined respiratory pathology. A, 2-dimensional (2D) image (top) and M-mode image (bottom) showing a normal lung pattern. The 2D image shows the main hallmarks, including ribs and reverberation artifacts from the pleura, whereas the M-mode image illustrates lung sliding. B, 2D image (top) and M-mode image (bottom) showing a pneumothorax. Both images show normal lung pattern to the left and absence of lung sliding and lung pulse to the right. C, 2D image showing and hypoechoic pleural effusion with collapsed/atelectatic lung pattern with increased tissue density and hyperechoic static air bronchograms. D, 2D image showing consolidation with tissue-like pattern and dynamic air bronchograms. E, 2D image demonstrating alveolar-interstitial syndrome with hyperechoic, vertical artifacts arising from the pleural line and reaching the bottom of the screen without fading (B-lines).
See online complemental digital content for examples of normal lung sliding (https://s3.amazonaws.com/iTU/iTeachU/LU+chapter/Lung+sliding.mp4), pneumothorax (https://s3.amazonaws.com/iTU/iTeachU/LU+chapter/No+lung+sliding.mp4), pleural effusion (https://s3.amazonaws.com/iTU/iTeachU/LU+chapter/Pleural+effusion+2.mov), and B-lines (https://s3.amazonaws.com/iTU/iTeachU/LU+chapter/B-lines.mp4). All videos are reproduced with permission of the University of Melbourne.

air bronchograms in affected lung.[2,12] Alveolar-interstitial syndrome was defined as 3 or more B-lines in a single rib space.[2,13] B-lines were defined strictly as hyperechoic, vertical artifacts arising from the pleural line and reaching the bottom of the screen without fading. In addition, B-lines should move with lung sliding and lung pulse, ablate reverberation artifacts from the pleura, but while typically laser-like in appearance, multiple B-lines can coalesce.[14] Pleural effusion was defined as an anechoic space between the parietal and visceral pleura with movement with the respiratory cycle (sinusoid sign).[2,7,15] When detected, the volume in milliliters (mL) of a nonloculated pleural effusion was estimated by measuring the maximal perpendicular intrapleural distance in centimeters and multiplying this by 200 mL/cm.[16] Pneumothorax was defined as the absence of lung sliding and lung pulse.[2,13,17] For confirmation of the absence, the linear array probe was used to obtain a high-resolution view of the parietal and visceral pleura.[18]

Outcomes

The primary end point was the incidence of clinically important respiratory pathology detectable by CXR, clinical examination, and lung ultrasound in patients undergoing cardiothoracic surgery. Secondary end points included the sensitivity and specificity of CXR and clinical examination compared with lung ultrasound as the reference method.

Statistical Analyses

Continuous data are presented as mean ± SD, and binary data are presented as percentages of patients or lung zones.

The proportion of patients with respiratory pathology was compared with an expected level of 20% of patients via a χ^2 test. Sensitivity and specificity are both presented as percentages with 95% confidence intervals (binomial exact). To assess estimates of agreement between the 3 modalities beyond that expected by chance, and to assess interobserver agreements beyond chance for clinical examination and lung ultrasound, Cohen's kappa (k) statistics was used. Values of $k < 0.20$ indicated poor strength of agreement, $k = 0.21$–0.4 fair strength of agreement, $k = 0.41$–0.60 moderate strength of agreement, $k = 0.61$–0.80 good strength of agreement, and $k = 0.81$–1.0 very good strength of agreement. P-values <.05 were considered statistically significant on our primary outcome, whereas only P-values <.01 were considered statistically significant on our secondary end points to adjust for multiple comparisons, all P-values are 2-sided.

We included a convenience sample of patients with no previous sample size calculation, wherefore the sample size was determined by the number of patients eligible within the inclusion period. With the given sample size of 78 patients, a significance level of 5%, and a statistical power of 90%, we were able to detect a 16% greater proportion of patients with respiratory pathology than our expected proportion of 20% of patients. Descriptive data were stored in Microsoft Excel 2016 (Microsoft Corp., Redmond, CA) and for statistical analyses we used Stata/IC 12.1 for Mac (Stata Corp., College Station, TX).

RESULTS

We included a total of 78 patients in the period from March to May 2015, of which 42 patients were preoperative and 36 patients were postoperative on the ward. The mean age was 62 ± 16 years, 82% were male, and the surgical procedures were as follows: coronary artery bypass graft surgery (40%), video-assisted thoracoscopic surgery (28%), valve replacement (17%), combined coronary artery bypass graft surgery and valve replacement (6%), and other (9%). A total of 468 lung zones were examined during the course of the study.

Respiratory Pathology Detected

Respiratory pathology was detected by lung ultrasound in 56% of the cohort; preoperatively 24% of the patients had pathology and postoperatively on the ward 94% had pathology. The proportion of patients with respiratory pathology (56%) was greater than the proportion expected (20%), $P < .01$. Pleural effusion was the most commonly detected pathology in preoperative as well as postoperative patients. There was no difference between cardiac and thoracic surgical patients in terms of pathology detected, neither the overall proportion of pathology nor any of the 5 different pathologies.

The proportions of defined respiratory pathology detected by CXR, clinical examination, and lung ultrasound in each lung zone are displayed in Table 1. Not surprisingly, respiratory pathology was not distributed uniformly within the lung; collapse, consolidation, alveolar interstitial syndrome, and pleural effusion were found at much greater rates in the lower zones of the chest, in comparison with upper zones of the chest. In contrast, pneumothorax was found more frequently in the upper zones of the lungs compared with the lower zones.

Diagnostic Performance of CXR and Clinical Examination

Sensitivity and specificity of CXR and clinical examination with lung ultrasound as the reference method are summarized in Table 2. Sensitivity of the different pathologies ranged from 7% to 69% (CXR), 7%–76% (clinical examination), and 14%–94% (combined). For both modalities as well as the combination, sensitivity was lowest in the detection of alveolar-interstitial syndrome and highest in detecting pleural effusion. The specificity of the different pathologies ranged from 91% to 98% (CXR), from 90% to 99% (clinical examination), and from 82% to 97% (combined).

Interobserver agreements beyond chance of clinical examination and lung ultrasound are displayed in Table 3, including observed and expected agreements. As seen, the agreement beyond chance of clinical examination ranged from 0.28 to 0.70, whereas agreements beyond chance were much greater when it came to lung ultrasound ranging from 0.84 to 0.97. In both modalities, there were statistically significant relationships between the observers for all the pathologies and in both modalities, consolidation had the lowest agreement beyond chance and collapse/atelectasis had the highest.

A description of patients in which pathology was missed by CXR and clinical examination by each of the 2 observers is displayed in Table 4. The greatest number of patients with no additional pathology was described in terms of alveolar-interstitial syndrome; the pathology with lowest sensitivity in both modalities. In terms of pleural effusion, the pathology with highest sensitivity in both modalities, the lowest number of patients with no additional pathology was found. Of the patients with pleural effusion missed by CXR, all had additional collapse/atelectasis, and of the patients with pleural effusion missed by clinical examination, all except one had additional collapse/atelectasis detected by ultrasound.

Agreements beyond chance between the 3 modalities are displayed in Table 5, including observed and expected agreements. The agreements beyond chance of pathologic diagnoses between CXR and lung ultrasound ranged from 0.11 to 0.64 across the 5 pathologies and 2 observers, whereas agreements beyond chance of pathologic diagnoses between clinical examination and lung ultrasound ranged from 0.08 to 0.71. Between clinical examination and CRX agreements, beyond chance of pathologic diagnoses ranged from 0 to 0.58, and there was no statistically significant agreement beyond chance of diagnosis of consolidation or alveolar-interstitial syndrome. All the remaining agreements beyond chance were statistically significant.

The categorization of pleural effusion size by CXR and clinical examination was compared with the calculated volume from lung ultrasound. In terms of CXR, effusions categorized as small had a mean volume of 362 mL for observer I and 329 mL for observer II, effusions categorized as moderate had a mean volume of 714 mL for observer I and 779 mL for observer II, and effusions categorized as large had a mean volume of 938 mL for observer I and 890 mL for observer II. Likewise, in terms of clinical examination, effusions categorized as small had a mean volume of 400 mL for observer I and 420 mL for observer II, according to lung ultrasound quantification; the effusions categorized as

Table 1. Overview of Pathology Detected by Chest X-Ray, Clinical Examination, and Lung Ultrasound for Each Lung Zone

Pathology	Chest X-Ray (%)	Clinical Examination (%)	Chest X-Ray and Clinical Examination (%)	Lung Ultrasound (%)
Left upper zone (n = 78)				
Normal	95	92	90	88
Collapse/atelectasis	1	1	3	3
Consolidation	0	2	3	1
Alveolar-interstitial syndrome	0	2	3	8
Pleural effusion	0	2	3	3
Pneumothorax	4	1	5	1
Left lower zone (n = 78)				
Normal	59	63	54	56
Collapse/atelectasis	17	28	35	39
Consolidation	18	3	21	10
Alveolar-interstitial syndrome	3	2	5	6
Pleural effusion	27	28	38	30
Pneumothorax	1	0	1	1
Left anterior zone (n = 78)				
Normal	–	99	–	92
Collapse/atelectasis	–	0	–	0
Consolidation	–	0	–	0
Alveolar-interstitial syndrome	–	1	–	4
Pleural effusion	–	0	–	2
Pneumothorax	–	1	–	3
Right upper zone (n = 78)				
Normal	95	97	92	92
Collapse/atelectasis	0	0	0	0
Consolidation	0	1	1	0
Alveolar-interstitial syndrome	0	2	3	4
Pleural effusion	0	1	1	0
Pneumothorax	5	0	5	4
Right lower zone (n = 78)				
Normal	68	63	55	56
Collapse/atelectasis	15	24	29	37
Consolidation	9	3	12	15
Alveolar-interstitial syndrome	3	2	5	8
Pleural effusion	22	24	32	27
Pneumothorax	0	0	0	1
Right anterior zone (n = 78)				
Normal	–	98	–	88
Collapse/atelectasis	–	0	–	0
Consolidation	–	1	–	0
Alveolar-interstitial syndrome	–	1	–	5
Pleural effusion	–	1	–	0
Pneumothorax	–	0	–	8

Data presented as percentages of patients and reported as means between the 2 observers.
–, pathology not detectable in the respective lung zone.

moderate had a mean volume of 414 mL for observer I and 713 mL for observer II; and effusions categorized as large had a mean volume of 1152 mL for observer I and 1480 mL for observer II.

DISCUSSION

In this prospective, observational pilot study, we demonstrated a high proportion of clinically important respiratory pathology in noncritically ill patients before and after cardiothoracic surgery, with the majority occurring after surgery. Furthermore, we showed that the conventionally used assessment tools, clinical examination, CXR, and the combination of the two, have poor diagnostic performances, whereas lung ultrasound, in contrast, had high estimate of interobserver agreement beyond that expected by chance even in novice examiners. Routine use of lung ultrasound in these settings may result in fewer missed diagnosis of clinically important respiratory pathology. Because missed pathology may lead to poor clinical outcome, our results suggest that lung ultrasound may become an important part of the perioperative assessment in the future. Importantly, this study suggests the need for randomized, controlled trials to determine whether lung ultrasound can change diagnoses and improve clinical outcomes.

In emergency and critical care medicine, numerous studies have investigated the comparative diagnostic performance of lung ultrasound[3,7,19] and, consistently, lung ultrasound is reported to be more sensitive and more specific in the detection of common respiratory pathology including consolidation,[7,12] pleural effusion,[20,21] alveolar-interstitial syndrome,[22,23] and pneumothorax[18] than conventional CXR. Although CT scan is indeed the gold standard, we, therefore, established lung ultrasound as the reference method to evaluate whether the proportion of clinically

Table 2. Sensitivity and Specificity of Chest X-Ray and Clinical Examination in Patients With Pathology Detected by Lung Ultrasound

Pathology	Modality	Sensitivity (95% CI)	Specificity (95% CI)
Collapse/atelectasis		(n = 35)	(n = 43)
	Chest X-ray	43 (26–61)	91 (79–98)
	Clinical examination	63 (45–78)	92 (81–98)
	Combined	71 (54–85)	89 (86–96)
Consolidation		(n = 13)	(n = 65)
	Chest X-ray	37 (13–66)	84 (75–93)
	Clinical examination	15 (2–45)	96 (89–100)
	Combined	52 (24–79)	82 (71–91)
Alveolar-interstitial syndrome		(n = 14)	(n = 64)
	Chest X-ray	7 (0–34)	98 (92–100)
	Clinical examination	7 (1–33)	98 (91–100)
	Combined	14 (3–42)	97 (90–100)
Pleural effusion		(n = 32)	(n = 46)
	Chest X-ray	69 (50–84)	91 (80–98)
	Clinical examination	78 (60–91)	90 (80–97)
	Combined	94 (79–99)	86 (75–95)
Pneumothorax		(n = 8)	(n = 70)
	Chest X-ray	29 (5–68)	94 (86–98)
	Clinical examination	6 (0–42)	99 (94–100)
	Combined	33 (8–72)	93 (86–98)

Data presented as percentages with 95% confidence intervals and reported as means between the 2 observers.
Abbreviation: CI, confidence interval.

Table 3. Estimates of Interobserver Agreement Between Clinical Examination and Lung Ultrasound Beyond That Expected by Chance

		Collapse/ Atelectasis	Consolidation	Alveolar-Interstitial Syndrome	Pleural Effusion	Pneumothorax
Clinical examination	Observed agreement	0.86	0.94	0.94	0.84	0.98
	Expected agreement	0.57	0.90	0.94	0.54	0.98
	Cohen's kappa	0.70	0.28	–	0.68	–
	(95% confidence interval)	(0.58–0.82)	(0.0–0.59)		(0.56–0.80)	
		$P < .0005$	$P < .0005$		$P < .0005$	
Lung ultrasound	Observed agreement	1.00	0.96	0.98	1.00	0.99
	Expected agreement	0.51	0.72	0.71	0.52	0.81
	Cohen's kappa	0.97	0.84	0.92	0.94	0.93
	(95% confidence interval)	(0.94–1.0)	(0.72–0.96)	(0.84–1.0)	(0.89–0.99)	(0.83–1.0)
		$P < 0.001$	$P < .001$	$P < .001$	$P < .001$	$P < .001$

Data presented as observed agreements, expected agreements, and Cohen's kappa coefficients reported with 95% confidence intervals and corresponding *P* values.
–, not calculated as observer II did not detect alveolar-interstitial syndrome or pneumothorax in any lung zones.

significant respiratory pathology in patients undergoing cardiothoracic surgery can justify the cost of implementing lung ultrasound into clinical practice, including training, equipment, and quality assurance. We found that clinically important respiratory pathology was detected in more than one quarter of cardiothoracic surgery patients before surgery and in almost all patients after surgery. Furthermore, in a substantial proportion of patients, respiratory pathology was not detected with CXR or clinical assessment, which could lead to poor outcome if left undiagnosed.

The most commonly detected pathology with lung ultrasound in this study was collapse/atelectasis, which was frequently missed by CXR, clinical examination, and the two in combination; a condition that has different etiology and management to consolidation. This is not surprising in the context of cardiac surgery, whereby there is a major chest incision, postoperative pain and reduced tidal volume, use of cardiopulmonary bypass, and frequently compromised cardiac function. Importantly, although most literature does not explicitly report collapse as a separate entity to consolidation, ultrasound enables successful differentiation of the 2 conditions.[11] The low sensitivity of CXR and clinical examination for atelectasis may be due to the detected collapse/atelectasis almost consistently being accompanied by a pleural effusion as it was demonstrated, which makes the diagnosis difficult by clinical examination. After cardiac surgery a radiologist may have an innate bias to report the pleural effusion and to ignore atelectasis. For consolidation, sensitivities of CXR and clinical examination were even lower than that of atelectasis, and the interobserver agreement beyond chance of clinical examination was poor. Consolidation was accompanied uniformly by pleural effusion. Notably, although our study included percussion and vocal resonance in the diagnostic criteria, and not only bronchial breathing, the low sensitivity of clinical examination is consistent with previous findings.[7,19]

Our data on the diagnostic performance of CXR and clinical examination are in line with previous experiences in the intensive care setting.[24,25] The recommendations from The American College of Radiology state that CXR should only

Table 4. Description of Patients With Missed Pathology by Chest X-Ray and Clinical Examination

Pathology (No. Patients Detected by Lung Ultrasound)	Modality (No. Patients With Missed Diagnosis)	Description of Patients With Missed Diagnosis (No. Patients With Additional Diagnoses Detected by Lung Ultrasound)
Observer I		
Collapse/atelectasis (n = 35)	Chest X-ray (n = 19)	Pleural effusion (n = 16), consolidation (n = 8), alveolar-interstitial syndrome (n = 5), pneumothorax (n = 4), no additional (n = 2)
	Clinical examination (n = 14)	Pleural effusion (n = 12), consolidation (n = 4), alveolar-interstitial syndrome (n = 4), pneumothorax (n = 2), no additional (n = 1)
Consolidation (n = 15)	Chest X-ray (n = 9)	Collapse/atelectasis (n = 9), pleural effusion (n = 9), alveolar-interstitial syndrome (n = 1)
	Clinical examination (n = 13)	Collapse/atelectasis (n = 13), pleural effusion (n = 12), alveolar-interstitial syndrome (n = 2)
Alveolar-interstitial syndrome (n = 14)	Chest X-ray (n = 13)	Collapse/atelectasis (n = 7), no additional (n = 5), pleural effusion (n = 5), pneumothorax (n = 4), consolidation (n = 2)
	Clinical examination (n = 12)	Collapse/atelectasis (n = 6), no additional (n = 5), pleural effusion (n = 4), pneumothorax (n = 4), consolidation (n = 2)
Pleural effusion (n = 32)	Chest X-ray (n = 10)	Collapse/atelectasis (n = 10), alveolar-interstitial syndrome (n = 4), pneumothorax (n = 3), consolidation (n = 3)
	Clinical examination (n = 6)	Collapse/atelectasis (n = 5), consolidation (n = 1), no additional (n = 1)
Pneumothorax (n = 9)	Chest X-ray (n = 6)	Collapse/atelectasis (n = 3), alveolar-interstitial syndrome (n = 3), pleural effusion (n = 2), no additional (n = 1)
	Clinical examination (n = 8)	Collapse/atelectasis (n = 6), pleural effusion (n = 5), alveolar-interstitial syndrome (n = 4)
Observer II		
Collapse/atelectasis (n = 35)	Chest X-ray (n = 20)	Pleural effusion (n = 16), consolidation (n = 6), alveolar-interstitial syndrome (n = 5), pneumothorax (n = 3), no additional (n = 2)
	Clinical examination (n = 12)	Pleural effusion (n = 10), consolidation (n = 4), alveolar-interstitial syndrome (n = 3), pneumothorax (n = 2), no additional (n = 1)
Consolidation (n = 12)	Chest X-ray (n = 8)	Collapse/atelectasis (n = 8), pleural effusion (n = 8), alveolar-interstitial syndrome (n = 1)
	Clinical examination (n = 10)	Collapse/atelectasis (n = 10), pleural effusion (n = 9), alveolar-interstitial syndrome (n = 2)
Alveolar-interstitial syndrome (n = 14)	Chest X-ray (n = 13)	Collapse/atelectasis (n = 8), pleural effusion (n = 6), no additional (n = 4), pneumothorax (n = 4), consolidation (n = 2)
	Clinical examination (n = 14)	Collapse/atelectasis (n = 8), pleural effusion (n = 6), no additional (n = 5), pneumothorax (n = 4), consolidation (n = 2)
Pleural effusion (n = 32)	Chest X-ray (n =10)	Collapse/atelectasis (n = 10), alveolar-interstitial syndrome (n = 5), pneumothorax (n = 3), consolidation (n = 2)
	Clinical examination (n = 8)	Collapse/atelectasis (n = 7), alveolar-interstitial syndrome (n = 2), consolidation (n = 1), no additional (n = 1)
Pneumothorax (n = 8)	Chest X-ray (n = 6)	Collapse/atelectasis (n = 3), alveolar-interstitial syndrome (n = 3), pleural effusion (n = 2), no additional (n = 1)
	Clinical examination (n = 8)	Collapse/atelectasis (n = 5), alveolar-interstitial syndrome (n = 4), pleural effusion (n = 4)

Data presented as absolute numbers of patients.

be performed for specific clinical indications after initial admission to the intensive care unit.[26] Others have shown than clinical examination is not sufficiently sensitive to replace CXR in the first 24 hours after cardiac surgery.[27] Lung ultrasound, however, is accurate, noninvasive, portable, and does not emit ionizing radiation and may therefore substitute CXR in this setting, although may not be as efficient as CXR at identifying positions of invasive catheters and tubes.

In this study, we demonstrated that conventional methods of assessment of respiratory pathology in nonventilated patients before and after cardiothoracic surgery have poor diagnostic performance and repeatability representing a significant area for improvement. We believe that lung ultrasound, being easily repeated and generally superior as a diagnostic tool,[7] has the potential to improve the perioperative assessment of patients in this setting.

For critical care physicians, learning to perform lung ultrasound has been reported to have a steep learning curve, but with knowledge of only a few ultrasound findings, a novice can effectively improve diagnostic accuracy of several clinically important respiratory pathologies.[2,14] The researchers who performed lung ultrasound in this study had no prior experience in lung ultrasound and received training in lung ultrasound before commencement of the study. They required 50 mentored scans to achieve a flat learning curve, and the inter-observer agreements beyond chance between the 2 observers were very strong (0.84–0.97), similar to previous reports.[19] The theoretical knowledge required for lung ultrasound is not excessive and is available widely. The time taken to perform the lung ultrasound typically is less than 5 minutes.[23] From a practical point of view, it is relatively simple for anesthetists, cardiac surgeons, or physiotherapists to incorporate lung ultrasound into their assessment because ultrasound equipment is available widely and many already perform ultrasound-guided vascular access and/or focused echocardiography. Nevertheless, before lung ultrasound is implemented as a part of standard care, randomized trials are warranted to assess whether lung ultrasound can change diagnoses and subsequently improve clinical outcomes.

Table 5. Estimates of Intraobserver Agreement Between Chest X-Ray, Clinical Examination, and Lung Ultrasound Beyond that Expected by Chance

		Collapse/ Atelectasis	Consolidation	Alveolar-Interstitial Syndrome	Pleural Effusion	Pneumothorax
Observer I						
Chest X-ray	Observed agreement	0.70	0.78	0.83	0.83	0.88
versus	Expected agreement	0.54	0.70	0.81	0.54	0.82
lung ultrasound	Cohen's kappa	0.40	0.44	0.12	0.50	0.16
	(95% confidence interval)	(0.27–0.53)	(0.31–0.57)	(0.0–0.28)	(0.34–0.66)	(0.00–0.38)
		P < .001	*P* < .001	*P* < .001	*P* < .001	*P* < .001
Clinical examination	Observed agreement	0.79	0.80	0.82	0.85	0.89
versus	Expected agreement	0.53	0.78	0.79	0.52	0.87
lung ultrasound	Cohen's kappa	0.55	0.16	0.27	0.70	0.23
	(95% confidence interval)	(0.43–0.67)	(0.0–0.34)	(0.08–0.46)	(0.59–0.81)	(0.00–0.49)
		P < .001	*P* < 0.001	*P* < .001	*P* < .001	*P* < .001
Clinical examination	Observed agreement	0.79	0.78	0.94	0.80	0.91
versus	Expected agreement	0.61	0.78	0.92	0.54	0.89
chest X-ray	Cohen's kappa	0.40	0.04	0.00	0.58	0.17
	(95% confidence interval)	(0.24–0.56)	(0.00–0.16)	(0.00–0.01)	(0.45–0.71)	(0.00–0.47)
		P < .001	*P* = .395	*P* = .724	*P* < .001	*P* < .001
Observer II						
Chest X-ray	Observed agreement	0.70	0.77	0.83	0.83	0.86
versus	Expected agreement	0.54	0.72	0.81	0.54	0.83
lung ultrasound	Cohen's kappa	0.40	0.22	0.11	0.64	0.16
	(95% confidence interval)	(0.27–0.53)	(0.03–0.41)	(0.0–0.26)	(0.52–0.76)	(0.00–0.38)
		P < .001	*P* < .001	*P* < .001	*P* < .001	*P* < .001
	Observed agreement	0.80	0.85	0.83	0.86	0.90
	Expected agreement	0.52	0.82	0.83	0.54	0.90
Clinical examination	Cohen's kappa	0.67	0.08	–	0.71	–
versus	(95% confidence interval)	(0.56–0.78)	(0.00–0.24)		(0.60–0.82)	
lung ultrasound		*P* < .001	*P* = .027		*P* < .001	
	Observed agreement	0.83	0.77	0.98	0.77	0.91
	Expected agreement	0.59	0.78	0.98	0.56	0.91
Clinical examination	Cohen's kappa	0.47	0.00	–	0.50	–
versus	(95% confidence interval)	(0.32–0.62)	(0.00–0.01)		(0.35–0.65)	
chest X-ray		*P* < .001	*P* = .663		*P* < .001	

Data presented as observed agreements, expected agreements, and Cohen's kappa coefficients reported with 95% confidence intervals and corresponding *P* values.

–, not calculated as observer II did not detect alveolar-interstitial syndrome or pneumothorax in any lung zones.

Limitations

First, this study was designed as a pilot study to assess different strategies for diagnosis of perioperative lung pathology; therefore, we included only a convenience sample of patients. Consequently, larger-scale studies are needed to reproduce our findings as well as to explore potential correlations between lung pathology and clinical outcomes. Second, the sensitivity of CXR was lower than expected, which may result from the radiologists not being supplied with a standardized form for their findings, and thus we cannot preclude that abnormalities were detected but for some reason not reported. Third, no conclusions can be drawn in terms of alveolar-interstitial syndrome and pneumothorax because their proportions were low and the second observer did not detect either pneumothorax or alveolar-interstitial syndrome on clinical examination. Thus, we were unable to complete the calculations of agreements beyond chance between modalities for observer II and interobserver agreements beyond chance for these 2 pathologies. Fourth, our ultrasound definition of pneumothorax was absence of lung sliding and lung pulse but not including demonstration of lung point. Even though this might reduce the specificity of this ultrasound diagnosis, the intention was to be able to investigate each of the 3 lung zones independently keeping in mind that the lung point might be found in another lung zone than the absence of lung sliding and lung pulse. Hence, the superiority of lung ultrasound compared with clinical assessment and CXR are weaker than for the other respiratory pathologies. Fifth, we chose to perform each of the assessments in the most optimal patient position, and hence, the positions were different for the 3 modalities. Obviously, this might have altered the distribution of pathologies between different lung zones and estimation of effusion sizes, but suboptimal patient position would clearly have impaired the external validity of our findings. Lastly, we are well-aware that CT scan is the gold standard in detection of respiratory pathology. Nevertheless, in this clinical setting, CT scan is often challenging due to, for instance, costs and time consumption; therefore, we chose lung ultrasound as the reference method for this study.

CONCLUSIONS

We showed that the detection of clinically important respiratory pathology is improved with lung ultrasound compared with conventional methods of assessment (CXR, clinical examination, and the 2 in combination) in a significant number of nonventilated and noncritically ill patients before and after cardiothoracic surgery. We demonstrated high estimate of interobserver agreement beyond that expected by chance for lung ultrasound even in novice examiners. Routine use

of lung ultrasound may be an important tool for perioperative assessment in this setting.

DISCLOSURES

Name: John W. Ford, MD.
Contribution: This author helped design the study, acquire and interpret the data, and revise the manuscript.
Name: Johan Heiberg, PhD.
Contribution: This author helped analyze the statistics, interpret the data, graphic illustrations, and draft the manuscript.
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Be FoCUSed: The Time Is Now!

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Anesthesiologists adopt newer technologies and methods in the hope that these may improve perioperative care and outcomes. This adoption occurs even when the benefits of the technology have not been rigorously demonstrated (eg, pulse oximetry) or remain in question (eg, pulmonary artery catheter). Recently, anesthesiologists have adopted ultrasound as another technology ostensibly to improve patient care in a variety of clinical settings. In this issue of *Anesthesia and Analgesia*, Coker and Zimmerman present a narrative review[1] and a simple, yet illustrative guide[2] detailing the use of focused cardiovascular ultrasound (FoCUS) for perioperative hemodynamic assessment.

In very simple terms, FoCUS describes transthoracic, or surface, ultrasound imaging of the heart, inferior vena cava, and aorta to gain information about the status of the cardiovascular system at the point of care.[3,4] Furthermore, FoCUS is an echocardiographic examination that can be employed as required by the clinical circumstance, from the preoperative setting to the postanesthesia care unit. One scenario where FoCUS may be of particular benefit is the expedient evaluation of the emergent surgery patient. It is important to emphasize that the scope of practice, and not the specific ultrasound machine used, defines FoCUS. Importantly, FoCUS does not replace a comprehensive echocardiographic examination that is typically performed by a licensed cardiac sonographer or physician.

FoCUS aims to qualitatively differentiate normal from pathologic findings, via the evaluation of size, anatomic appearance, and motion with two-dimensional echocardiography. Such evaluation is based on comparisons with the neighboring structures and recognition of motion patterns.[5] For example, the physician performing FoCUS should be able to diagnose the presence of large pericardial or pleural fluid collections, marked enlargement of cardiac chambers, and may provide evidence of valvular heart disease. As the authors describe, such evaluation is relatively easy and fast, and provides important information. While the limited two-dimensional images generated during a FoCUS examination may provide clues to the presence of valvular heart disease, such as leaflet calcification or chamber enlargement, questions regarding severity of valve pathology cannot be definitively answered. Size determination is accomplished by visual estimation, based on comparison with neighboring structures. Attempts to measure exact dimensions are not only ill-advised, but also defeat the purpose of a FoCUS examination, which is, simply stated, "lean, mean, and quick." Any information should be considered within the context of the overall clinical picture to be useful for the diagnosis or exclusion of a pathologic finding. When clinically indicated, the anesthesiologist should request further, more comprehensive imaging performed by an expert, if the FoCUS-derived information is limited.

The actual ultrasound machine may vary from expensive, stand-alone platforms, equipped with three-dimensional and strain rate packages, to pocket-sized devices capable only of two-dimensional imaging. It is precisely because of the limited imaging capabilities of some devices, and the abbreviated training of some interpreting physicians, that these tests aid clinical decision support, as opposed to diagnosis.

A timely question now is how to implement the use of FoCUS within our specialty. As described in practice guidelines documents[3,4] and subjectively experienced by many transthoracic- or transesophageal-certified anesthesiologists, FoCUS is not bound by the practice and training rigors required for performing transthoracic or transesophageal echocardiography. As the technology advances and the size and cost of the FoCUS devices decrease, we anticipate that, as with the pulse oximeter, FoCUS will be ubiquitous in the very near future. The only remaining limitation to the widespread use of FoCUS will be our willingness to learn the technique and to adopt it. As an aside, current evidence suggests that FoCUS skills are quickly and easily acquired,[6] although skills diminish if not practiced enough.[7] Currently, critical care and emergency medicine,[8,9] for example, have evaluated various scenarios that show adoption of FoCUS is an important triage or screening tool. In perioperative medicine, several small-scale or pilot studies[10] suggest that the FoCUS examinations can change patient management. Similar types of studies need to be repeated on a larger, generalizable scale. It therefore follows that time has come for FoCUS to be critically evaluated to find its place in perioperative medicine.

As we add FoCUS to our perioperative diagnostic armamentarium, we should consider several key points. First,

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we need to remind ourselves that FoCUS is an abbreviated, focused ultrasound examination, aimed at answering simple questions in dichotomous fashion. Instead of trying to grade abnormalities as mild, moderate, or severe, we should instead look to answer clinical questions with responses of "yes or no," and "present or absent." As an example, the presence, or absence, of gross left ventricular functional abnormalities, the size of the ventricles, and the presence or absence of a pericardial effusion can be used to optimize the treatment of hypotension. Abundant, meaningful examination protocols using FoCUS already exist. It will be up to each individual to choose the FoCUS device/protocol that fits her or his type and style of practice.

Second, FoCUS should not be performed or interpreted in isolation. FoCUS should complement the physical examination and clinical judgment of the physician. For example, in the absence of related symptoms or an audible murmur, an abnormally appearing aortic valve detected during a FoCUS examination should not be the sole criterion for canceling an anesthetic and surgical procedure. Instead, it should be a reason to request additional imaging and an echocardiographic expert's opinion, if the anticipated surgical risk is other than low.

Third, and more important, the implementation of FoCUS should be supported by experts in ultrasound imaging, such as trained anesthesiologists, intensivists,[11] or, ideally, cardiologists. The adoption of transesophageal echocardiography into contemporary cardiovascular anesthesiology practice should serve as a model for in the incorporation of FoCUS into general anesthesia practice. The successful adoption of ultrasound imaging into the practice of cardiovascular anesthesiology occurred because the focus was on patient care, "not protecting practice silos and a source of income." Although perioperative transesophageal echocardiography, when practiced by trained physicians, may be a billable service, the same cannot be said of FoCUS. FoCUS is not a billable procedure, and no such procedural code exists.

Finally, professionalism and introspection should guide the adoption of FoCUS. As important as it is for the "gurus" among us not to hinder the practice of FoCUS by noncardiovascular anesthesiologists, it is equally essential for the FoCUS zealots not to overestimate their diagnostic capabilities.

The clinical skill of FoCUS is now widely taught during the formative years of medical education, much the same as the use of a stethoscope.[12] Indeed, we should make ultrasound imaging, in general, and cardiovascular ultrasound imaging, in particular, a required clinical skill during anesthesiology training. Anesthesiologists currently are using ultrasound to perform nerve blocks, estimate intracranial pressure, diagnose pneumothorax or pleural fluid, or even detect endotracheal intubation.[13] It is time to explore and hopefully realize the full clinical potential of perioperative FoCUS for the optimal care and outcomes of our patients.

DISCLOSURES

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Point-of-Care Ultrasound: Novel Technology to Routine Perioperative Assessment Tool

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Traditional ultrasound (US) devices were large and often confined to imaging laboratories (cardiology, radiology, and obstetrics). Recently, however, technological advances have made portable US devices more affordable with functionality similar to "high-end" units used in imaging laboratories.[1] This advancement has allowed health care providers the ability to perform US examinations at the bedside and use it for procedural, diagnostic, and screening applications, with improvement in patient care.[2–5] For anesthesiologists, this is an opportunity to deploy US in the perioperative medicine setting, outside the operating room.

During the past decade, the utility of point of care in the perioperative setting has focused primarily on central venous access and regional anesthesia. Point-of-care ultrasound (POCUS) has proven to significantly lower complication rates for central line placement and was listed as 1 of 12 most highly rated patient safety practices by the Agency for Healthcare Research and Quality.[6] As a result, it has rapidly become a standard of care.[7,8] Similarly, the use of POCUS has proven to be of benefit for regional anesthesia, and guidelines have indicated its utility toward improving block onset time, reducing number of needle passes, and avoiding vascular puncture.[9] As the presence of POCUS in the perioperative setting continues to grow, its utility to improve perioperative care in other areas is beginning to be demonstrated.

In this issue of *Anesthesia and Analgesia*, Yao et al[10] demonstrated the utility of POCUS to evaluate for patients who are likely to be a difficult laryngoscopy secondary to decreased temporomandibular joint mobility. Specifically, the authors assessed for temporomandibular joint mobility by directly measuring condylar translational distance using a novel US examination. This observational blinded study demonstrated that the direct assessment of a reduced condylar translational distance (defined in the study as <10 mm) had the greatest sensitivity and specificity for predicting a difficult laryngoscopy versus interincisor distance, upper lip bite test, mandibular protrusion, condyle-tragus distance, thyromental distance, and Mallampati classification.[10] Overall, this study demonstrates the utility of POCUS to facilitate the routine procedure of airway examination.

Similarly in this issue, Haskins et al[11] demonstrate another novel modality for perioperative POCUS by using a well-supported abdominal POCUS examination to detect intra-abdominal fluid extravasation (IAFE) in patients who had undergone hip arthroscopy and subsequently correlating the presence of IAFE to increased pain scores in the postanesthesia care unit. Specifically, this group used probably the most researched POCUS examination, the Focused Assessment with Sonography for Trauma examination, to detect the presence of IAFE.[11] Of particular interest is the reported incidence of IAFE found in this study, with a value that was a magnitude greater than what has been reported previously. Overall, this study is one of the first perioperative POCUS studies to demonstrate the utility of perioperative abdominal sonography.

These works are just a few of several recent publications that have demonstrated the utility of POCUS for perioperative care beyond central vascular access and regional anesthesia. Emerging areas of POCUS that have demonstrated to be relevant for the perioperative physician include transthoracic echocardiography, assessment of gastric volume, and location of the endotracheal tube.[12–16] Recently, the works of Canty et al[12] and Cowie[13] have demonstrated that a focused transthoracic echocardiography examination can be performed by an anesthesiologist and, when implemented, can positively impact perioperative patient care by altering management. Others have demonstrated similar results after implementing a comprehensive perioperative POC educational curriculum to anesthesiology residents.[5] Perlas et al[14,15] reported that the presence of fluid in the antrum, identified by US, correlated with a clinically significant amount of gastric volume. Finally, the utility of POCUS to detect appropriate endotracheal intubation via assessment of tracheal dilation and presence of bilateral pleural lung sliding has been demonstrated to be far superior than traditional auscultation.[16]

Despite these positive studies supporting perioperative POCUS, there is much more that can be developed. Specialties such as critical care and emergency medicine have demonstrated patient care benefit with the use of POCUS to examine for pulmonary, intracranial, and

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vascular pathology.[3,17] Currently, examination of the utility of these POCUS modalities has not been evaluated in the perioperative setting.

In addition, these specialties have developed formalized educational and certification pathways. In fact, emergency medicine has adopted POCUS training as a "core competency" for residency training and provide a year of fellowship training in clinical ultrasonography.[18] Although there has been some development in formalizing a comprehensive perioperative POCUS educational curriculum,[5] this has not gained widespread adoption. This is despite the interest of POCUS education reported by anesthesiology residents.[19,20]

As acute care physicians of the perioperative arena, along with a growing presence in the pre- and postoperative period, anesthesiologists more frequently will encounter patient care scenarios that have proven to be aided by POCUS. Because anesthesiologists were one of the first adopters of US, it seems intuitive that we would embrace this technology for all the relevant approaches it may provide to improve perioperative care.[21] Currently, however, POCUS technology is improving at a far faster rate than what our specialty is doing to incorporate all of its utility. Truly, we have gone from pioneers in the development of POCUS to a specialty that is behind when compared with some medical specialties.

The works of Yao et al[10] and Haskins et al[11] emphasize the important value of POCUS for anesthesiology. Both studies have shown that using US in the perioperative setting is not just convenient and safe, but it also changes management and potential outcomes. As research continues to be developed on the clinical utility of perioperative POCUS, our specialty will need to embrace a more comprehensive endorsement of this technology. Recently, a multisubspecialty group reviewed the current applications of perioperative US and its training.[22] This group reported a "call to action" on this topic and emphasized the importance of our specialty's societies to develop standards of training such that proficiency in perioperative US is expected on completion of accredited residency training.[22]

Regarding education, there has been some development in formalizing a comprehensive perioperative POCUS educational curriculum (FORESIGHT: Focused Perioperative Risk Evaluation Sonography Involving Gastro-abdominal Hemodynamic and Transthoracic Ultrasound), which is now available free online at www.foresightultrasound.com.[5] Similarly, the Society of Critical Care Medicine has online educational tools at http://www.sccm.org/Education-Center/Ultrasound/Pages/default.aspx. Finally, the American Institute of Ultrasound (http://www.aium.org) also has many online educational resources.

It is important to note that the American Medical Association passed a resolution (#802) stating that all medical specialties have the right to use US in accordance with specialty-specific practice standards.[23] Therefore, the impetus is on our specialty to develop: structured guidelines, endorsed educational pathways, and certified credentialing processes to incorporate this new assessment tool into everyday practice. The significance of this development cannot be overstated as the limitations and potential harm of POCUS without these processes have been suggested.[24] Once in place, anesthesiologists can evaluate the widespread clinical impact of incorporating this technology.

Adjustment of current patient care standards from advancing technology has always been strongly intertwined with anesthesiology. From advances such as pulse oximetry, capnography, and cardiac output assessment devices, anesthesiologists have constantly changed the standards of care using technology to advance patient safety. It is now time for our specialty to do the same with POCUS.

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Preprocedure Ultrasonography Before Initiating a Neuraxial Anesthetic Procedure

Cristian Arzola, MD, MSc

"Excellence is an art won by training and habituation. We are what we repeatedly do. Excellence, then, is not an act but a habit."

—Aristotle

Ultrasonography has helped physicians care for patients for more than half a century. Its potential to facilitate neuraxial blockade insertion was first established over 3 decades ago.[1] In 2001, Grau et al[2] reported that preprocedure ultrasonography reduced the number of puncture attempts needed to establish epidural analgesia in women with risk factors for difficult neuraxial block insertion. From that point forward, multiple studies cumulated to support the efficacy of ultrasonography to facilitate safe, efficient, and effective neuraxial blockade.

In 2008, the National Institute for Health and Clinical Excellence (NICE) in the United Kingdom determined that sufficient evidence had been published to support the routine use of "ultrasound to facilitate the catheterization of the epidural space."[3] At that time, skeptical clinicians raised concerns about cost, utility, and evidence.[4] In March 2016, the American Society of Regional Anesthesia and Pain Medicine (ASRA) published the second evidence-based medicine assessment of ultrasound-guided regional anesthesia[5] to "enable practitioners to make an informed evaluation regarding the role of ultrasound-guided regional anesthesia in their practice." Based on multiple studies and 2 meta-analyses,[6,7] ultrasound improves accuracy in identifying surface anatomy when compared with palpation (moderate quality of evidence) and accurately predicts the depth-to-target distance to reach the epidural or intrathecal space (high quality of evidence). Importantly, ultrasound improves the efficacy of neuraxial anesthesia (high quality of evidence) demonstrating a 50% reduced risk of technical failure (relative risk 0.51; 95% confidence interval 0.32–0.80) when compared with palpation as well as a reduced number of needle passes required for obtain a successful neuraxial procedure. Evidence was found to support ultrasound-assisted neuraxial blockade for a range of patient populations, including obese parturients,[8,9] the elderly, and those with previous spine surgery or spinal deformities. Multiple insertion attempts can be distressing for any patient. For obstetric surgery, in particular, neuraxial technical failure often leads to general anesthesia with its increased risk for patient harm.[10]

Despite mounting evidence of the utility of ultrasonography to facilitate neuraxial blockade, few anesthesia providers regularly use it in their practice.[11] What are the barriers to widespread uptake? Technical expertise is certainly 1 barrier. Although hands-on workshops are regularly offered in scientific conferences, there is limited research on training and assessment modalities of this particular skill.[12,13] Neuraxial changes in pregnancy may further impede successful implementation of ultrasonography for neuraxial procedures in obstetric patients.[14]

For most anesthesia providers, blind neuraxial procedures work well almost all of the time. The added utility of ultrasound assistance may not be readily apparent in daily clinical practice. In the current issue of the Journal, an article by Tawfik et al[15] appears to support this point. This randomized trial failed to demonstrate a significant improvement in the rate of successful epidural catheterization at the first needle pass when assisted by preprocedural ultrasonography. The study was well designed and reflects the general clinical practice. A single clinician experienced in both traditional palpation and ultrasound-assisted techniques performed equally well with a 60% success rate at the first needle pass, regardless of technique, for a group of patients with palpable landmarks. Consistent with previous studies, for experienced anesthesia providers, ultrasound assistance does not improve the success rate for neuraxial block insertion in subjects with palpable spinous processes.[16,17]

Nevertheless, in the study by Tawfik et al,[15] a single woman assigned to blind neuraxial block insertion eventually requested general anesthesia after enduring multiple unsuccessful skin punctures and insertion attempts. This too reflects the general clinical practice. Occasionally, blind neuraxial block insertion proves to be impossible.

Surveys from the Obstetric Anaesthetists Association (OAA) reveal anesthetists would definitely consider ultrasound in assisting placement in patients with difficult backs and after failure of standard insertion techniques.[11] The belief that ultrasonography can be used effectively only when the procedure is technically difficult rests on the assumption that

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the technology can be deployed with little practice. Based on the observations of our research group after 12 years of investigating this topic and training countless clinicians at different levels, technical proficiency requires extensive experience in routine cases in which palpable landmarks are easily identified. Pattern recognition and meticulous skin markings cannot be overstated to obtain proficiency, skills that originate from deliberate and habitual practice.

A preprocedural ultrasonography examination of the spine accurately delineates the underlying relevant anatomy.[18] Although image quality tends to deteriorate in patients with increasing body mass index, modifications in technique can improve the information obtained despite poor sonoanatomy. For example, a modified scanning technique alleviates subcutaneous tissue compression by the ultrasound probe and improves the accuracy for estimating the distance to the epidural space.[19] The combination of multiple measurements in different planes and to different landmarks may provide surrogate information about distance to midline punctures. For example, the distance to the epidural space obtained in the paramedian sagittal oblique plane or the distance to an imaginary line interconnecting the posterior aspects of the transverse processes as seen in the transverse median plane both approximate the distance to the epidural space for midline punctures when such depth is not easily measured in the transverse median plane.[19]

The use of ultrasonography is the standard of practice in obstetrics and widely accepted by pregnant women. Furthermore, the low-frequency curvilinear transducer utilized during the abdominal examination in pregnancy is the very same needed for ultrasound-assisted neuraxial procedures. Therefore, first, parturients are already familiarized with ultrasonography examinations, and second, the issue of cost and availability may be initially circumvented by sharing equipment on most labor and delivery units. The debated issue of delaying the initiation of the neuraxial procedure because of ultrasound imaging and skin markings has not been fully answered in the study by Tawfik et al[15] or others studies.[16] Nevertheless, once ultrasonography is incorporated in the workflow, the time needed for preprocedural marking becomes more efficient with practice to better translate an optimal needle insertion point. This can be performed by an accurate marking in the form of a skin indentation by a small plastic device (syringe or hub of a needle) rather than simply ink markings from a nonsterile pen, which are usually wiped away with application of the skin preparation solution. Although the patient may slightly change position during the short period of time between the ultrasound imaging and actual neuraxial procedure, this usually does not represent a major hindrance as long as the patient is encouraged to adopt the same previous position during the preprocedural ultrasonography.

As Johann von Goethe said, "Knowing is not enough; we must apply. Willing is not enough; we must do." Accumulating evidence confirms that neuraxial ultrasonography facilitates effective neuraxial blockade. The reluctance of incorporating its use routinely, especially when no major time delay is added, may be weighed against the benefits when applied with proficiency in the cases of deemed difficulty. The opportunity to rescue a failed neuraxial technique performed by traditional palpation describes an even greater relevance of ultrasonography in obstetric anesthesia. Tawfik et al[15] add another piece of information for preprocedural ultrasound, which continues evolving in its best evidence-based indications for clinical practice. ■

DISCLOSURE

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