Pictorial Essay

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Optimizing Imaging Techniques for the Fetal Heart: A Pictorial Essay

ABSTRACT

Cardiac defects are the most common congenital anomalies in the fetus. In the majority of cases, these anomalies can be detectable by sonography. The utility of diagnostic ultrasound in fetal heart assessment depends on the quality and completeness of the exam. This pictorial essay will focus on the Sonography Canada National Competency Guideline preferred image views for assessment of the fetal heart. To achieve the best outcomes, image optimization and exam efficiency will be discussed for this challenging organ.

Introduction

Fetal cardiac abnormalities occur in 8 of 1000 live births.[1] The ability of sonography to identify the presence of these abnormalities as early as possible prenatally allows for parental counselling and the potential to improve birth outcomes. Although the fetal heart is scanned throughout pregnancy, the optimal time to scan for these defects is 18–22 weeks' gestation.[2] Imaging of the fetal heart provides some unique challenges over other areas routinely scanned by sonographers. At this time, fetal movement is unpredictable, the fetal heart is very small (approximately 25mm in size[1]), and normally beats between 120 and 180 bpm (beats per minute).[3] Maternal body habitus will also play a role in the sonographer's ability to visualize fetal structures. All of these factors contribute to the challenge to produce high-quality images necessitating the use of image optimization techniques. Poor imaging of the fetal heart is one of the most common reasons for a patient to be recalled.[1] This pictorial essay will discuss the accepted fetal heart views and optimization strategies to produce high-quality sonographic images.

Review of Standard Fetal Heart Images

Sonography Canadas National Competency Guidelines recommends screening of the fetal heart to include the following fetal imaging: 4 chamber (4CH), stomach for situs, left ventricular outflow tract (LVOT), right ventricular outflow tract (RVOT), 3 vessel view (3VV), aortic arch (AA), ductal arch (DA), and m-mode for fetal heart rate (FHR).[4] A Phillips EPIQ systems was utilized to obtain all images

4 Chamber View (4CH)

To obtain the 4CH view (Figure 1) the transducer is oriented transverse on the fetal thorax with a slight angulation towards the fetal head and fetal right shoulder.[2]

An optimal 4CH view can rule out 10 to 96% of fetal heart abnormalities.[3] It will assess the normalcy of interventricular septum, interatrial septum, movement of foramen ovale, compare the size of ventricles and atria, as well as the movement and location of the mitral valve and tricuspid valve. This view is also good for demonstrating

Figure 1. 4 chamber view demonstrating heart size (1/3 size of thorax), situs (left side of thorax), and axis (45° angle towards the fetal left side). The following anatomy is also assessed; Ao = aorta; LA = left atrium; RA = right atrium; LV = left ventricle; RV = right ventricle; IVS = interventricular septum; IAS = interatrial septum; FO = foramen ovale; MV = mitral valve; TV = tricuspid valve.[5]

the pericardium, myocardium, and endocardium. It is the best view for demonstrating pericardial effusion, pleural effusion, presence of intracardiac tumors and arrhythmias.[3]

LVOT

The LVOT (Figure 2) is obtained by angling the transducer more superiorly towards the fetal head, from a 4CH view.[6] The orientation of the aorta and left ventricle is the main feature of this image. The size of the ascending aorta/aortic root and the movement of the aortic valve should also be assessed when imaging this view; rule of thumb, the diameter of the normal aorta is approximately 4mm at 20 weeks' gestation.[3] A normal LVOT image rules out abnormalities of the interventricular septum, aortic stenosis, and truncal abnormalities.

RVOT

To obtain the RVOT long-axis view (Figure 3A) the transducer is further angled superiorly towards the fetal head.[2] The RVOT can also be viewed as a short-axis view (Figure 3B) by rotating the transducer 90° counterclockwise from the long axis view. The combination of the 2 views will rule out pulmonary stenosis, aortic stenosis, bicuspid aortic valve, and size discrepancy of Ao and MPA (the Ao and MPA should be approximately the same size).[3]

3 Vessel View (3VV)

Another view to demonstrate the relationship of the Ao and MPA is the 3VV (Figure 4). From the long axis, RVOT view the transducer is angled even further upwards towards the fetal head.[6] This view is the most superior view of the fetal heart. It is best for evaluating the size and orientation of the Ao and MPA. Truncal abnormalities, stenosis of Ao or MPA are examples of the abnormalities this view can rule out.[3]

Aortic Arch (AA) & Ductal Arch (DA)

The final views of the fetal heart routinely scanned by the general sonographer are the AA and DA. These are the only views taken using a sagittal approach to the fetal thorax (Figure 5).[6] The AA view is best for demonstrating coarctation of the aorta and the DA view provides the only assessment for abnormality of the ductus arteriosus.[3]

Image of Optimization Techniques

Frequency

The imaging frequency used will determine the level of resolution vs penetration obtained in the produced image. A higher frequency setting is best for optimal resolution; but a low enough setting to penetrate to the maximum depth of the image is important (Figure 6). It is constantly a trade-off between resolution and penetration.[7]

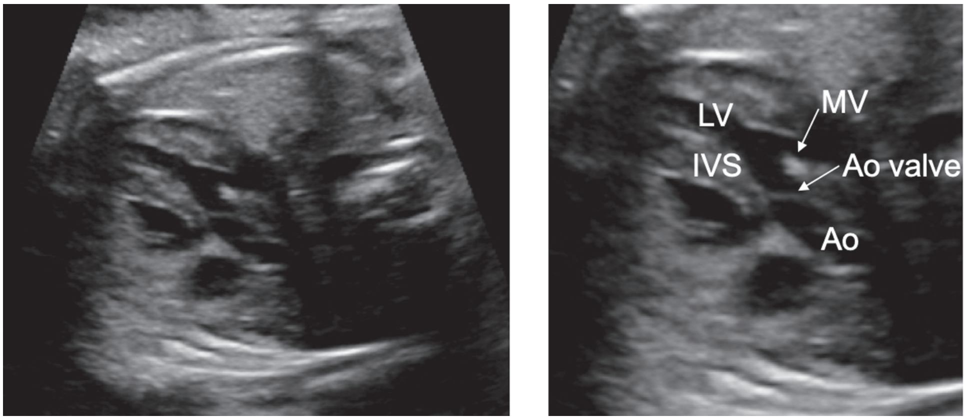

Figure 2. LVOT demonstrating continuity of interventricular septum with the aorta and orientation of the mitral valve with the posterior wall of the aorta. Size of aorta can also be measured in this view. LV= left ventricle; MV = mitral valve; IVS = interventricular septum; Ao = Aorta.[5]

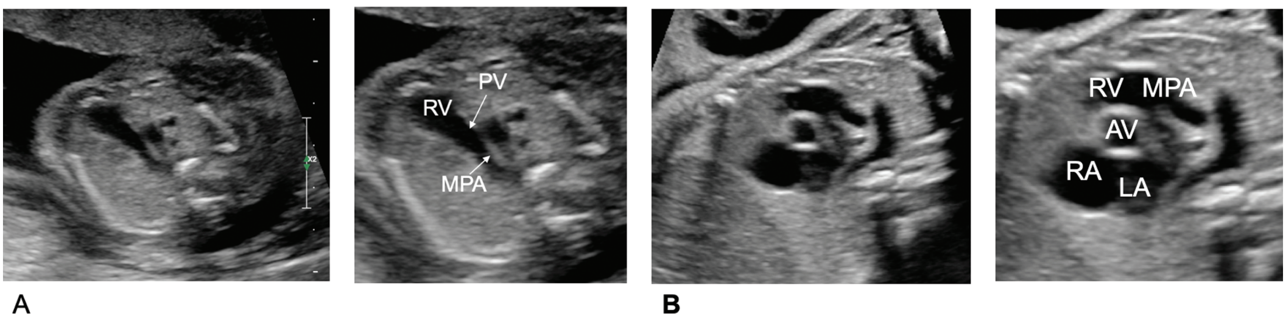

Figure 3. (A) Long axis RVOT demonstrating RV, PV pulmonary valve, and MPA main pulmonary artery. (B) Short axis RVOT demonstrating RV, MPA, AV aortic valve, RA, and LA. Both RVOT views assess the continuity of the RV with the MPA with visualization of the pulmonary valve. The short axis view further demonstrates the relationship between the Ao and MPA.[5]

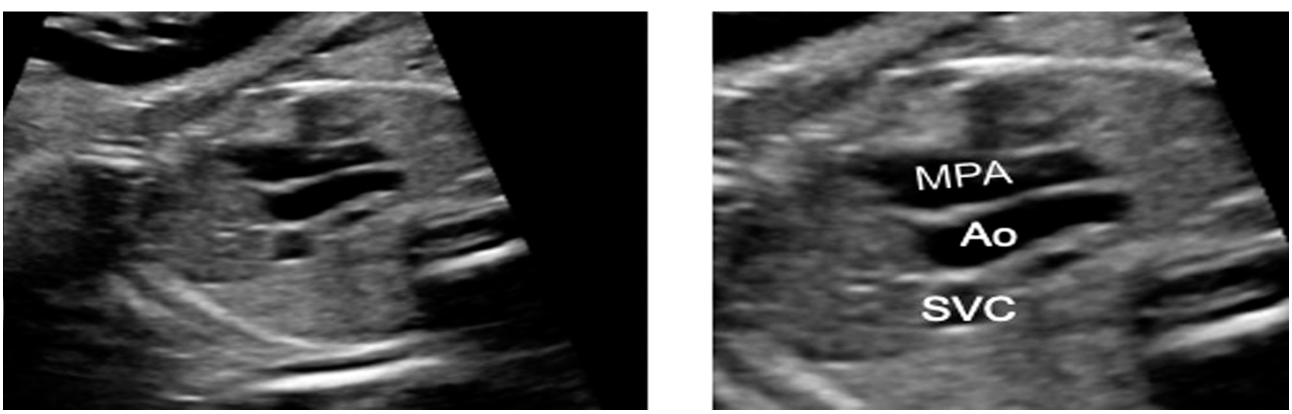

Figure 4. 3 vessel view (3VV) demonstrating the relationship of Ao, MPA, and SVC superior vena cava. The 3VV is used to rule out abnormalities of the Ao and MPA. Both should be approximately the same size and they should run parallel to each other in this view.[5]

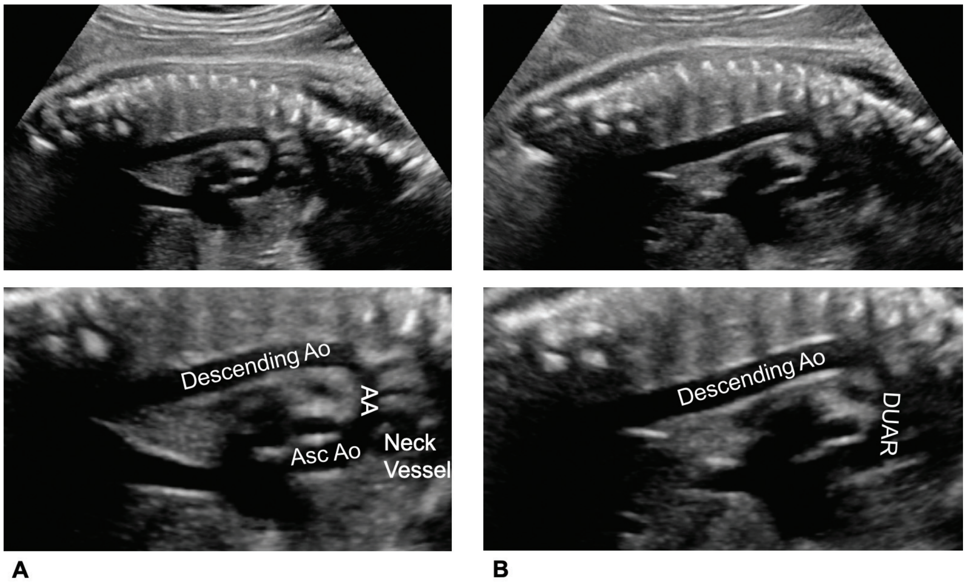

Figure 5. (A) Aortic arch demonstrating Asc Ao ascending aorta, AA aortic arch, and Descending Ao aorta. The aorta exits the LV anteriorly in a candycane-shaped arch that runs parallel along the fetal spine. The neck vessels are on the superior portion of the arch. (B) Ductal arch view demonstrating descending aorta and DUAR ductus arteriosus. The DUAR view demonstrates the connection of the MPA and aorta by the ductus arteriosus (DUAR) in the shape of a hockey stick. The DUAR is slightly larger in diameter than the aorta.[5]

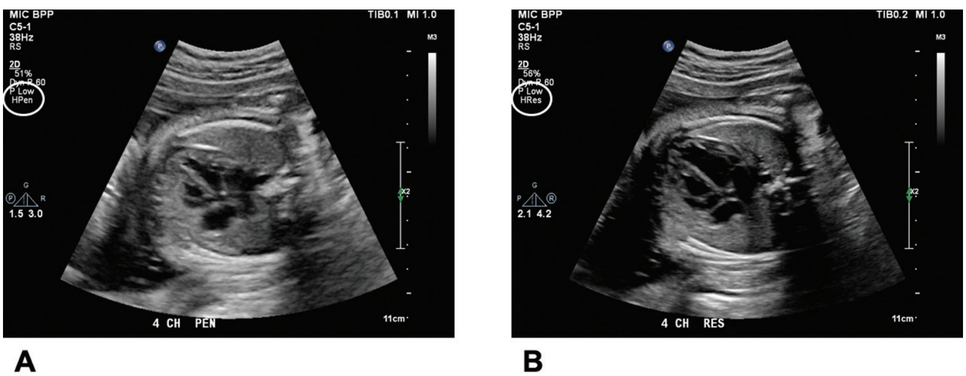

Figure 6. (A) This image was produced with the lowest frequency setting available with the C5-1 transducer (at the 1.5MHz end of the zone). Notice the over-penetration and lack of detail resolution. (B) The image was produced using the highest frequency setting available with the C5-1 transducer (at the 4.2MHz end of the zone). Superior detail resolution is demonstrated. It is important to note penetration has not been compromised and all of the deeper structures are well visualized. Both images utilized harmonics which is why the frequency range isn't a direct 1-5MHz relationship.[5]

Harmonics

The utilization of harmonics allows for optimization of image resolution. The theory behind harmonic imaging is quite simple. The beam is transmitted out at a low frequency and the return beam is received at 2× the transmitted frequency. This acts to improve detail resolution but maintain adequate penetration. There is a potential downfall; the received frequency may not maintain enough penetration to adequately demonstrate very deep structures.[7] However, all images should be attempted with harmonics to optimize the image (Figure 7).

Compression

The fetal heart is a structure that has a relatively high contrast. To best demonstrate this the dynamic range or compression setting of the machine should be optimized. High contrast equates to a low compression setting (low dynamic range) which means fewer shades of grey will be represented. Conversely, low contrast utilizes many shades of grey thus requiring a high compression setting (high dynamic range) (Figure 8).[7] The dynamic range optimal for the fetal heart should be low enough to demonstrate the chambers well but not too low to cause loss of information in the walls. In contrast, the fetal kidneys will be better visualized with a higher dynamic range as they have lower contrast with the rest of the abdominal structures. The preset for an obstetric scan will have a compression setting that is somewhere in the upper-middle range, a middle ground between the high and low contrast structures. A decrease in the dynamic range can be used to optimize for the heart. Conversely, if the goal is to visualize the fetal lungs the dynamic range would likely need to be increased.

Imaging Window

The maternal abdomen allows for the sonographer to place the transducer on various areas to optimize the approach taken to image the fetal heart (Figure 9).

Although transducer placement/orientation improves images, sonographers frequently fail to utilize this

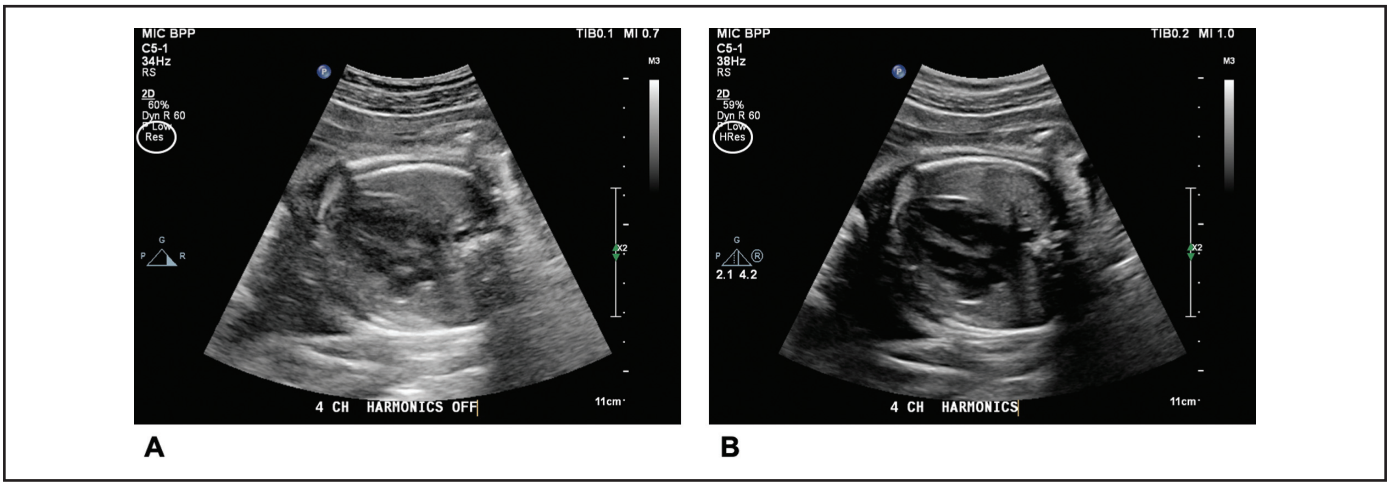

Figure 7. (A) No harmonics, (B) Harmonics utilized. There is a substantial improvement in the detail resolution in image B without impairment of penetration.[5]

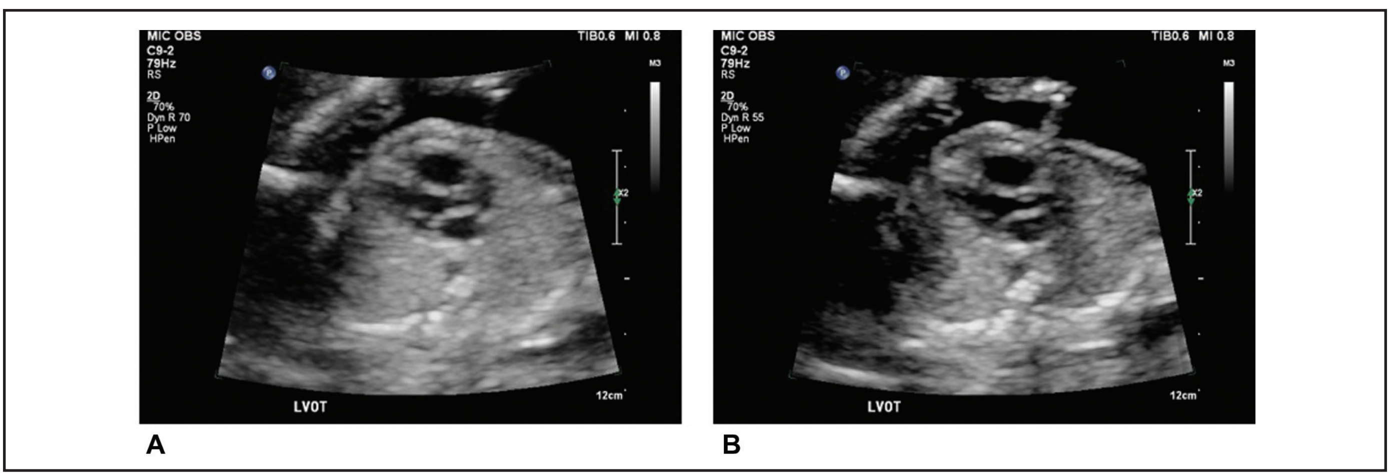

Figure 8. (A) Higher compression setting utilized (dynamic range 70DB), heart structures are not well defined. (B) Optimal compression setting for the fetal heart (dynamic range 55DB) providing a good balance between an optimal resolution of the heart walls and also of the chambers (the actual values of dynamic range will vary between ultrasound systems).[5]

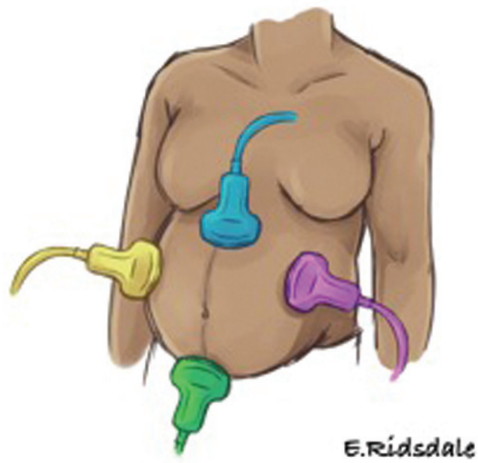

Figure 9. Diagram demonstrates the many different locations the transducer can be placed on the maternal abdomen. Image created by Em Ridsdale and included with permission.

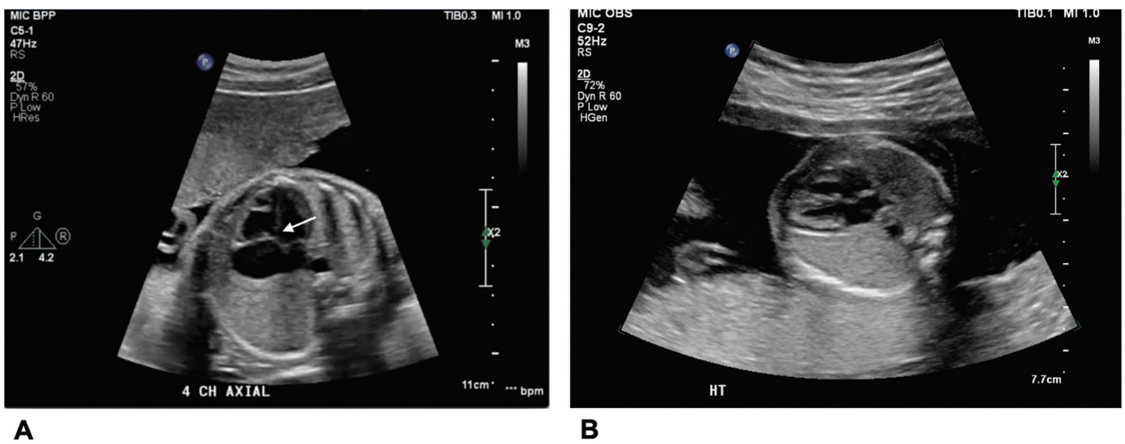

Figure 10. (A) Image taken from a window that orients the fetal heart in an axial lie. The MV, TV, and chambers are well demonstrated, but the IVS is poorly assessed and appears to have a possible septal defect (indicated by white arrow). (B) Image taken from an alternate window that orients the heart horizontally allowing for optimal visualization of the IVS, FO, and chambers, however, the MV and TV are poorly demonstrated. Note the possible septal defect seen in the apical window is now proven to be artefactual.[4]

optimization strategy resulting in suboptimal imaging (Figure 10). To obtain optimal images in 2-D the ultrasound beam should be oriented perpendicular to the reflectors desired.[7] Different parts of the heart will be imaged with the best resolution possible by using different windows.

The LVOT and RVOT views are also best demonstrated with the heart closer to a horizontal lie on the screen. The reason behind this is maximum detail resolution is achieved when the beam is perpendicular to the structure of interest, utilization of the specular reflection principle.

Colour Doppler imaging and pulsed wave Doppler imaging follow different rules due to the process by which the information is obtained. The Doppler angle requires there to be an angle of incidence less than or greater than 90° to register flow direction.[5] Optimization for Doppler will be achieved by scanning with the incident beam at an angle other than 90°.

Depth

Optimizing your imaging depth improves visualization of the heart by making it larger and improving the perceived resolution. It also increases the frame rate resulting in improved temporal resolution. Good temporal resolution allows us to better appreciate the fetal heart in real-time accounting for its very fast motion. By decreasing the depth, the beam has to travel, the sound beam can get to the max depth quicker. This decreases the line time, which decreases the time it takes to produce each frame.[7] The result is an increase in the frame rate (number of frames that can be produced per second). The faster frame rate means better temporal resolution (Figure 11).

Focus

The best detail resolution is achieved at the focus, or point where the beam is at its narrowest.[7] Current ultrasound systems have a focal zone (not a single point) that has variable size and can be placed at variable depth. To optimize the detail resolution of the fetal heart you need to maximize not only the location of the focus but also the size of the focal zone (Figure 12). This will give you the best possible detail resolution for the imaging situation.

Sector Width

Sector width is another tool that can be used to improve both detail resolution and temporal resolution. Utilizing a narrow sector width decreases the number of lines required to produce

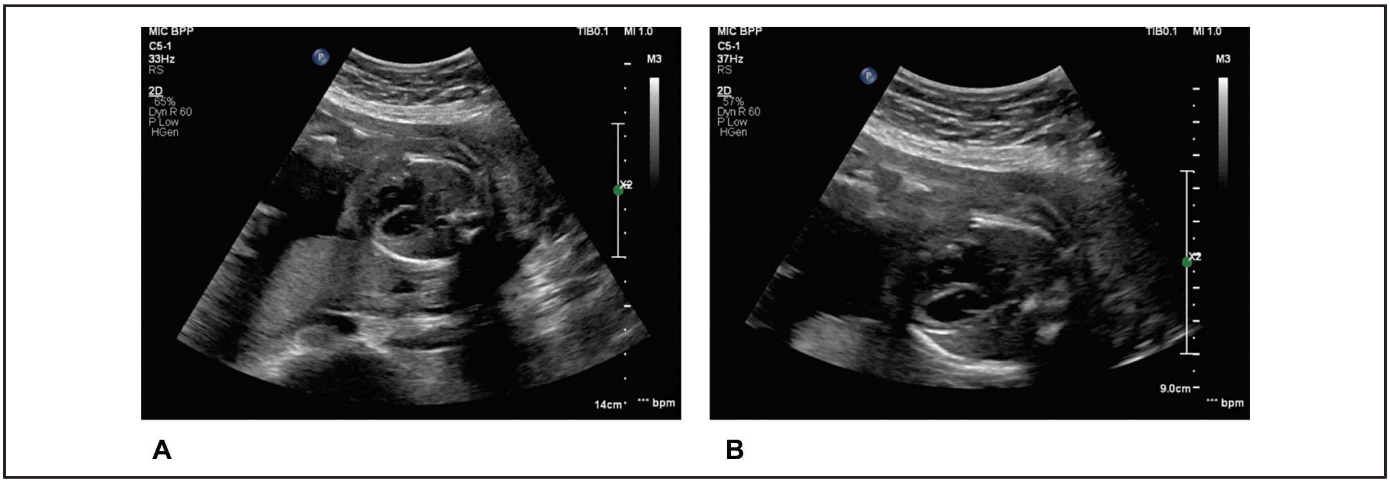

Figure 11. (A) Maximum depth set at 14 cm. (B) Maximum depth set at 9 cm. By utilizing a maximum depth that only includes the most posterior aspect of the fetal thorax the size of the fetal heart is maximized. There is also an improvement in the perceived resolution because distracting structures at deeper depths have been removed from the image. Note: the frame rate increased from 33Hz to 37 Hz an increase of 3 frames per second.[5]

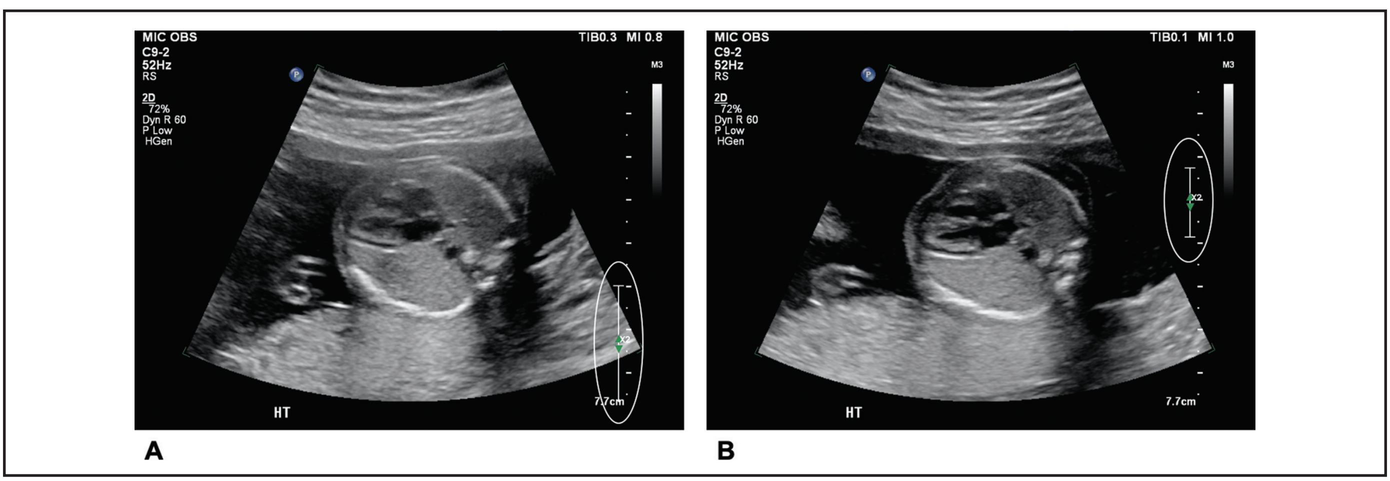

Figure 12. A. Focus (circled on image) set too deep and too large. B. Improved detail resolution is demonstrated with the focus set to the size of the fetal heart with a small buffer (these babies don't always hold still) and the deepest part of the zone is placed at the posterior border of heart.[5]

the image, this decreases the frame time thereby increasing the frame rate and improving temporal resolution.[7] Due to the high rate of motion of the fetal heart improved temporal resolution is very important for real-time observation of its rhythm. Detail resolution is improved by the increased line density created by using the narrower sector width (Figure 13). The perceived image resolution is also improved by removing extraneous information from the image allowing your eyes to focus on the fetal heart.

Advanced Image Optimization Techniques

Read versus Write Magnification (Zoom)

There are two different methods utilized by the ultrasound system to achieve magnification of the image. Each method has different effects on image resolution. Read magnification is performed by simply enlarging each pixel in the image increasing the size of the entire image, original image resolution remains unchanged. Write magnification is a more complex process. The sonographer selects an area to be magnified and then the ultrasound system

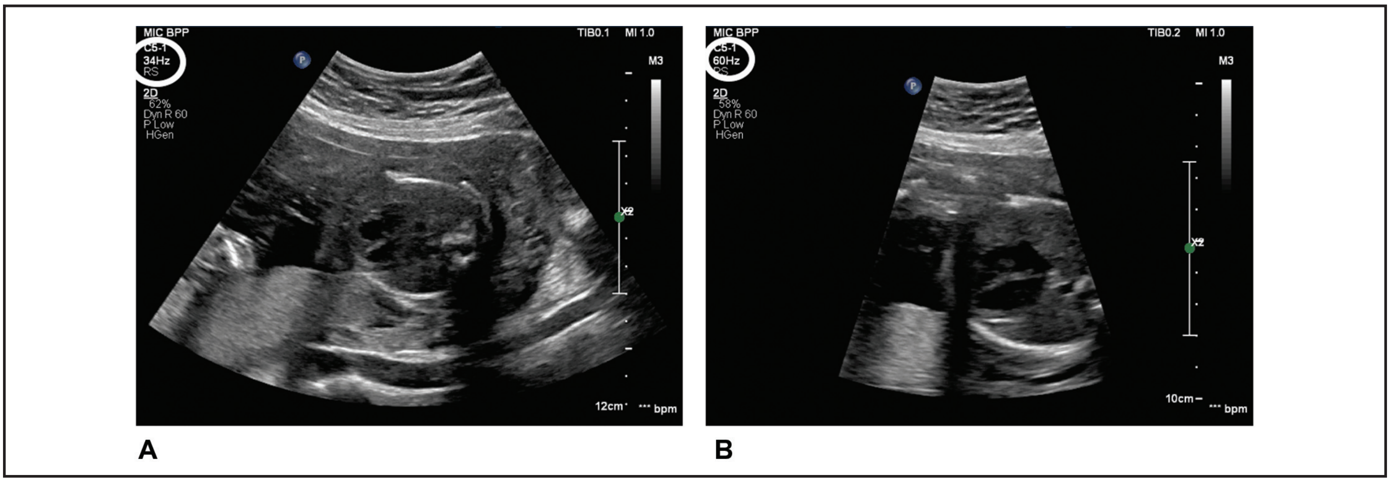

Figure 13. (A) Wide sector width with frame rate 34 Hz. (B) Narrow sector width with frame rate 60 Hz. Image B demonstrates improved detail resolution, both actual and perceived, with a significant increase in frame rate (improved temporal resolution would be appreciated in real-time).[5]

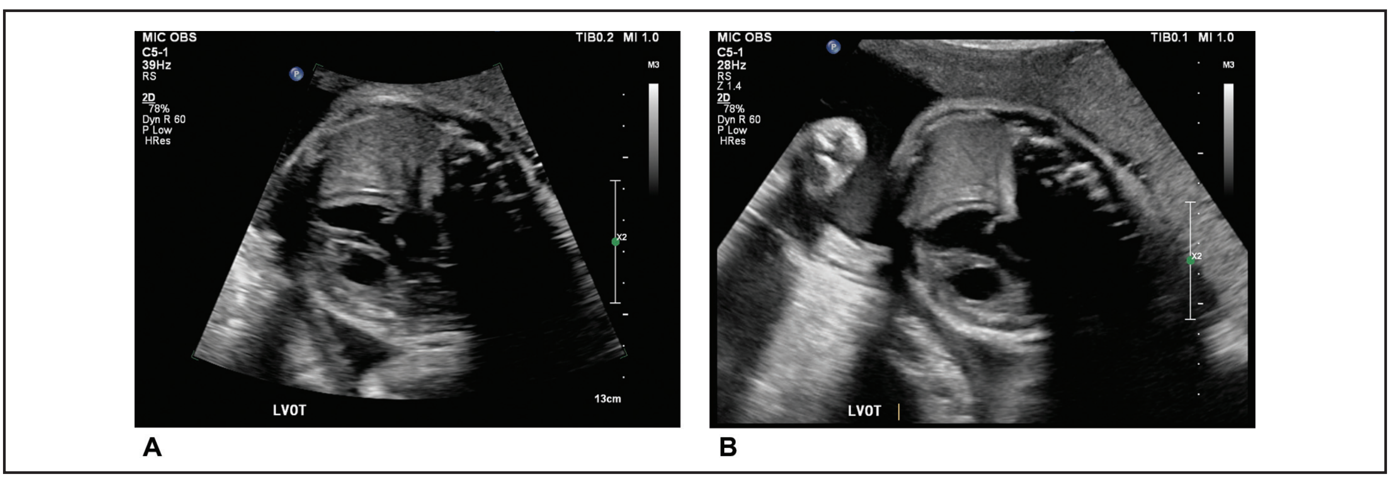

Figure 14. (A) Write magnification was used to zoom in on the LVOT demonstrating the heart structures larger and with improved image resolution. (B) Read-only magnification was used to enlarge the entire image including the heart, the actual resolution is maintained but the perceived resolution is much worse resulting in a larger but less clear image.[5]

will rescan the new smaller area but with the line density utilized for a whole image. The increased line density over the smaller area results in improved detail resolution.[7] Given the improved resolution achieved with write magnification it follows that the fetal heart would benefit greatly from the utilization of write magnification, especially in the first and second trimesters (Figure 14).

Averaging / Persistence

Smoothing is an averaging technique where neighbouring pixels are averaged together (Figure 15). This will act to accentuate pixels occurring in most sample spaces and decrease the visualization of pixels in only 1 or a few pixel spaces. Both the colour overlay and 2-D image are affected. This averaging technique is very effective for imaging structures that are not moving or moving at a relatively consistent rate. The result is a smoother image with better image quality.[7]

Another averaging technique used to improve image quality is persistence. Persistence averages frames together with more weight assigned to later frames. This can result in loss of information for events that occurred early in the frame cycle as well as information that occurred in only a few frames.[7] Since the fetal heart is beating at such a fast rate; image quality will be optimized by utilizing a lower persistence setting. For 2-D imaging, smoothing and persistence settings are typically set much higher as it is optimal to try and average out motion of structures from breathing and referred motion from vessel movement.

Colour Imaging / Priority

To produce diagnostic colour Doppler imaging of the fetal heart the sonographer must first optimize the size of the colour box, set a colour scale to minimize aliasing, and increase or decrease the colour gain to appropriate levels (Figure 16). Occasionally the

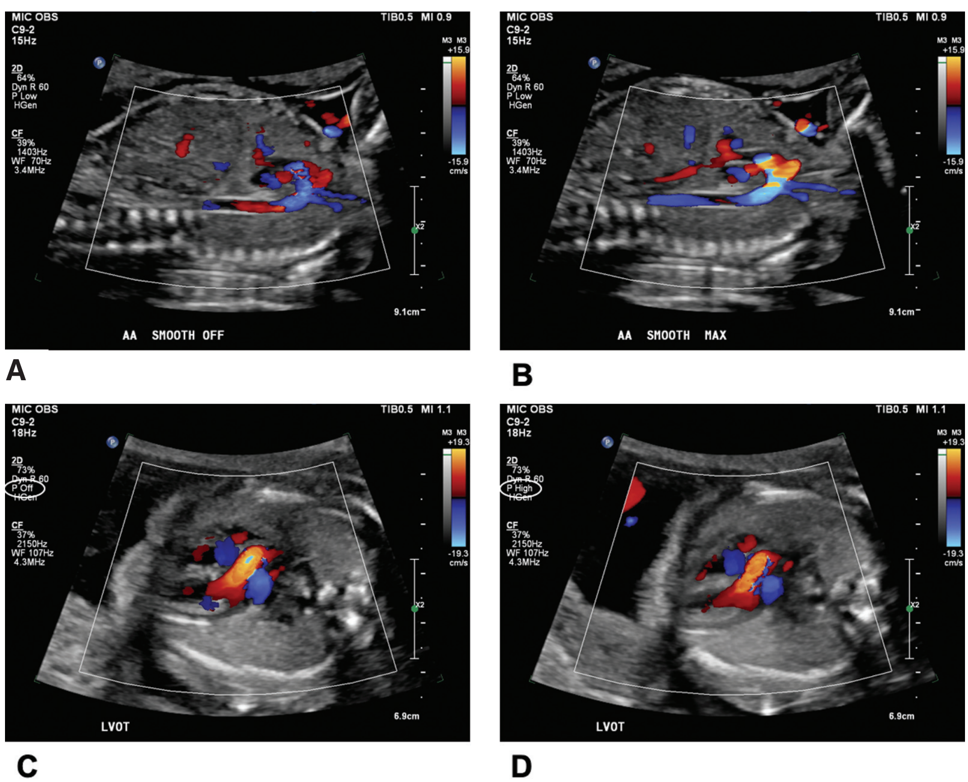

Figure 15. (A) Smoothing turned off. (B) Smoothing turned on demonstrating a smoothed image where flow velocity information is more clearly demonstrated. (C) Persistence off (circled on image). Notice the aliasing demonstrated through the aortic valve. (D) The image was obtained with persistence set at its maximum level (circled on image), the aliasing is not demonstrated. It was a short-term event early in the frame cycle which resulted in it being averaged out.[5]

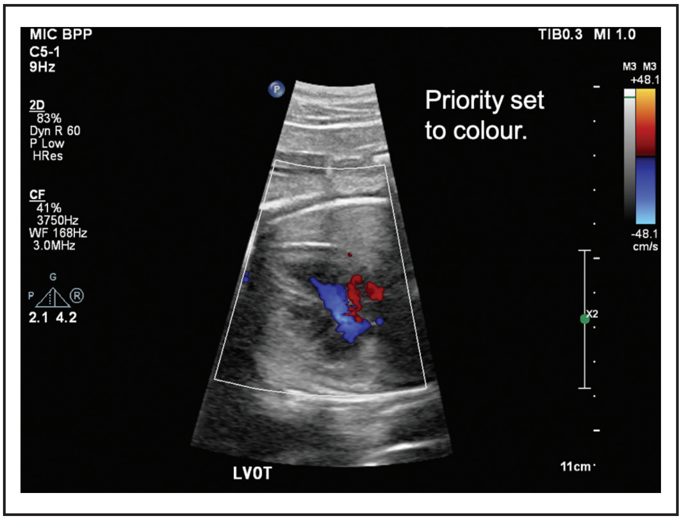

Figure 16. Set the colour box to the size of the heart with a buffer to allow for fetal movement. The colour scale is set to minimize aliasing. The colour gain is optimized to fill the chambers/outflow tract fully without bleeding over. Colour priority is set to provide a good quality colour image of the LVOT proving there is no ventricular septal defect present. Note the 2-D image is not diagnostic for the structures demonstrated.[5]

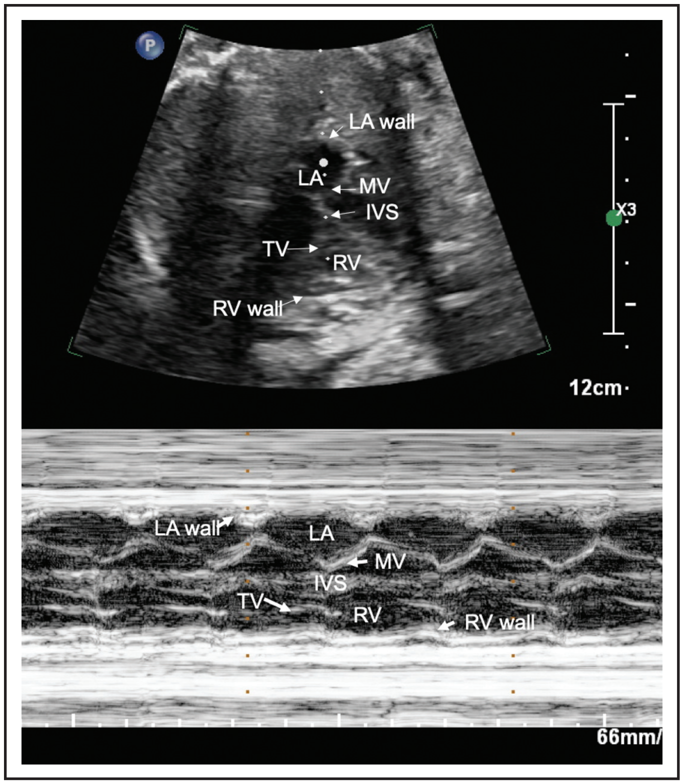

Figure 17. M-mode shows the motion of each reflector in a single scan line over time. The trace line shows the scan line represented on the m-mode trace. Each reflector in the 2-D image of the heart is represented on the m-mode trace.

aforementioned techniques do not result in optimal images; in this situation, it can be advantageous to alter the colour priority. Recall from ultrasound instrumentation a colour image is produced by overlaying colour Doppler information on a 2-D image. When the colour priority is increased the colour processing is weighted with higher importance improving colour visualization.[7] As there is only so much processing possible the cost is a loss of image processing for the 2-D image resulting in poor image quality of the 2-D component of the image.

OPTIMIZING M-MODE

M-mode imaging is used to determine the fetal heart rate (FHR) on every obstetric ultrasound performed. Utilization of the previously discussed factors before obtaining the m-mode trace will result in the best m-mode trace possible making it much easier to produce any necessary measurements. The information available by properly positioned and optimized m-mode is quite substantial. M-mode is essential to demonstrate arrhythmias (bradycardia, tachycardia, premature ventricular contractions PVC, premature atrial contractions PAC) (Figure 17). The placement of the fetal heart and orientation of the trace line must be considered to demonstrate these different arrhythmias (Figure 18).

M-mode can also be used to show pericardial effusion (Figure 19). Since a pericardial effusion will be best demonstrated with the heart lying horizontally on the screen, this is the optimal position for taking the m-mode trace. A measurement of the pericardial fluid will show if there is a pericardial effusion. Pericardial effusion is defined as a fluid collection >2mm measured on a m-mode trace.[8]

Summary

For easy patients, optimization techniques may seem irrelevant. The preset options provided by the ultrasound system often provide diagnostic images with a little adjustment on these patients though many of the discussed techniques will provide an even higher quality image. However, for technically difficult patients image optimization is essential to

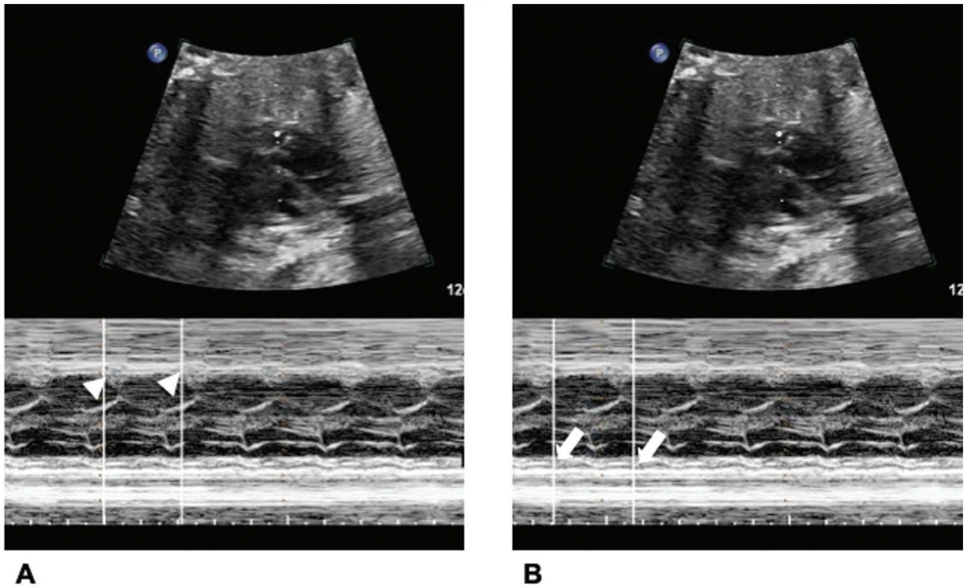

Figure 18. The trace line needs to traverse both an atrium and a ventricle to assess the timing of the beats on the same m-mode trace. This necessitates the utilization of an appropriate scan window. The rate of atrial contraction and ventricular contraction can be measured independently of the same trace. Trace line traverses the first atrium then ventricle. (A) Measurement of atrial heart rate, atrial wall noted with arrowheads. (B) Measurement of ventricular heart rate, ventricular wall noted with full arrows. [4]

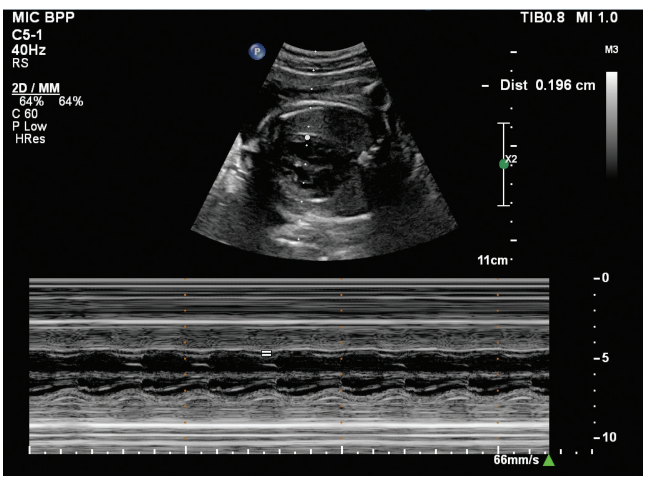

Figure 19. M-mode trace demonstrating measurement for normal pericardial fluid. The trace line goes through first the pericardial sac, pericardial fluid, myocardium of the LV, LV, IVS, RV, myocardium of RV then posterior pericardial sac. The wall most anterior in the image is seen best, therefore the best place to measure the fluid.[5]

produce diagnostic images and rule out pathology. The optimization techniques discussed throughout this article should provide the sonographer with multiple tools to help image the fetal heart with more speed, effectiveness, and better image quality.

Acknowledgements

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Image created by Em Ridsdale and used with permission.

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1. What image technique optimizes temporal resolution by decreasing line time?

a) Compression
b) Frequency
c) Persistence
d) Depth

2. In which of the following situations could priority be used to optimize imaging of the fetal heart?

a) When assessing an arrhythmia with m-mode.
b) When using colour Doppler to demonstrate a ventricular septal defect.
c) When increasing the depth setting.
d) All of the above.

3. Increasing the system compression or dynamic range will result in which of the following?

a) Increased temporal resolution
b) Increased image contrast
c) Decreased image contrast
d) Both b and c

4. Which type of magnification will result in improved detail resolution?

a) Read magnification
b) Write magnification
c) Both a and b
d) None of the above

5. When performing m-mode the trace line should be place through both an atrium and a ventricle to diagnose which of the following?

a) Premature Ventricular Contraction (PVC)
b) Pericardial Effusion
c) Pleural Effusion
d) Ventricular Septal Defect (VSD)