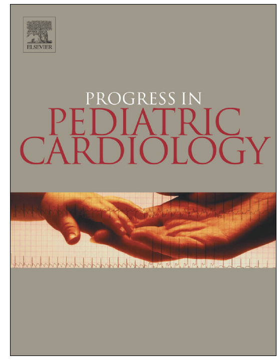
Journal Pre-proof



Segmental approach to performing a standard pediatric echocardiogram

Peace C. Madueme, Alejandro Arevalo, Nivedit Kudchadker, Shubhika Srivastava

PII: S1058-9813(20)30129-6

DOI: https://doi.org/10.1016/j.ppedcard.2020.101260

Reference: PPC 101260

To appear in: *Progress in Pediatric Cardiology*

Received date: 13 May 2020

Revised date: 13 June 2020

Accepted date: 16 June 2020

Please cite this article as: P.C. Madueme, A. Arevalo, N. Kudchadker, et al., Segmental approach to performing a standard pediatric echocardiogram, *Progress in Pediatric Cardiology* (2020), https://doi.org/10.1016/j.ppedcard.2020.101260

Progress in Pediatric Cardiology

Title: Segmental Approach to Performing a standard Pediatric Echocardiogram

Peace C Madueme[1,2], Alejandro Arevalo[1,2], Nivedit Kudchadker[1], Shubhika Srivastava[2,4]

[1]Nemours Cardiac Center, Nemours Children's Hospital, Orlando, FL

[2]Nemours/A.I. Dupont Hospital for Children, Wilmington, DL

[3]Department of Pediatrics, University of Central Florida College of Medicine, Orlando, FL

[4]Department of Pediatrics, Sidney Medical College, Thomas Jefferson University, Wilmington, DE

Corresponding Author:

Peace C Madueme

Nemours Cardiac Center

13535 Nemours Parkway

Orlando FL 32827

Office: 407-567-4581

Cell: 407-982-6932

Email: peace.madueme@nemours.org

Abstract:

The field of pediatric cardiology is rich with abnormal anatomy, unique congenital malformations and unusual surgical corrections that can be challenging to adequately image. The comprehensive pediatric echocardiogram is uniquely different from our adult colleagues and requires a systematic segmental approach to evaluate a wide range of structural and congenital abnormalities. This segmental approach focuses on the cardiac segments and the structures that connect them. The pediatric echocardiogram must adequately and efficiently differentiate and establish the cardiac structures in multiple planes with color and Doppler confirmation. The protocol for image acquisition is the extension of this segmental approach and should be designed with the comfort of the patient in mind, as well as the need to acquire all the necessary information in a swift and reproducible fashion. As such, the sequence of the obtained images is not and should not be the focus, but rather the comprehensive acquisition of the salient data from each imaging window. Herein, we describe the protocol used enterprise wide at three institutional locations for the systematic assessment of cardiac structure and anatomy.

Keywords: pediatric echocardiogram; segmental; congenital heart disease; echo protocol

Background

The pediatric echocardiographic assessment is one that strives to describe multiple aspects of the presenting cardiac problem, including anatomy, function, and physiology. It requires a comprehensive and systematic approach to the study while taking into consideration, indication of the study, age of the patient, environment in which the study is performed and comfort of the patient. This is especially important within the pediatric population which spans from the newborn child to the near adult. The pediatric echocardiographic assessment has to be comprehensive as it must encompass the scope of detecting structural and functional abnormalities that encompasses the myriad of congenital heart disease, genetic maladaptation such as cardiomyopathies, and acquired heart disease such as Kawasaki disease.

The segmental approach is inclusive of the nomenclature used to describe the diverse presentations of anatomy and structure. Classically, two different nomenclature techniques have been employed. The first, famously pioneered by Richard and Stella Van Praagh, describes the cardiac anatomy in a segmental fashion based on spatial relationship of the heart chamber to each other and chirality, with three cardiac segments and two connecting segments (atrioventricular junction and infundibulum).[1] The second method, pioneered by Bob Anderson, similarly describes the cardiac anatomy in a segmental form with 3 components and describes connections between them by concordance.[2] A normal heart by Van Praagh will be described as normal cardiac anatomy {S, D, S} and by Anderson as – usual atrial arrangement, concordant atrioventricular connections and concordant ventricular arterial connections. Neither is absolutely correct or incorrect, though the differences in style has led to a creation of nomenclature camps depending on where physicians trained and regions of the country. This has led to some confusion when it comes to describing cardiac anatomy and often requires someone to be well versed in both nomenclature techniques. When in doubt, simply describing the anatomy and discarding the nomenclature norms has also been used and becomes a third technique within an already complex paradigm of describing cardiac anatomy that is already inherently complex.[3]

Echocardiographic protocols are designed to comprehensively evaluate the pediatric cardiac anatomy and function using 2D images, color flow mapping and color Doppler from multiple imaging planes and orthogonal views. Sweeps of the heart (fixed transducer position with angulation) are included within the study and are key to understanding spatial relationships. Cine loops or multiple beat recordings of valves and vessels with translocation of the transducer from standard imaging planes is unique to congenital echocardiography. The exam is structured by the imaging planes as defined by the American Society of Echocardiography.[4] These include parasternal, subcostal (subxiphoid), apical and suprasternal windows, in orthogonal planes for each imaging location. By convention, pediatric echocardiographic images are displayed in an anatomically correct position on the viewing screen. As such, the anterior and superior cardiac structures are typically displayed at the top of the screen while the right side of the heart is displayed on the left side of the screen. The exception to this is with parasternal long axis imaging where the cardiac apex is always displayed on the left thereby maintaining the anatomical position of the heart within the chest. Classically, imaging is performed initially in the long axis plane, followed by the orthogonal short axis plane, realizing that the imaging planes are relative to the heart and not the body. Individual institutions should have a documented written protocol that should outline the necessary views and the manner in which they should be obtained. Most protocols are similar but may have subtle differences. Some of these differences may involve the protocol sequence, how the anatomic images are displayed relative to the screen or the scanning side (right versus left handed). A common misconception is that the segmental approach for congenital heart disease must begin with the subcostal view. However, how the study is begun and the sequence of the views should not be the focus of any protocol, but rather ensuring a complete study with a focused and consistent acquisition of all the necessary information from all the different views in a segmental fashion while maintaining comfort of the child should be the goal of any comprehensive echocardiographic study. Discrepancies in hemodynamic assessment of pressure gradients between catheterization based data and echocardiographic Doppler data are evident if the heart rate and cardiac output are different between the two states. Stevenson et al have shown that echocardiographic Doppler estimates of pressure gradients in unsedated children were 41.5% greater than pressure gradients measured in the cardiac catheterization laboratory in sedated children.[5 6]

In our echocardiography lab, an enterprise-wide standardized protocol has been adopted across three sites to maintain reproducibility. The sequence of the images obtained is variable and latitude is given to conform to workflow differences between locations. Some of our sites begin the exam in the subcostal position to determine cardiac situs and progress cephalad (subcostal to apical to parasternal to suprasternal to right parasternal). Given that the incidence of complex congenital heart disease with abnormal situs is <1% and the absence of a dedicated sedation program for specific age children, some of our sites begin the exam in the less caustic parasternal view to obtain potentially more accurate valve and Doppler evaluations in toddlers and children. This reduces the possibility of heart rate variability and allows for more comprehensive evaluation of common anatomic pathologies prior to the patient becoming distressed.[5-7] Regardless of the sequence, the entirety of the images obtained remains uniform and standardized. Herein, we will describe the protocol beginning in the parasternal position as described by Snider[6]. Thereafter, the study progresses to apical, to subcostal, to suprasternal and culminating in right parasternal border views. The most caustic imaging view, suprasternal, is at the end of the protocol unless aortic pathology, such as aortic coarctation, is strongly suspected. In such cases, suprasternal imaging may be performed first in an uncooperative or ill child in order to get the pertinent information for rapid clinical therapy or prior to losing imaging windows. Whenever indicated, the sequence of the protocol may need to be adjusted or modified based on the clinical situation or the cooperation of the patient. For example, an uncooperative child with Kawasaki disease will have a study that begins with parasternal short axis coronary imaging. All images are displayed in the anatomically correct position as previously described by convention. Lab personnel may be left or right handed, and rooms can be manipulated to accommodate sonographer scanning preference. All lab features adhere to published guidelines and standards as set forth by the American Society of Echocardiography and the Intersocietal Accreditation Commission.[4 8]

Parasternal Long and Short Axis

The child is positioned in the left lateral decubitus position preferably or supine for comfort. This view is obtained next to the sternum within or above the 4th intercostal space which allows for an optimal imaging window. If the image appears like an inverted apical view – one is probably too low on the chest. The long axis plane is obtained with the transducer indicator at approximately 11 o'clock which follows the long axis of a normally positioned heart (Fig.1). The parasternal view optimally evaluates the anatomy and morphology of the intracardiac valves in both planes. The standard neutral position evaluates the left atrium, mitral valve, left ventricle, left ventricular outflow tract and aortic valve. This view is useful for assessing the aortic and mitral valve anatomy and can demonstrate the presence or absence of fibrous continuity between the two valves. Interrogation of the ventricular septum is best evaluated in this plane as the transducer ultrasound beam is perpendicular to the septum which provides reliable 2D imaging. The transducer ultrasound beam is also therefore parallel to flow from any ventricular shunt which is optimal for Doppler interrogation. Assessment of the proximal aorta can also be performed by sliding the transducer cephalad to bring out the ascending aorta at the level of the right pulmonary artery (Fig.2). The parasternal long axis view is the optimal view for proximal 2D aortic dimensions, including the aortic annulus, root and ascending aorta. The transducer is then swept to the right hip to evaluate the right ventricle, tricuspid valve and right atrium. Often, the mouth of the coronary sinus draining to the right atrium can be best appreciated with this view. Sweeping to the left shoulder can then provide visualization of the right ventricular outflow tract and pulmonary valve. The sweep to the left shoulder provides an ideal view for measuring the pulmonary valve annulus by 2D. It is important and necessary to repeat the ventricular septal interrogation while sweeping to the right hip and left shoulder to identify unusually located defects. The short axis plane is then obtained by rotating 90 degrees clockwise to approximately the 2 o'clock position (Fig.3). Typically, imaging begins with a full sweep from apex to base by 2D and then by color. All four valves are again evaluated for anatomy and function. The mitral and aortic valves are best seen "en face" in this plane for evaluation of leaflet anatomy. Doppler interrogation of the mitral and aortic valves is typically not possible in the long or short axis plane secondary to suboptimal angles of insonation and are better assessed in other imaging planes. The tricuspid and pulmonary valves can often be interrogated from the parasternal views by Doppler. The pulmonary valve can also be seen "en face" with clockwise rotation of the transducer to ~4 o'clock which can be useful in the setting of significant pulmonary valve pathology (Fig.4). The branch pulmonary arteries are best seen in the short axis view or high parasternal view and can be measured in this view. Coronary imaging is then performed in the parasternal views which provides the closest proximity of the highest frequency transducer to the coronary arteries. Confirmation of 2D findings with color fill of the coronary arteries is key to increased confidence of delineating coronary artery origin and proximal course. Clockwise rotation of the transducer can often elongate the left coronary artery and demonstrate the bifurcation more effectively. Coronary presets with imaging software are common due to the challenges of visualizing the coronary anatomy with confidence. The Nyquist limit should be lowered when interrogating the coronaries, usually to around 20 cm/s. Additionally, compression settings are usually lowered to enhance vessel contrast and to better display the coronary lumen. Of note, Motion mode (M-mode) is acquired in the short axis plane at the level of the papillary muscles. Though this technique is falling out of favor and equivalent 2D measurements are becoming the norm, our lab continues to acquire this data for functional assessment due to the ease of acquisition and the superior temporal resolution. As always, with each structure and in each plane, imaging is performed initially by 2D imaging, color mapping and then Doppler interrogation if appropriate.

Apical 4 Chamber

The apical view is obtained typically with the transducer at the cardiac apical impulse or toward the axilla at the nipple line with the indicator at 3 o'clock (Fig.5). The child can be placed supine or optimally in a left lateral decubitus position with the left arm raised. Once again, the sequential analysis of the cardiac segments is performed, typically from posterior to anterior. The coronary sinus can be well seen posteriorly in the left atrioventricular groove. A dilated coronary sinus can be indicative of a left superior vena cava draining to the structure. The atria can be evaluated in this plane, primarily for the assessment of size. Care should be taken in assessing the septum from this plane as image dropout is common due to the parallel angle of the ultrasound beam to the septum. Apical imaging is classically the best for evaluation of the atrioventricular valves and determining morphology. 2D measurements of the atrioventricular valves is best obtained in this view and can be compared to established published normal values. The tricuspid valve has three leaflets, has attachments to the ventricular septum, is more apically displaced and follows the morphologic right ventricle. The mitral valve has two leaflets, does not usually have attachments to the septum and follows the morphologic left ventricle. Ventricular morphology can be best seen from this view with assessment of trabeculations, moderator band and ventricular shape to help establish right from left ventricle. Further anterior sweeping then displays initially the left ventricular outflow tract (apical 5 chamber view) and then the right ventricular outflow tract. The ventricular outflows are best evaluated in the apical view as they are in parallel with the ultrasound beam resulting in accurate Doppler assessments. Additional dedicated imaging of the anterior right ventricle can be performed by sliding the transducer medially for better visualization of the right ventricular free wall. The orthogonal 2 chamber view is obtained by rotating the transducer counterclockwise with the indicator now at ~11 o'clock (Fig.6). This view focuses on the left atrium, mitral valve, left ventricle and the left ventricular outflow tract. The 2 chamber view is used most frequently for quantification of atrial and ventricular volumes in a biplane format. The 3 chamber view can be useful for visualizing subaortic pathology such as subaortic membranes. Once again, the convention of 2D imaging, then color mapping and then Doppler interrogation is our standard, but the style of this acquisition can differ from lab to lab and from sonographer to sonographer.

Subcostal

The determinants of cardiac position and the cardiac structures are the abdominal viscera and the thoracic sidedness as defined by atrial position. The asymmetry of these structures follows a predictable pattern that can be applied to expectations for the cardiac anatomy. Abdominal situs focuses on the position of four cardinal structures: liver, stomach, spleen and the abdominal great vessels (aorta and inferior vena cava). This is best obtained in a transverse axial plane which maintains the right/left orientation. Normal abdominal situs is manifested by a right sided liver, right sided inferior vena cava, left sided stomach, left sided spleen at the greater curvature of the stomach, and left sided abdominal aorta (Fig.7). Abdominal situs inversus is the mirror opposite with a left sided liver and inferior vena cava with a right sided stomach, spleen and aorta. The abdominal situs has implications for expectations for cardiac situs and pathology. For example, a normally positioned heart (levocardia) has a high incidence of structural abnormalities in the setting of abdominal situs inversus, while an abnormally positioned heart (dextrocardia) often has normal anatomy in the setting of situs inversus. The transducer is positioned immediately below the xiphoid process with the indicator at ~3 o'clock. The liver and stomach positions are noted. The position of the inferior vena cava and the aorta relative to midline and each other are noted. The inferior vena cava is usually located rightward and anterior of the aorta, even in the setting of a right aortic arch. If the IVC is not easily identifiable, interruption of the inferior vena cava should be suspected and can often be confirmed by the presence of a dilated azygous vein that courses posterior to the aorta leftward of the spine. From the transverse view, sweeping superiorly while crossing the diaphragm can identify pleural effusions effectively. The orthogonal plane is then obtained by rotating the transducer clockwise to the ~6 o'clock position to obtain a long axis view of the great vessels. From this view, drainage of the suprahepatic inferior vena cava to the heart inclusive of the hepatic veins can be demonstrated. The descending abdominal aorta can be interrogated well in this plane, often requiring slight superior/inferior angulation in order to achieve a near parallel angle of insonation for an optimal Doppler signal (Fig.8).

Subcostal imaging then progresses more cephalad to demonstrate the cardiac anatomy in the coronal and sagittal planes with the child supine. Subcostal imaging can be optimized by raising the knees or having the child breath out to minimize lung artifact. Younger children and infants may be intolerant of this view due to the probe pressure in the abdomen. The coronal plane is obtained by placing the transducer in the upper abdomen below the xiphoid process with the indicator usually oriented towards 3 o'clock (Fig.9). Ideally, a third of the imaging window is occupied by the liver and diaphragm inferiorly with the heart in the far field. From this view, imaging of the systemic veins as they drain to the right atrium can be reliably demonstrated. The atrium can then be evaluated and often, atrial situs can be performed by assessing the appendages, the atrial septum that separates the two atria and the coronary sinus. The right atrial appendage is broad based while the left atrial appendage is finger-like. This view is the best view for demonstrating juxtaposition of the atrial appendages, a finding that can be present with specific complex lesions. The atrial septum is best seen from the subcostal view and often times, the septal morphology can help with thoracic situs determination. The thicker limbus of the septum secundum follows the location of the right atrium. Evaluation of the atrial septum for septal defects is ideal from the subcostal plane as the ultrasound beam is perpendicular to the septum, allowing for the best imaging resolution and is parallel to any intracardiac shunting flow, allowing for the most accurate Doppler interrogation. The coronary sinus is a left sided structure that always courses posterior to the left atrium if present. The entrance of the supra-hepatic portion of the inferior vena cava, coronary sinus os and atrial septal morphology aid in determining right atrial morphology. The appendage morphology is unique to each atrium but cannot be used as the primary indicator to define atrial morphology. All of these structures, if visualized well, can help determine atrial sidedness which mimics thoracic situs. Continuing to sweep anteriorly, provides good visualization of the two atrioventricular valves that connect the atria to the ventricles. Slow sweeps of the ventricular septum with a lower Nyquist setting is performed to evaluate for ventricular septal defects. Lastly, further sweeping anteriorly, displays the ventricular outflow tracts and the great vessels. Evaluation of the outflow tracts in the subcostal view is especially useful in the setting of complex congenital heart disease with conotruncal abnormalities as the great vessel relationship can be well seen and the presence or absence of conal tissue can be identified. In all instances, the standard technique is to evaluate by 2D including sweeps, followed by color flow mapping and then Doppler interrogation of areas of interest. The imaging of discrete structures in then performed in the orthogonal sagittal plane with the transducer indicator now at 6 o'clock (Fig.10). Imaging progresses gradually from right to left or vice versa with confirmation of previously demonstrated structures. Some structures are better seen in the sagittal plane versus coronal due to the course of the structure of interest. For example, the venous drainage to the right atrium is often better appreciated in the sagittal plane where the classic "bicaval" view can be obtained. This view is optimal for identifying the Eustachian valve, an embryological structural remnant located on the anterior surface of the inferior vena cava mouth that should not be confused with the atrial septum. Additionally, the elusive right upper pulmonary vein, can often be seen draining posterior to the superior vena cava and anterior to the right pulmonary artery.

Suprasternal Long and Short Axis

The fourth standard imaging plane is the suprasternal view which is may be poorly tolerated in young pediatric patients. Laying supine, the key to optimal imaging is full extension of the neck, often requiring a roll or pillow under the shoulder to achieve hyperextension. This view is obtained by placing the probe in the supraclavicular area or suprasternal notch while the child's head is hyperextended. The long axis view is obtained with the transducer indicator at approximately 1-2 o'clock and displays the aortic arch in the classic "candy cane" format (Fig.11). This view is obtainable in patients if they have a normal left aortic arch. In the setting of a right aortic arch, the transducer may need to be oriented more towards 11 o'clock. The suprasternal view is the best location for evaluating coarctation of the aorta by 2D and Doppler assessment. Sweeping leftward can elongate the left pulmonary artery as it courses from anterior to posterior. The orthogonal suprasternal short axis view is obtained by rotating 90 degrees clockwise with the indicator at approximately 3-4 o'clock (Fig.12). Arch branching is identified in this view by following the branching pattern of the first head and neck vessel (brachiocephalic or innominate artery). Branching to the right is consistent with a left aortic arch while branching to the left is consistent with a right aortic arch. If arch branching cannot be demonstrated in the short axis view, a tracheal sweep can be performed in the long axis view by starting rightward and sweeping left. In the setting of a right aortic arch, the arch will be visualized in its entirety prior to visualizing the tracheal rings. With a normal left aortic arch, the tracheal rings will be seen prior to seeing the entire arch. The presence of a left superior vena cava can be well seen from the short axis view by sweeping leftward. In young patients, the pulmonary veins are very well assessed in this view. All four pulmonary veins can be seen in the far field in the so called "crab view" (Fig.13). Imaging of each structure is initially performed in 2D, followed by color flow and finally Doppler interrogation if appropriate.

Right Parasternal and High Right Parasternal

A right parasternal view is the final imaging plane and is performed especially if adequate visualization of the superior vena cava or septum was not previously obtained. This view is diagnostic in the evaluation of sinus venosus defects or unusual partial pulmonary venous drainage (Fig. 14). The transducer is positioned rightward of the sternum with the indicator at 12 o'clock, running parallel with systemic venous drainage. The short axis high right parasternal using the same imaging window is obtained by clock-wise 90-degree rotation of the transducer with the indicator at 3 o'clock. This view profiles the septum and veins in the orthogonal plane. The high right parasternal infraclavicular or parasagittal views are often used to interrogate stenotic gradients across the aortic valve which provides a parallel angle of insonation for Doppler interrogation of the aortic gradient.

Ductal view

The ductal view is a useful modified view for better visualization of the juxtaductal region in the context of aortic coarctation (Fig. 15). The view is a parasagittal sweep with the transducer positioned in the high left parasternal/infraclavicular area with the indicator at 12'o'clock. The sweep involves titling the transducer towards the midline, profiling the ascending aorta and then tilting it towards the midclavicular line to profile the main pulmonary artery, left pulmonary artery and then ending with the descending aorta. This view is useful in imaging aortic coarctation, the distal transverse arch and Isthmus and also the left upper pulmonary vein.

High left parasternal/infraclavicular

The high left parasternal or high left short axis view is the orthogonal view to the previously mentioned ductal view and is useful for better visualization of the branch pulmonary arteries and pulmonary veins. This view is obtained by 90-degree clockwise rotation of the transducer with the indicator at 3 o'clock.

Reporting

The final element of the segmental cardiac evaluation is the reporting which have been defined by the American Society of Echocardiography and complemented by the Intersocietal Accreditation Commission.[4 8] Each lab should have a standardized format of reporting that includes the demographic data, study information, clinical information, pertinent findings and a summary section. The two goals of the report are to 1) communicate the findings to both cardiac and non-cardiac clinicians in an accurate and comprehensive fashion and 2) maintain billing compliance. There are numerous available software packages for reporting that are now focused on structured reporting in a segmental format. These formats are broken down into a) structural findings, b) measurements of structures by 2D and M-mode, c) Doppler measurements, and d) assessment of ventricular function. The structural findings should be reported in a segmental approach. Typically, this format is: Cardiac position, systemic veins, pulmonary veins, atria, atrial septum, atrioventricular valves, ventricles, ventricular septum, semilunar valves, great vessels, extracardiac vessels, coronary arteries and pericardium. Quantitative measurements of structures and chamber dimensions are performed as per the American Society of Echocardiography guidelines and are reported as absolute values with corresponding age and size appropriate z-score values based on published normals.[9] Doppler interrogation as appropriate for valves and areas of interest are interrogated as peak or mean velocities and graded based on previously established normal ranges of severity. Finally, both systolic and diastolic ventricular function are evaluated based on the images obtained. Several metrics can be obtained to ensure intrinsic consistency (shortening fraction vs ejection fraction vs strain).

Conclusion

Adherence to a protocol as described above that follows a segmental format can improve pediatric cardiac assessment and can be modified as necessary to fit the clinical situation. Pediatric patients are not always cooperative and sometimes obtaining the most important information or going “out of order” is necessary to be efficient. Similarly, the sequence of the protocol should not be the focus, but rather ensuring that all the necessary information is obtained in all the standard views. Appropriate imaging at each echocardiographic window in the same predictable, consistent and reproducible manner will yield the necessary information to allow accurate interpretation and concise reporting.

REFERENCES

1. Van Praagh R. Diagnosis of complex congenital heart disease: morphologic-anatomic method and terminology. Cardiovasc Intervent Radiol 1984;**7**(3-4):115-20 doi: 10.1007/bf02552810[published Online First: Epub Date]|.

2. Anderson RH, Becker AE, Freedom RM, et al. Sequential segmental analysis of congenital heart disease. Pediatr Cardiol 1984;**5**(4):281-7 doi: 10.1007/BF02424973[published Online First: Epub Date]|.

3. Franklin RCG, Beland MJ, Colan SD, et al. Nomenclature for congenital and paediatric cardiac disease: the International Paediatric and Congenital Cardiac Code (IPCCC) and the Eleventh Iteration of the International Classification of Diseases (ICD-11). Cardiol Young 2017;**27**(10):1872-938 doi: 10.1017/S1047951117002244[published Online First: Epub Date]|.

4. Lai WW, Geva T, Shirali GS, et al. Guidelines and standards for performance of a pediatric echocardiogram: a report from the Task Force of the Pediatric Council of the American Society of Echocardiography. J Am Soc Echocardiogr 2006;**19**(12):1413-30 doi: 10.1016/j.echo.2006.09.001[published Online First: Epub Date]|.

5. Stevenson JG, Kawabori I, French JW. Doppler pressure gradient estimation in children. Accuracy, effect of activity and exercise, and the need for sedation during examination. Acta Paediatr Scand Suppl 1986;**329**:78-86 doi: 10.1111/j.1651-2227.1986.tb10390.x[published Online First: Epub Date]|.

6. Snider AR, Serwer GA, Ritter SB. *Echocardiography in pediatric heart disease*. 2nd ed. St. Louis: Mosby, 1997.

7. Cape EG, Yoganathan AP, Levine RA. Increased heart rate can cause underestimation of regurgitant jet size by Doppler color flow mapping. J Am Coll Cardiol 1993;**21**(4):1029-37 doi: 10.1016/0735-1097(93)90364-7[published Online First: Epub Date]|.

8. Commission IA. The IAC Standards and Guidelines for Pediatric Echocardiography Accreditation. Secondary The IAC Standards and Guidelines for Pediatric Echocardiography Accreditation 2017. https://www.intersocietal.org/echo/standards/IACPediatricEchocardiographyStandards2017.pdf.

9. Lopez L, Colan SD, Frommelt PC, et al. Recommendations for quantification methods during the performance of a pediatric echocardiogram: a report from the Pediatric Measurements Writing Group of the American Society of Echocardiography Pediatric and Congenital Heart Disease Council. J Am Soc Echocardiogr 2010;**23**(5):465-95; quiz 576-7 doi: 10.1016/j.echo.2010.03.019[published Online First: Epub Date]|.

Acknowledgments

The authors wish to thank and acknowledge all illustrations in this manuscript which were created by Daniel Biggers.

Funding:

This manuscript did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

FIGURES

Figure 1

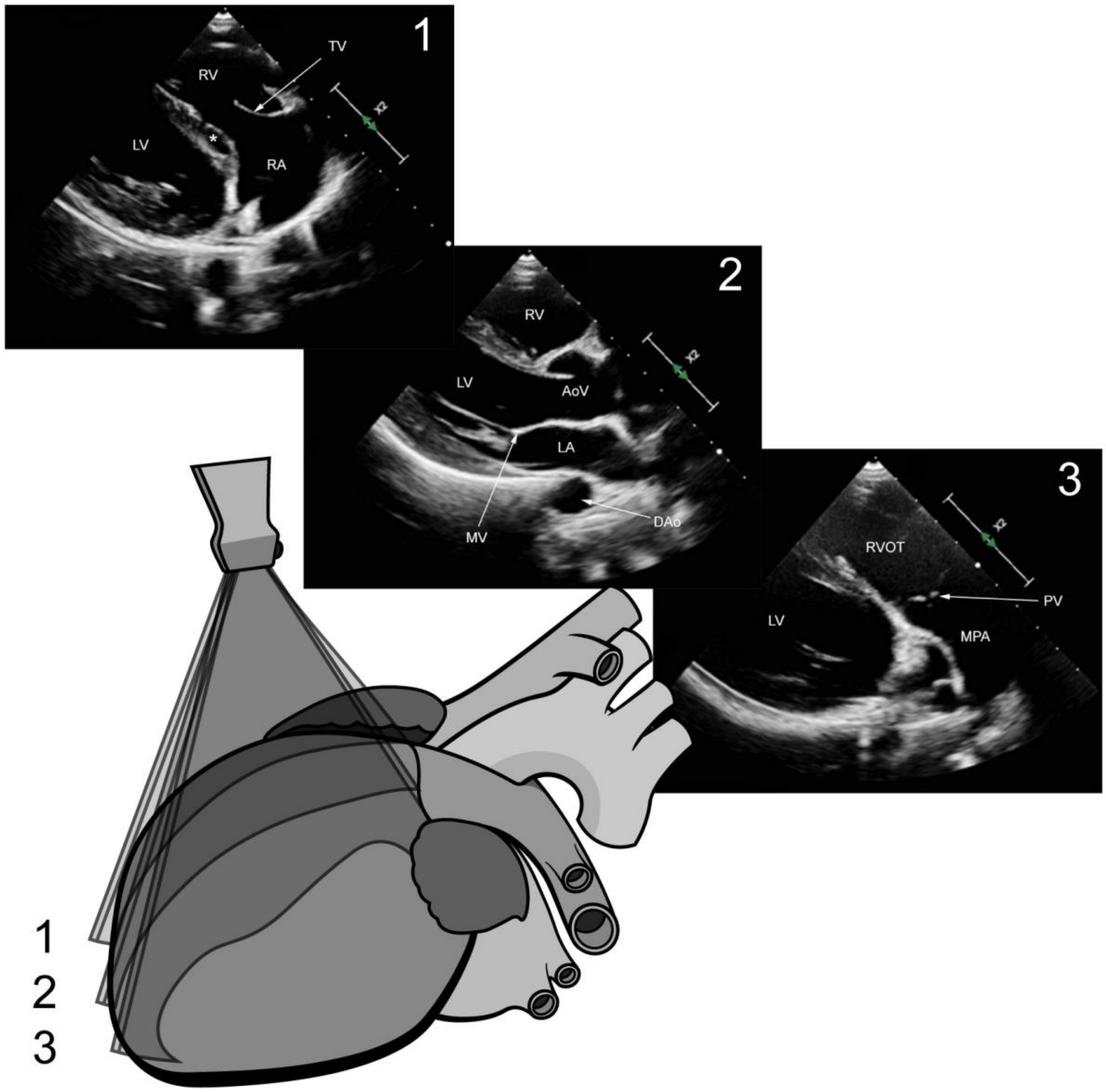


Figure 2

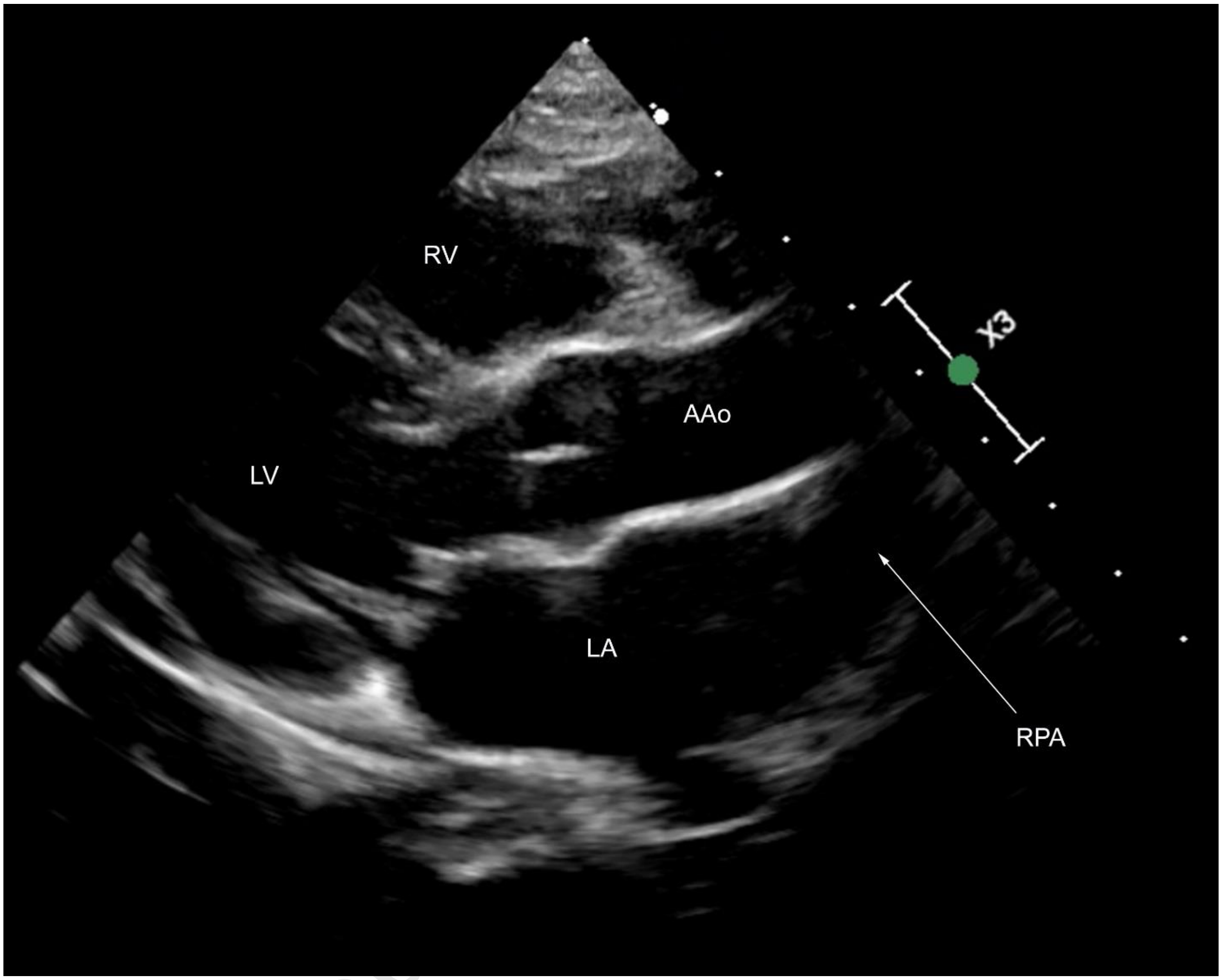


Figure 3

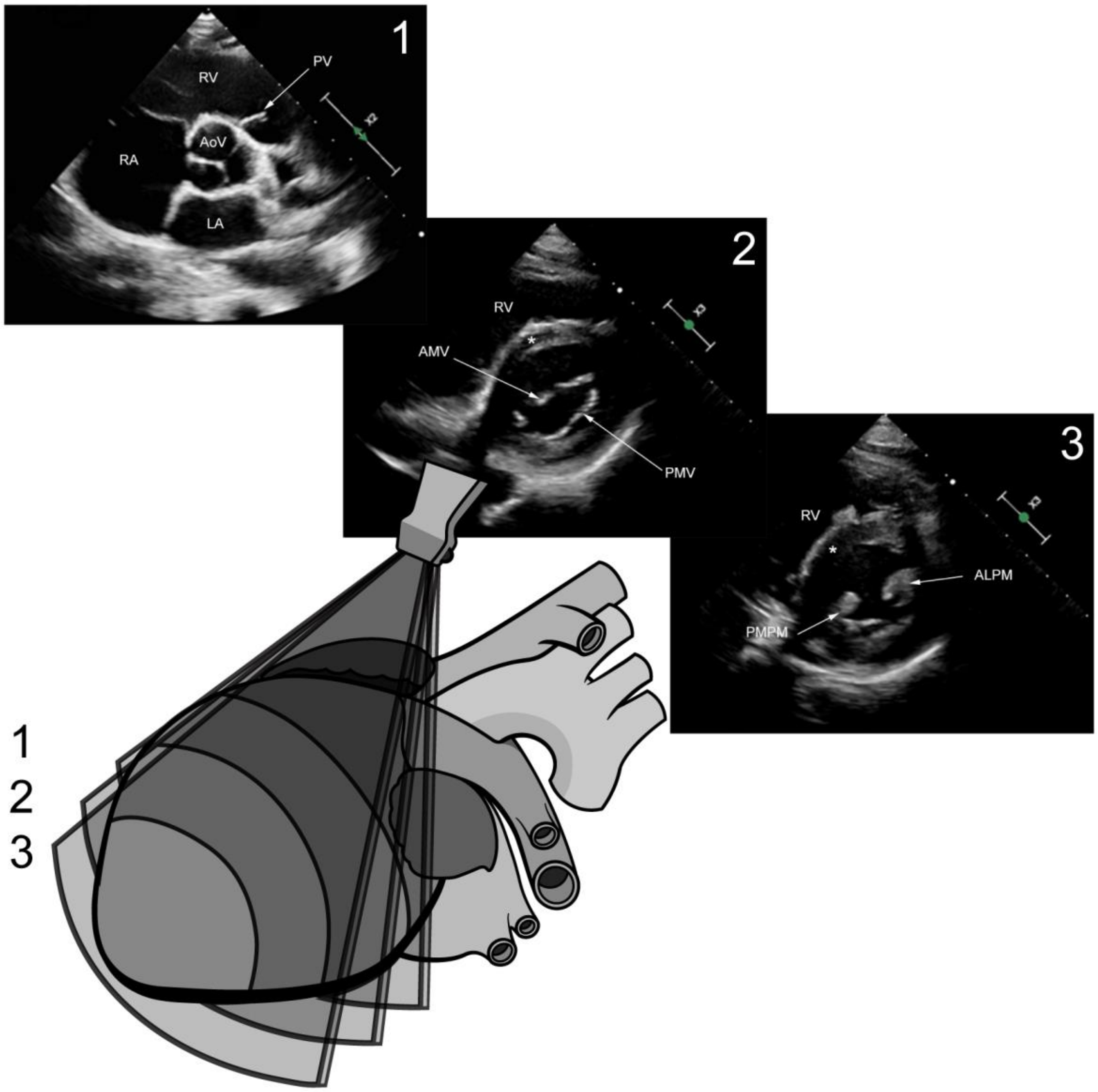


Figure 4

Figure 5

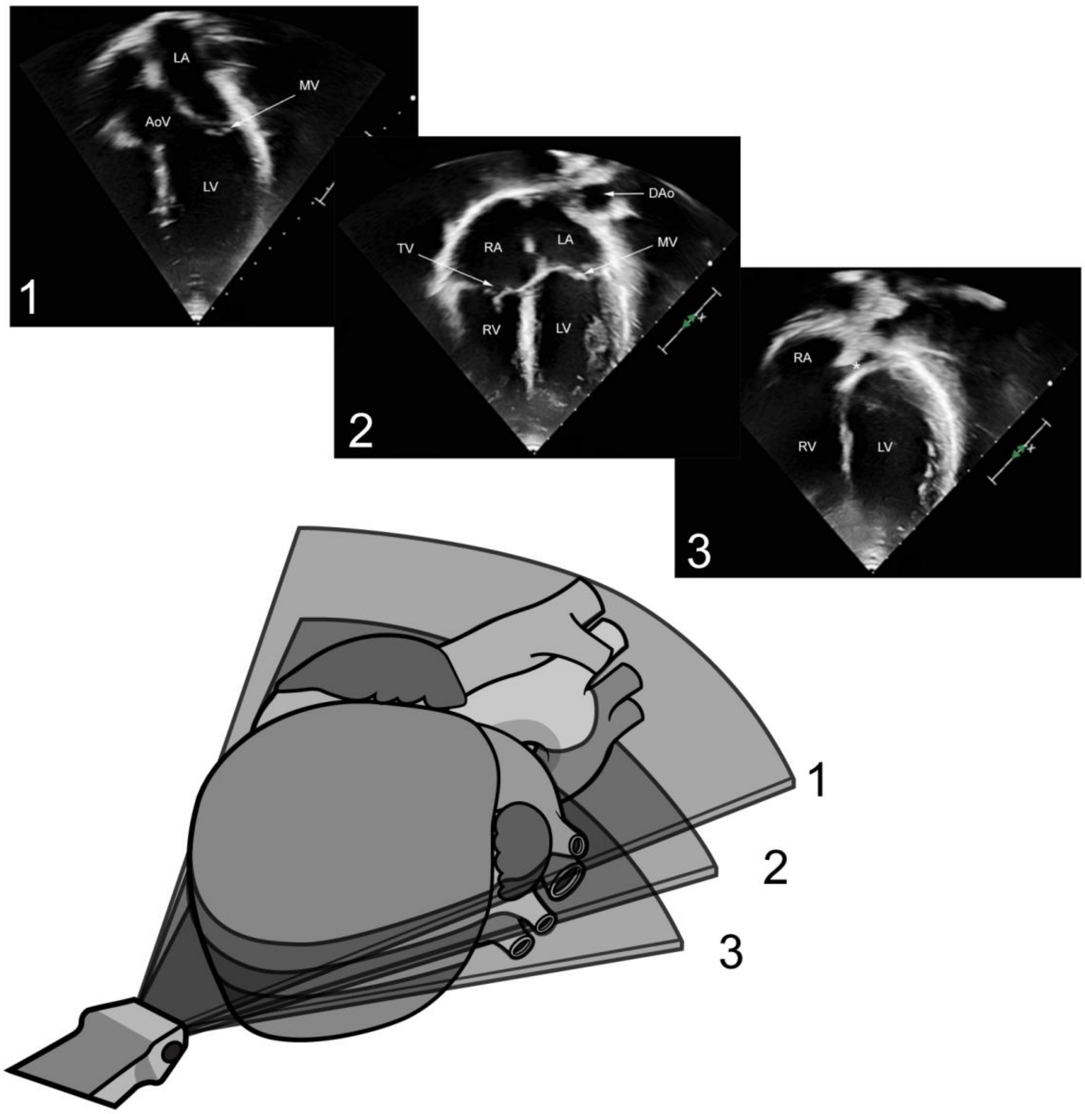


Figure. 6

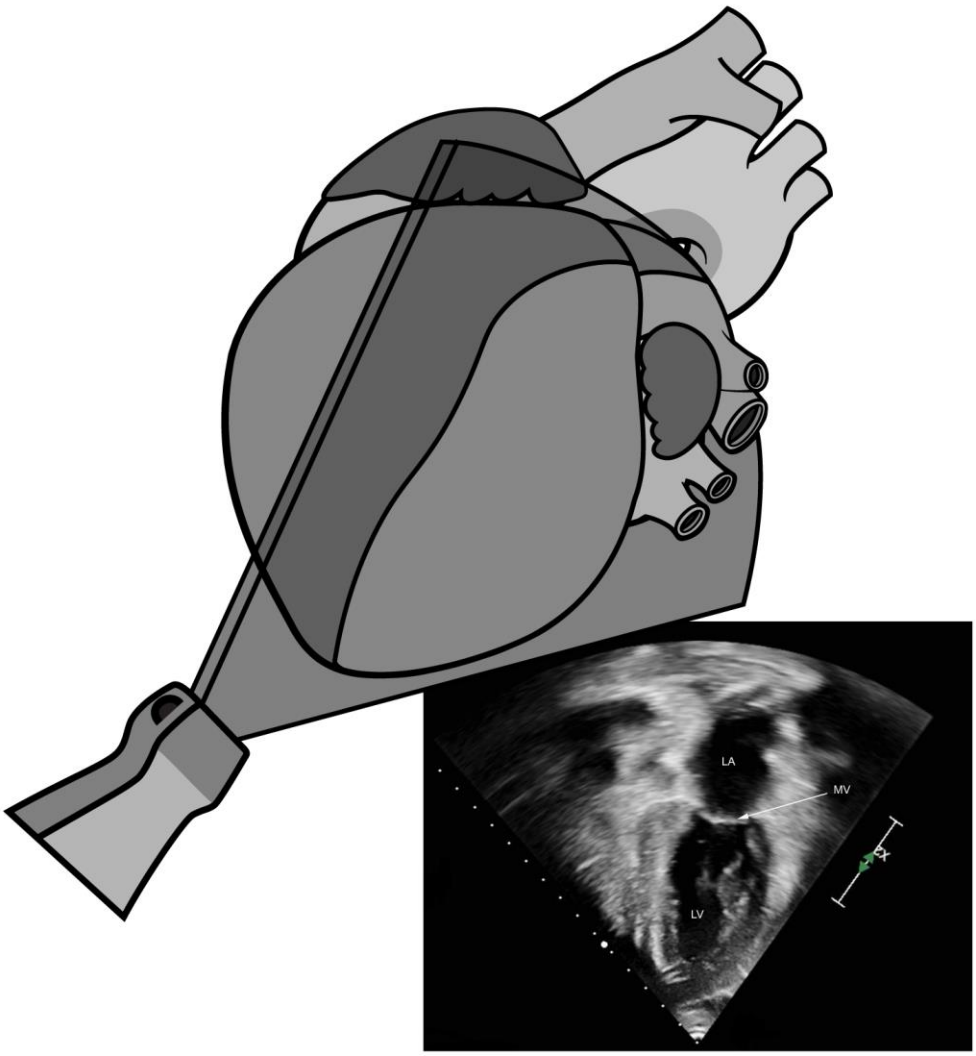


Figure 7

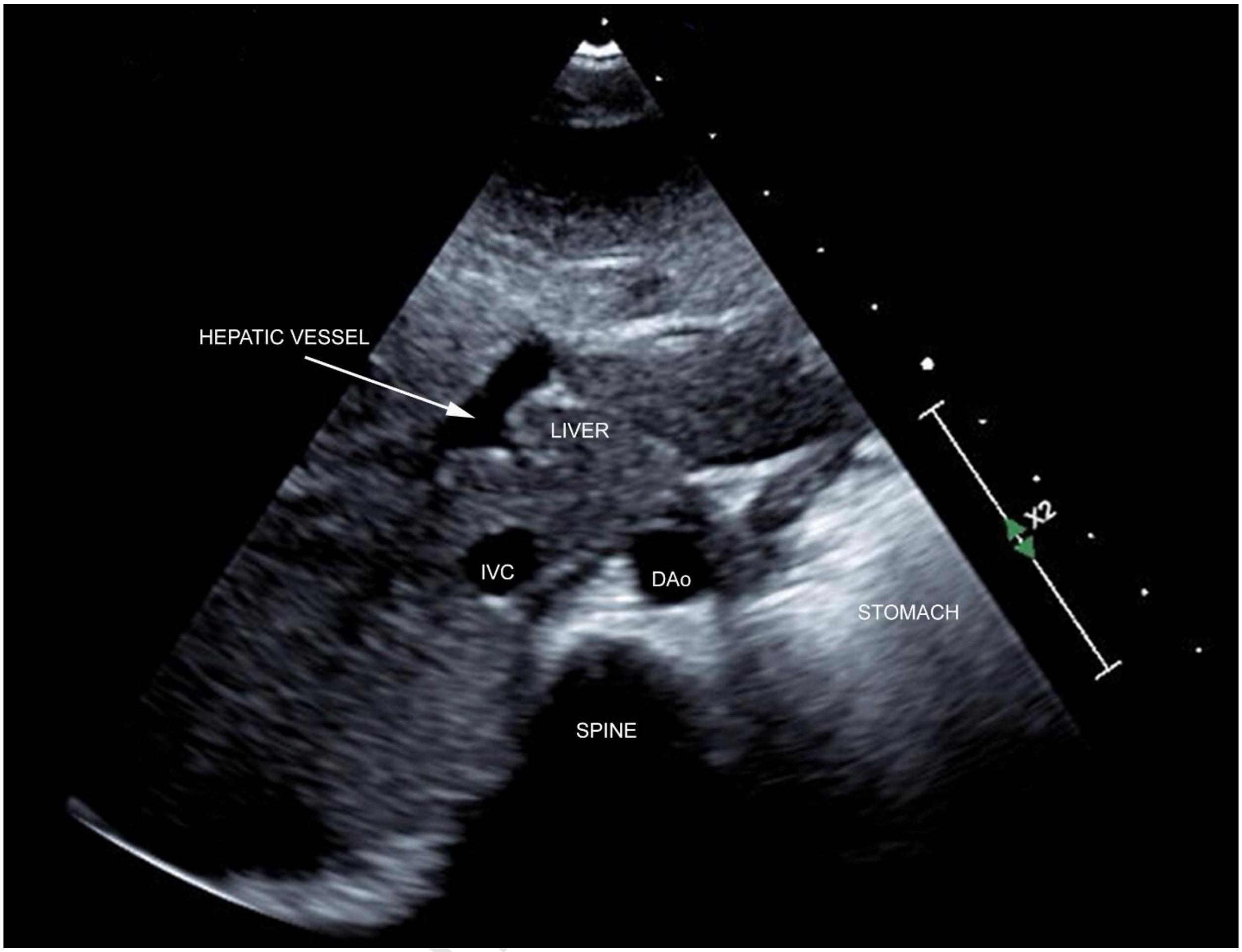


Figure 8

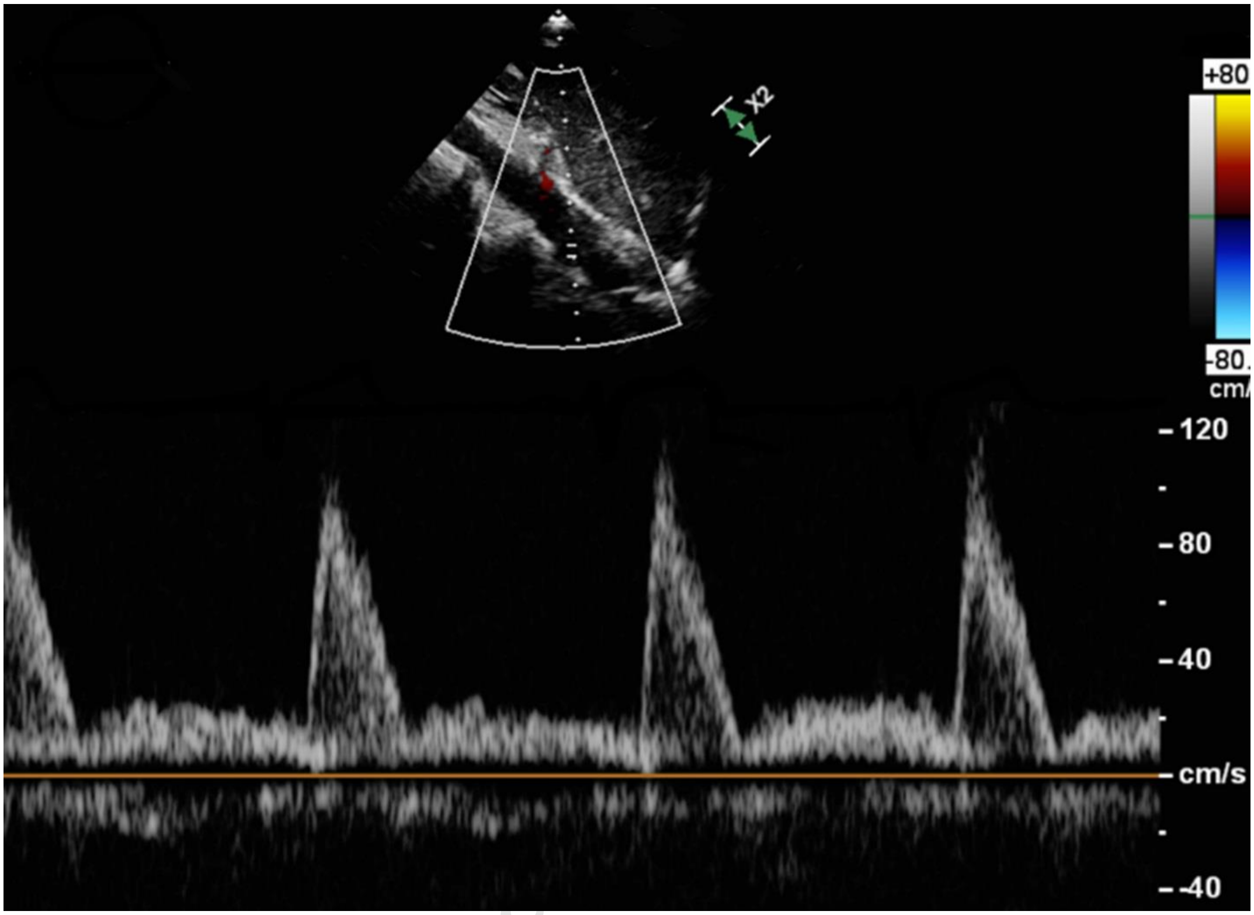


Figure. 9

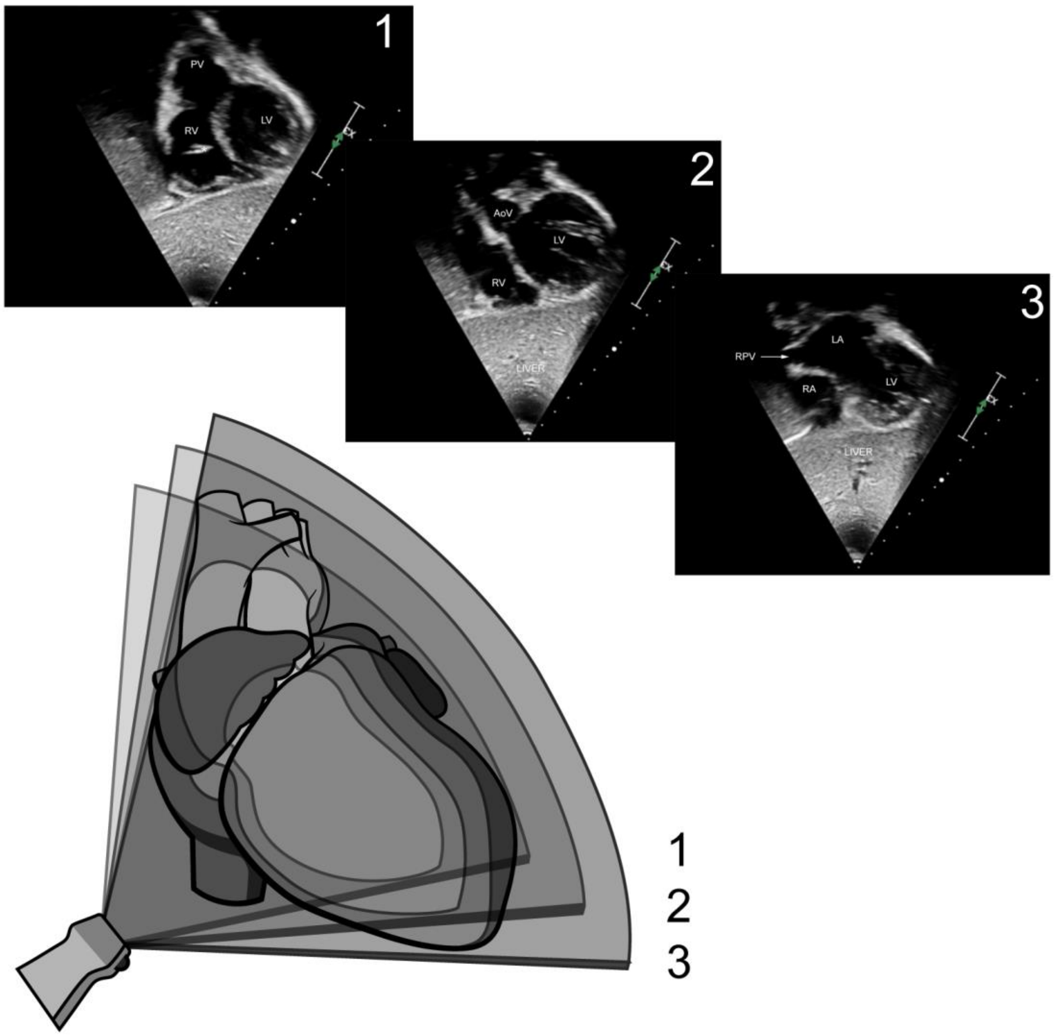


Figure. 10

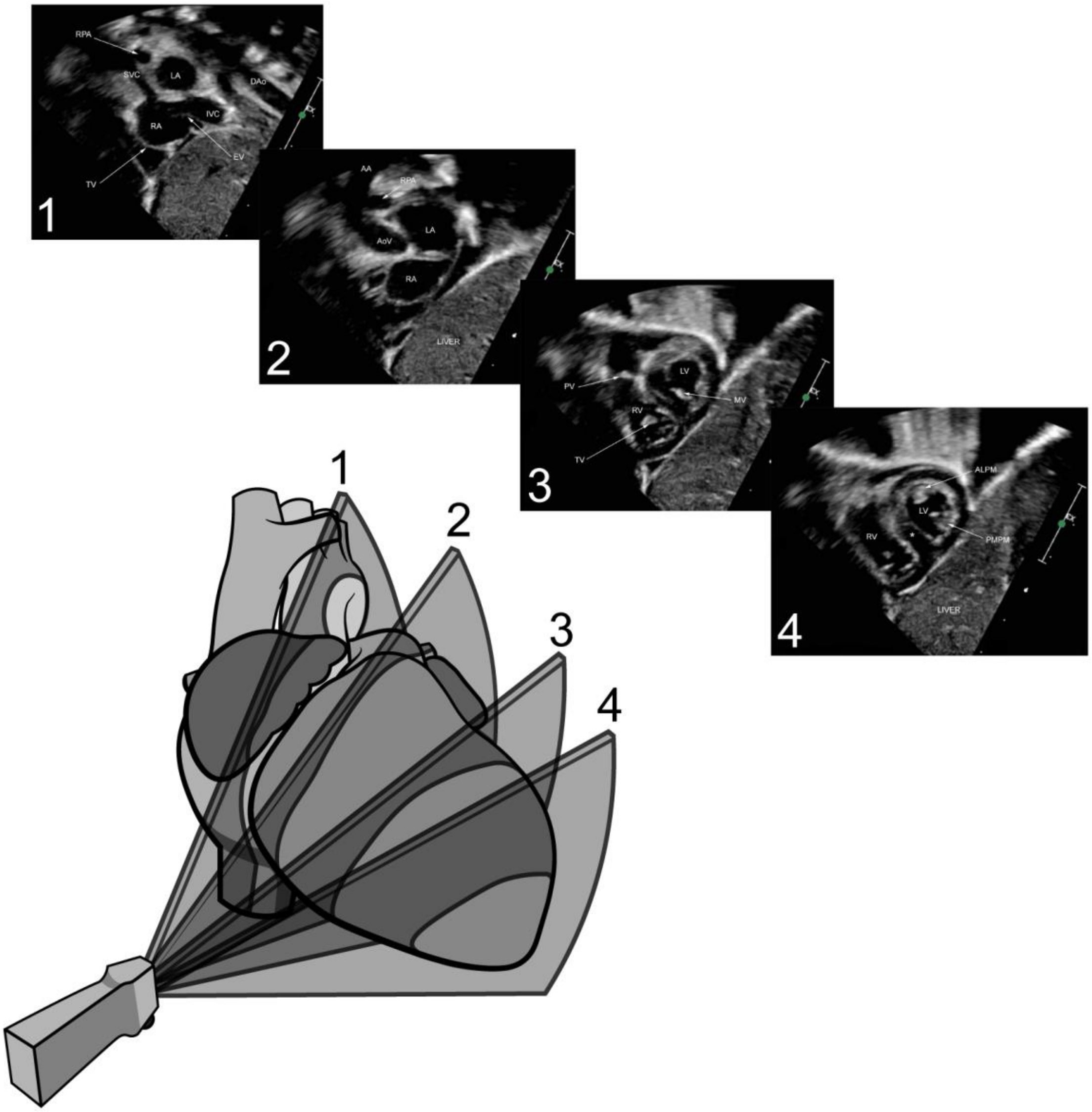

RPA
SVC
LA
DAo
RA
IVC
EV
TV
1
AA
RPA
AoV
LA
RA
LIVER
2
LV
PV
MV
RV
TV
3
ALPM
LV
RV
PMPM
LIVER
4
1
2
3
4

Figure. 11

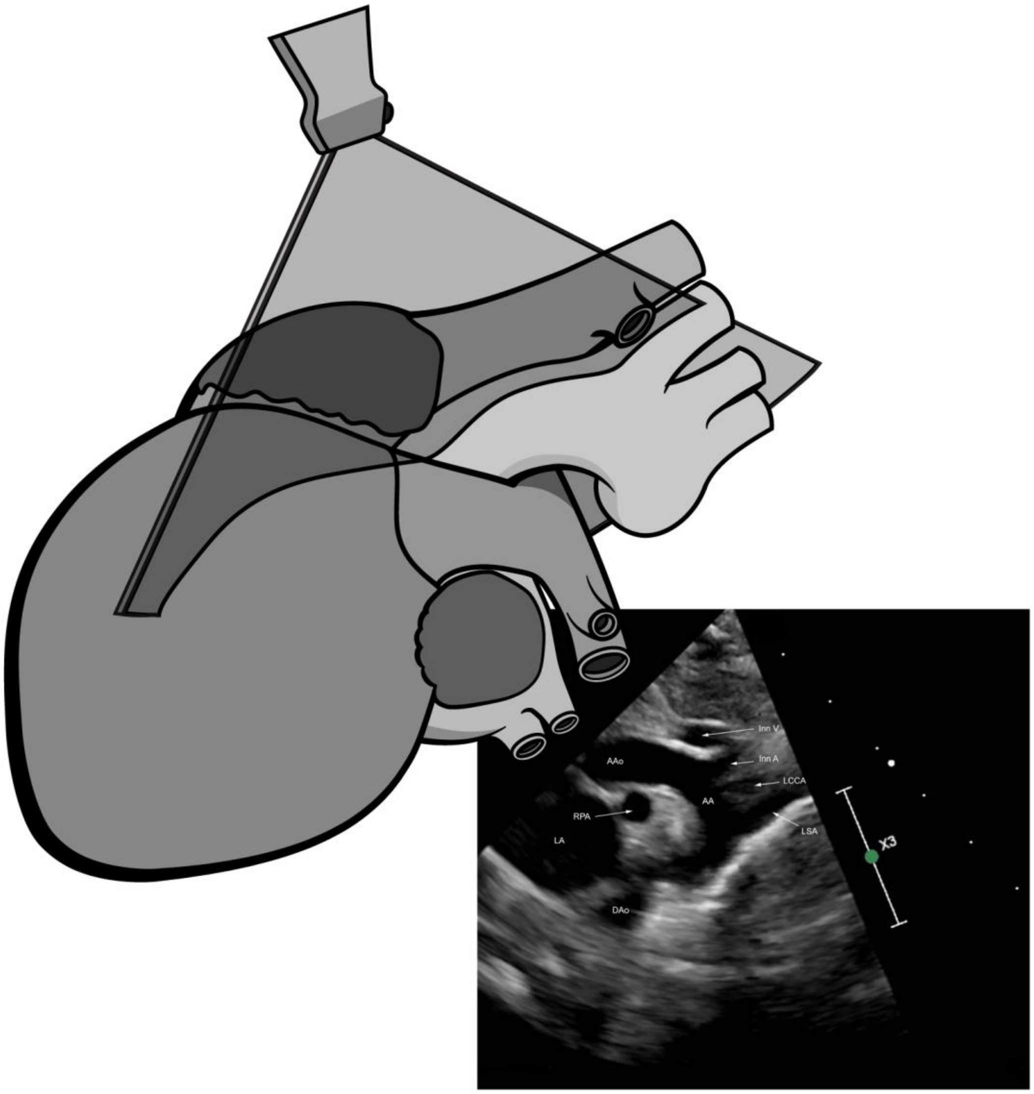


Figure. 12

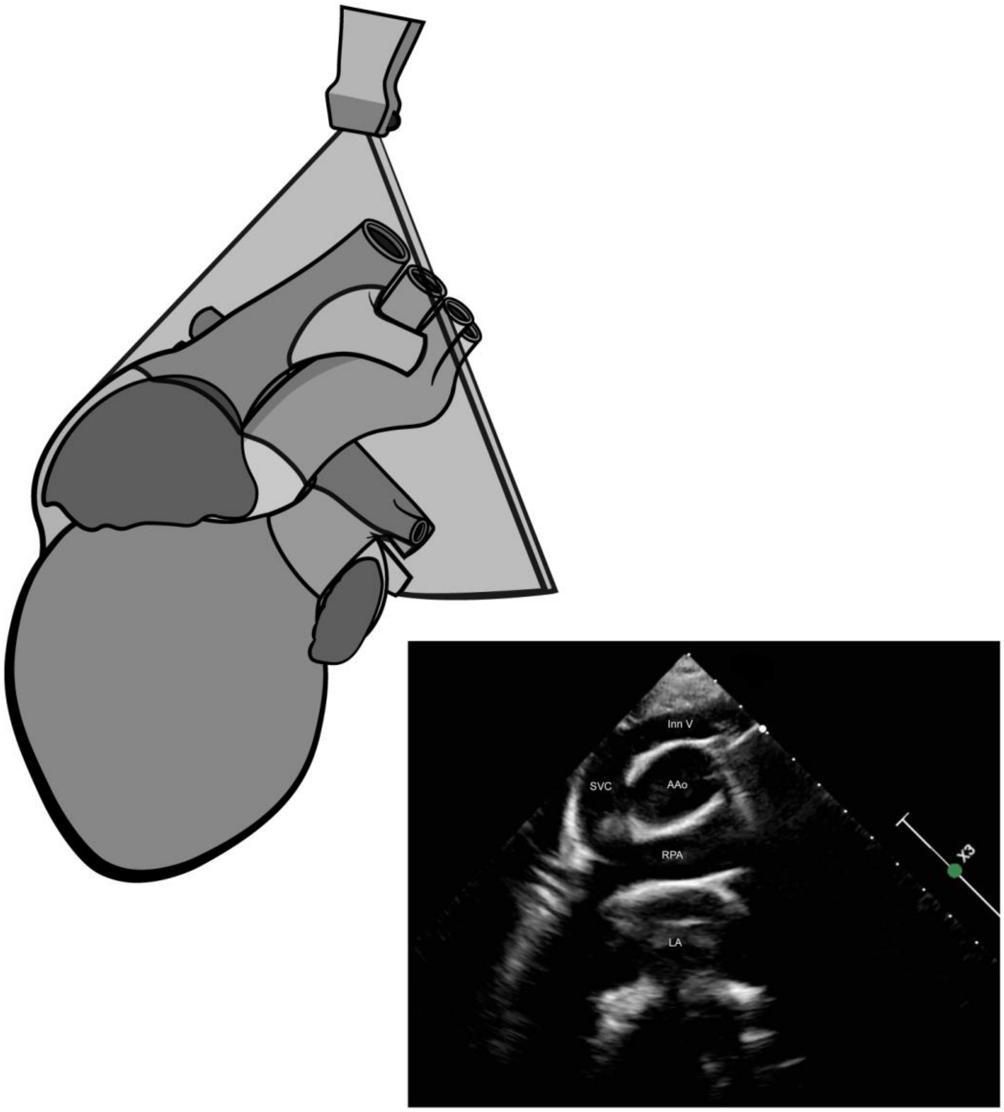


Figure. 13

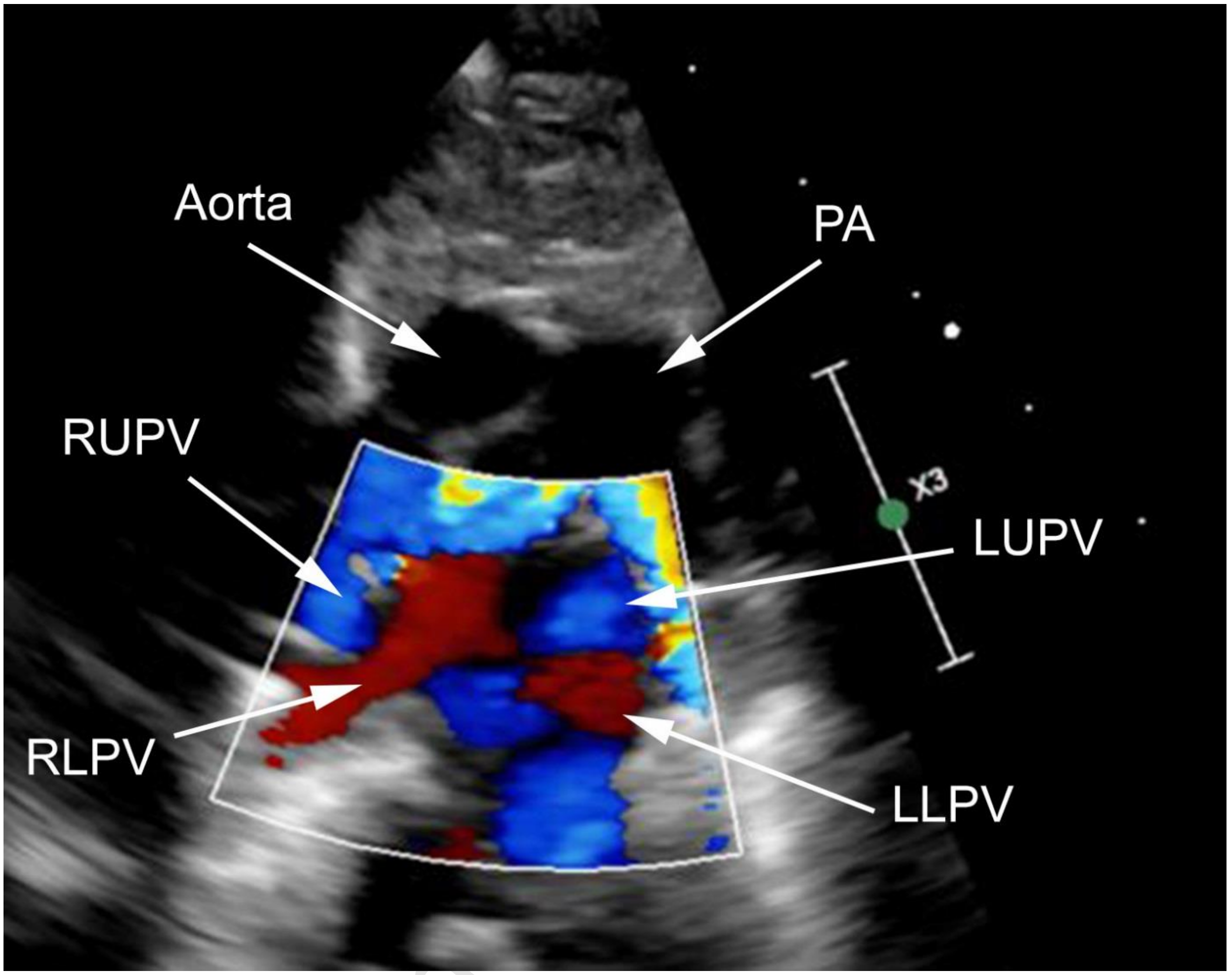


Figure. 14

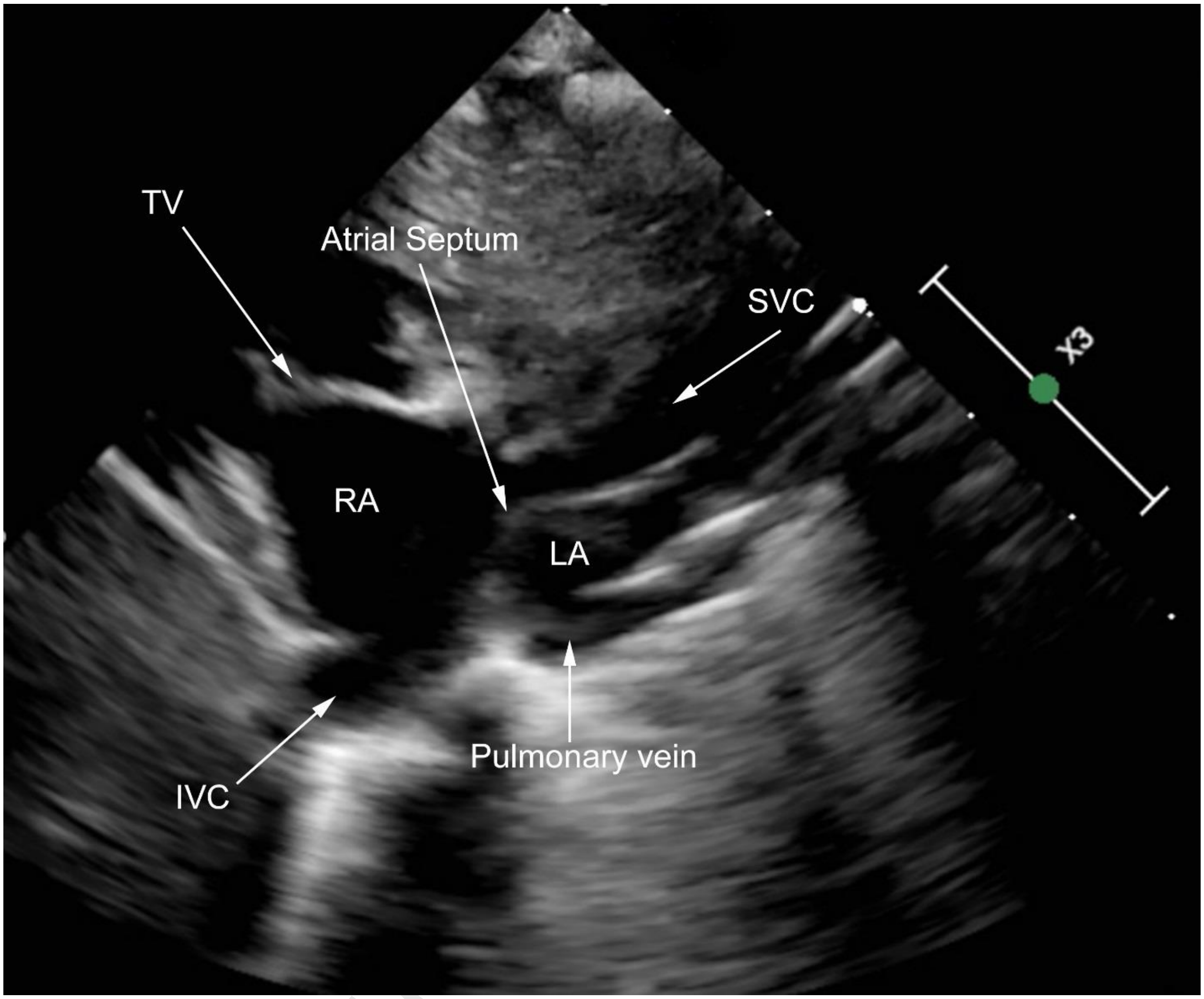
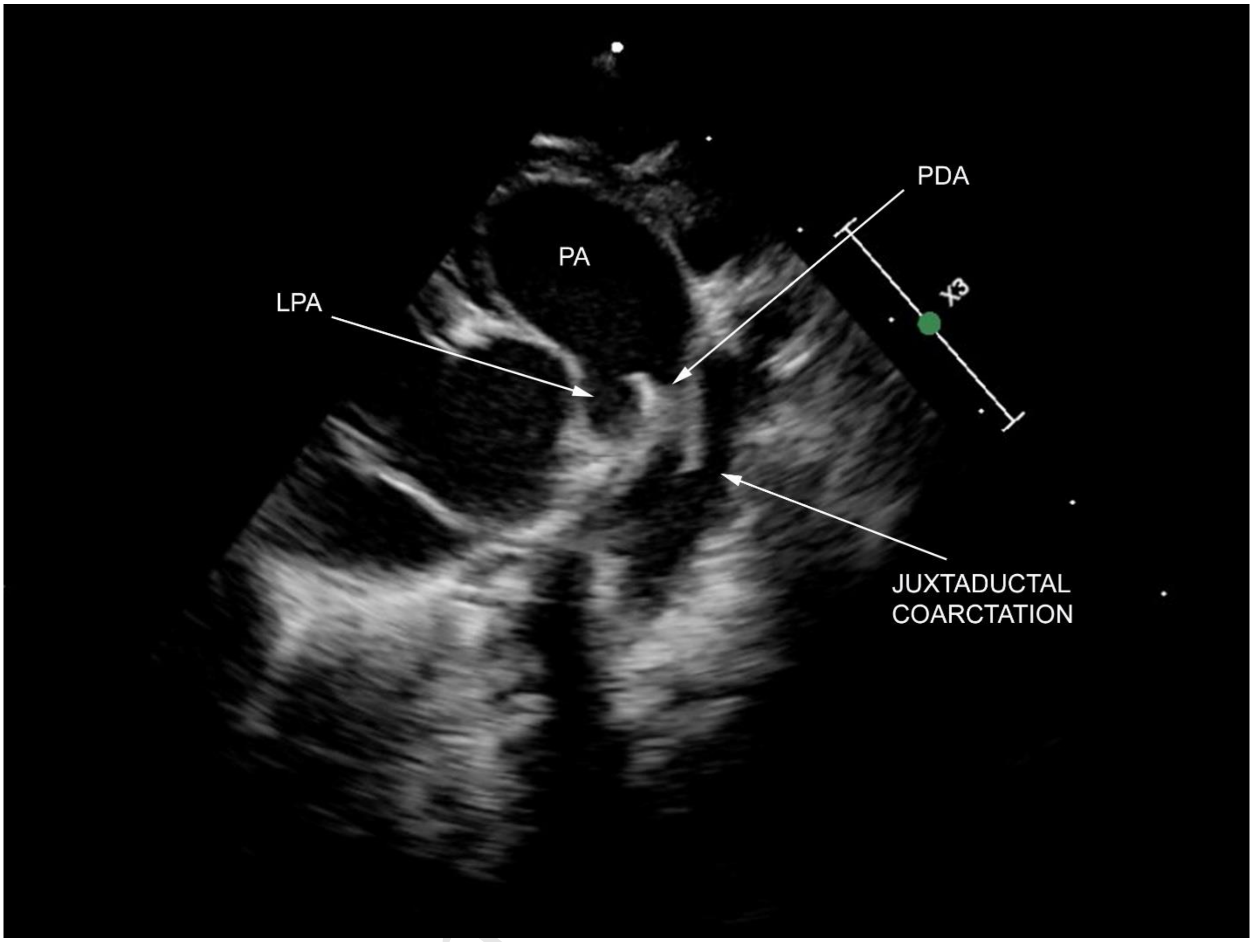


Figure. 15



CAPTIONS

Figure 1. Parasternal Long Axis

Parasternal long axis views sweeping from the right hip to left shoulder. 1) Sweep to right hip showing right ventricle (RV), tricuspid valve (TV), left ventricle (LV), right atrium (RA) and interventricular septum (*). 2) Standard mid view additionally showing aortic valve (AoV), mitral valve (MV), left atrium (LA) and descending aorta (DAo). 3) Sweep to the left shoulder additionally showing the right ventricular outflow tract (RVOT), pulmonary valve (PV) and main pulmonary artery (MPA).

Figure 2. Ascending Aorta

Parasternal long axis image slid up towards the head to better image the ascending aorta. Right ventricle (RV), left ventricle (LV), ascending aorta (AAo), left atrium (LA) and right pulmonary artery (RPA).

Figure 3. Parasternal Short Axis

Parasternal short axis views sweeping from base to apex. 1) View at the base showing the right ventricle (RV), pulmonary valve (PV), right atrium (RA), aortic valve (AoV) and left atrium (LA). 2) Mid ventricular view additionally showing the anterior mitral valve leaflet (AMV), posterior mitral valve leaflet (PMV) and the septum (*). 3) Apical view additionally showing the posteromedial papillary muscle (PMPM) and the anterolateral papillary muscle (ALPM).

Figure 4. Pulmonary Valve En Face

Parasternal short axis with indicator at ~4 o'clock demonstrating the pulmonary valve (PV) en face. The aortic valve (AoV) and left atrium (LA) are also demonstrated.

Figure 5. Apical 4 Chamber

Apical 4 chamber sweep from anterior to posterior. 1) Anterior sweep showing the aortic valve (AoV), left atrium (LA), mitral valve (MV) and left ventricle (LV). 2) Mid view additionally showing the right atrium (RA), right ventricle (RV), left ventricle (LV), tricuspid valve (TV) and descending aorta (Dao). 3) Posterior sweep additionally demonstrates the coronary sinus (*).

Figure 6. Apical 2 Chamber

Apical 2 chamber view showing the left atrium (LA), left ventricle (LV) and mitral valve (MV).

Figure 7. Subcostal Transverse View

Transverse situs view demonstrating the inferior vena cava (IVC), descending aorta (Dao) along with the liver, spine, stomach (filled with gastric contents) and hepatic vessels.

Figure 8. Descending Aorta Doppler

Doppler interrogation of the descending abdominal aorta showing pulsatile flow. Note the optimized angle of insonation at approximately 45 degrees relative to the aorta.

Figure 9. Subcostal Coronal

Subcostal coronal view sweeping from right to left. 1) Rightward view showing the pulmonary valve (PV), right ventricle (RV), left ventricle (LV) and moderator band (*). 2) Mid view additionally showing the aortic valve (AoV). Leftward view additionally showing the right atrium (RA), left atrium (LA) and right pulmonary vein (RPV).

Figure 10. Subcostal Sagittal

Subcostal sagittal sweeping from right/superior to left/inferior. 1) Rightward view showing the right pulmonary artery (RPA), superior vena cava (SVC), left atrium (LA), right atrium (RA), inferior vena cava (IVC), tricuspid valve (TV), descending aorta (DAo) and Eustachian valve (EV). 2) Leftward progression additionally shows the ascending aorta (AA). Leftward sweep additionally shows the pulmonary valve (PV), tricuspid valve (TV), mitral valve (MV), right ventricle (RV) and left ventricle (LV). Far left sweep additionally showing the anterolateral papillary muscle (ALPM), posteromedial papillary muscle (PMPM) and the interventricular septum (*).

Figure 11. Suprasternal Long Axis

Suprasternal long axis “candy cane” view demonstrating the ascending aorta (AAo), aortic arch (AA), descending aorta (DAo), innominate vein (Inn V), innominate artery (Inn A), left common carotid artery (LCCA), left subclavian artery (LSA), right pulmonary artery (RPA) and left atrium (LA).

Figure 12. Suprasternal Short Axis

Suprasternal short axis view showing the innominate vein (Inn V), superior vena cava (SVC), ascending aorta (AAo), right pulmonary artery (RPA) and left atrium (LA).

Figure 13. Crab View of Pulmonary Veins

Pulmonary vein "crab view" showing the aorta, pulmonary artery (PA), right upper pulmonary vein (RUPV), right lower pulmonary vein (RLPV), left upper pulmonary vein (LUPV) and left lower pulmonary vein (LLPV).

Figure 14. Right Parasternal

Right parasternal view showing the superior vena cava (SVC), left atrium (LA), inferior vena cava (IVC), right atrium (RA) and tricuspid valve (TV). The atrial septum and pulmonary vein drainage are also seen.

Figure 15. Ductal View

High left parasternal view showing the juxtaductal region in the setting of a coarctation. Patent ductus arteriosus (PDA), pulmonary artery (PA) and left pulmonary artery (LPA).

AUTHOR STATEMENT

- Peace Madueme: Conceptualization, Supervision and Writing – Original draft
- Alejandro Arevalo: Writing – Reviewing and editing
- Nivedit Kudchadker: Writing – Reviewing and editing
- Shubhika Srivastava: Writing – Reviewing and editing

CONFLICT OF INTEREST

Declarations of interest: None

HIGHLIGHTS

- Pediatric congenital echocardiography should be performed in a segmental fashion
- The study focus should be to acquire a complete study in a reproducible manner
- Convention is to acquire 2D images followed by color mapping, then Doppler assessment
- A good understanding of normal cardiac anatomy is necessary
- Kids are not small adults