21

CHAPTER

Application of Spatial and Temporal Image Correlation in the Fetal Heart Evaluation

Marcin Wiechec, Agnieszka Nocun, Jill Beithon

INTRODUCTION

From the beginning of the new millennium attempts were made to apply the use of three-dimensional (3D) ultrasound in fetal echocardiography. In 2001, a study was published which utilized Doppler-gated 3D fetal echocardiography on 22 abnormal cardiac cases.[1] It was proven that fetal cardiac 3D was feasible and provided examiners with additional information. Later, Bega and co-workers compared the number of cardiac views and structures obtained from two-dimensional (2D) ultrasound to images acquired from static 3D volume datasets.[2] The same time limits (scan duration of 10 minutes) were utilized in both groups of images as was the same machine, a Voluson 530D, one of the first volume ultrasound machines. In this study, it was proven that better results were achieved by means of the 3D approach. Bega showed for the first time the advantages of volume ultrasound in fetal echocardiography, including the utilization of independent volume review, teleconsultation and operator training. A breakthrough in 3D fetal echocardiography took place in 2003, when a spatial and temporal image correlation (STIC) algorithm was introduced, which is dedicated for detailed fetal echocardiography.[3] This is one of the newest volume ultrasound modalities, which provides 3D reconstruction of a tiny organ whose walls contract at a fast frequency of about 150 beats per minute. In classic 2D echocardiography, the examiner evaluates the fetal heart by manually moving the transducer through particular cardiac views imagining a 3D reconstruction. The information gained is dependent on the examiners image optimization and scanning skills, the examiners knowledge of cardiac anatomy and anomalies, and the spatial imagination of the interpreting physician. The STIC technique permits replacing this subjective reconstruction by actual spatially and temporally correct cardiac ultrasound images.

TECHNICAL CONSIDERATIONS

The concept of STIC consists of a very slow static 3D acquisition of the fetal heart, encompassing approximately 25 cycles.[4] During the process of acquisition, the beam is swept through the heart capturing diastole and systole in tiny subphases,[5] e.g. as the beam sweeps into the four chamber view it is recorded in the phase of early then mid and late diastole, then early mid and late systole. As the sweep continues into the five chamber view it is also captured in the phase of early mid and late diastole, then early mid and late systole, and so on, until the sweep reaches the most superior part of the heart, the transverse section of the aortic arch. The result is one large static volume block. Each individual subphase of the cardiac cycle is then rearranged temporally and grouped into new separate volume blocks. Eventually, approximately 20–40 blocks come into being.[5] The quality of the final product depends on the speed of the acquisition sweep. A slower sweep allows for more subphases of the cardiac cycle to be obtained, grouped together and rearranged, which adds spatial information to the final product. The final product is presented in the form of an orderly dynamic

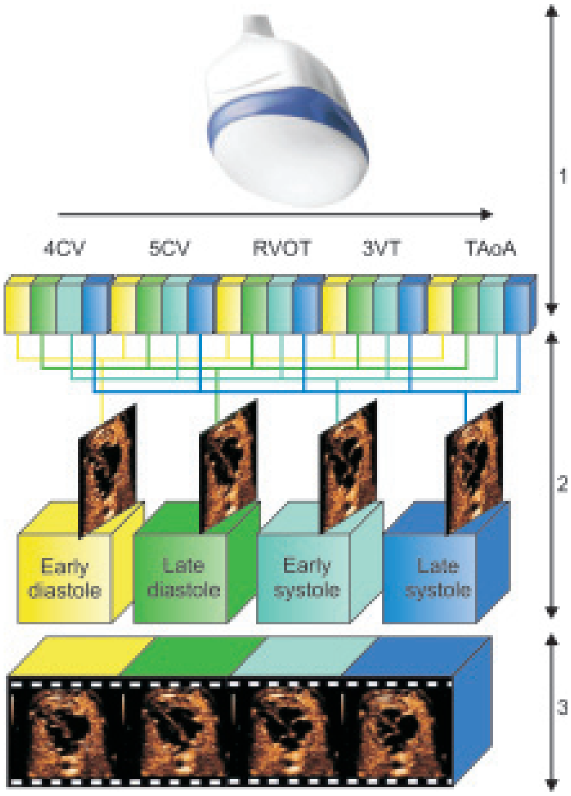


Figure 21.1: STIC acquisition and processing is presented: One slow 3D sweep. The machine detects the location and timing of each systolic beat and calculates the heart rate. Then the system determines the time frame between each beat, which allows for rearranging of the B-mode frames into a new order depending on their temporal event within the heart cycle. Since the machine knows the length of the sweep and the heart rate, it can calculate the location of each peak systolic frame and other points in the cardiac cycle and combine the information in it with all the other frames of the corresponding times. Because many frames at the exact time reference are averaged together, the temporal resolution compares to a high frame rate B-mode image. The rearranging results in a final product of one heart cycle replayed in a continuous cine loop

sequence, a clip, which is arranged into one full cardiac cycle, from the early phase of diastole to the late phase of systole in all planes, from the four chamber view to the transverse section of the aortic arch **(Fig. 21.1)**.

THE PROCESS OF FETAL HEART ASSESSMENT IN STIC MODE

The fetal heart evaluation by using STIC technology can be divided into the following stages:

- The preparation of the 2D image and the STIC volume acquisition

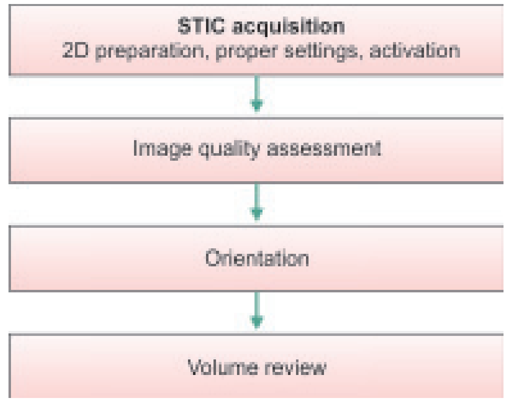


Figure 21.2: Stages of fetal cardiac evaluation by using STIC mode

- Assessing the quality of an acquired volume dataset
- The orientation of the STIC volume
- Reviewing the acquired STIC information **(Fig. 21.2)**.

THE PREPARATION OF THE 2D IMAGE AND THE STIC VOLUME ACQUISITION

The STIC acquisition is a process of rewriting 2D information into a 3D volume dataset. An acquisition sweep takes from 7.5 to 15 seconds depending on selected adjustments. Adequate preparation of the 2D image before the acquisition and proper STIC settings however is more time consuming. This is the basis of what will result in the best quality volume dataset allowing for the most accurate diagnoses.

Probe Selection

Selection of an appropriate probe is one of the key issues before the STIC acquisition is started. A transabdominal probe with a frequency range of 4–8MHz is optimal for the first and second trimesters until about 24 weeks of gestation. After this period, ossified ribs generate shadowing, which obscure cardiac views and affect the quality of volume acquisition. After 24 weeks of gestation, a transabdominal transducer with a frequency range of 2–5 MHz is generally more usable due to better penetration capabilities. After 30 weeks of gestation a 2–5 MHz probe is necessary for successful STIC acquisitions. One must also consider the patients' body mass index (BMI) in selecting a probe and in the cases of obesity the probe with better penetration is the one of choice. It is ideal to have both of the aforementioned probes available. In 2009, a new matrix array transducer was introduced with a frequency range covering the mid ranges of the two above mentioned probes. This probe is a good alternative. For transvaginal STIC acquisitions the most suitable probe has a frequency range of 5–9 MHz, but a probe providing 6–12 MHz frequency range can provide especially high resolution for some selected cases between 11 and 12 weeks of gestation.

An Appropriate Acoustic Window

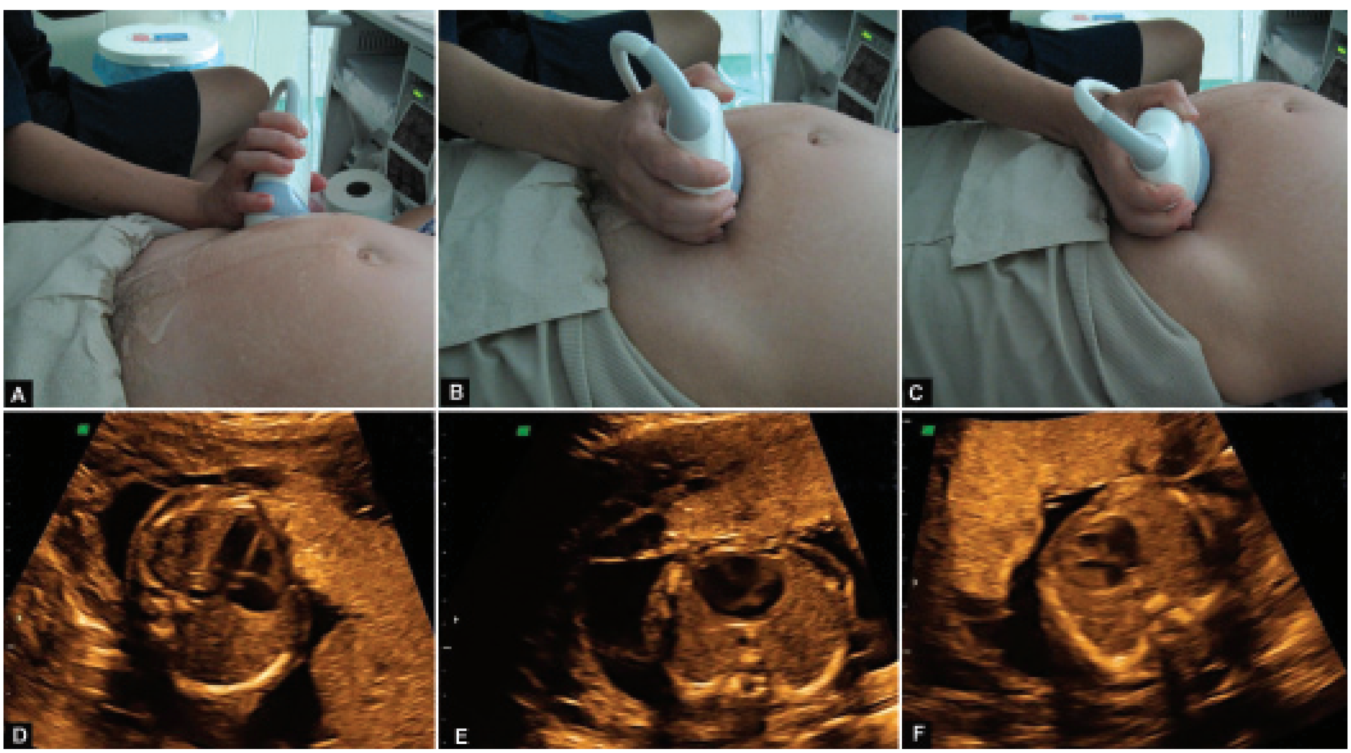
Every STIC acquisition should be preceded by the proper probe selection and 2D image optimization. The next step is the selection of a suitable acoustic window, which will assure the examiner of the proper amount of information, which is to be acquired into the volume block. Several practical considerations are described below.

Fetal Position

In order to avoid shadowing from the fetal spine and ribs, it is necessary to move the probe to a position where the beam will insonate the fetus from an anterior approach if at all possible. The examiner maneuvers the probe on the abdomen of the patient to effectively create the impression of the fetus being turned by the examiner **(Figs 21.3A to F)**.

Selection of Acquisition Plane

In the STIC mode, the most popular way of acquiring the volume dataset is by evaluating the heart from transverse sections through the fetal chest.[6] The acquisition plane A then becomes transverse cross-sections beginning at the level of the upper abdomen to include the fetal stomach (this aids in situs determination). Proceeding superiorly are the four- and five-chamber views, the right outflow tract view and the three vessels and trachea view. Planes B and C are the reconstructed views, which are orthogonal planes to A, that is to say sagittal and coronal. It is very important to make sure that the transverse section of plane that you are identifying as your start of acquisition is a true transverse plane and not oblique. Watch carefully for the ribs in the fetal chest to appear similar on both the right and left sides and that the fetal abdomen and chest are round and not elongated. Keep your image angle wide enough to view the entire width of the fetus so



Figures 21.3A to F: Translation technique is shown, which is actually nothing more than changing the application point of the transducer. At the time of translation the same section through the fetal chest is displayed on the monitor, but the relationship between the transducer and the target changes. Translation is used for identifying the most suitable insonation angle. (A to C) Movements with the probe on the patient's abdomen; (D to F) Effect of translation on the image

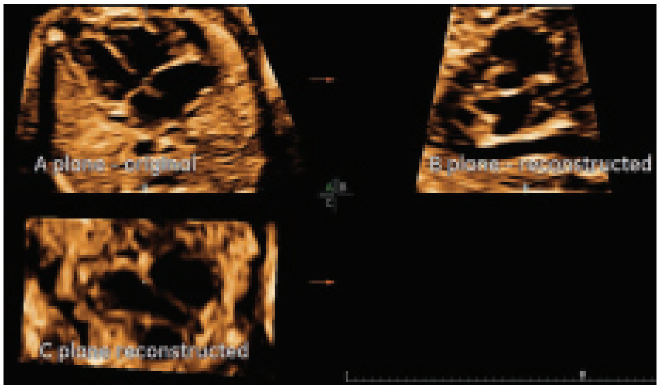


Figure 21.4: Transverse volume acquisition. The A plane is the original acquisition plane; the B plane is a sagittal plane, which is reconstructed from the A plane; the C plane is a coronal plane, which is reconstructed from the A plane

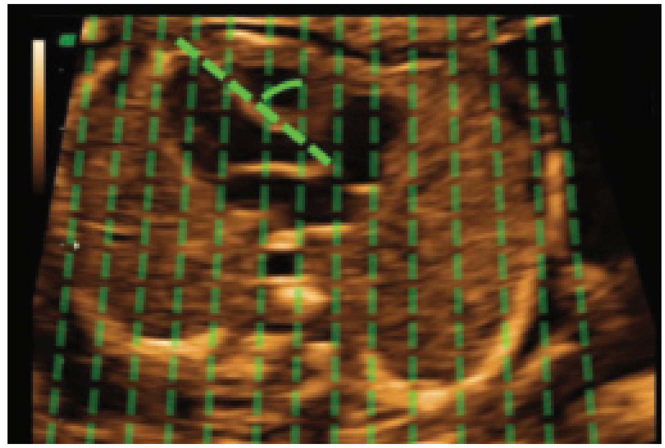


Figure 21.6: The optimal insonation angle to the interventricular septum is 45°

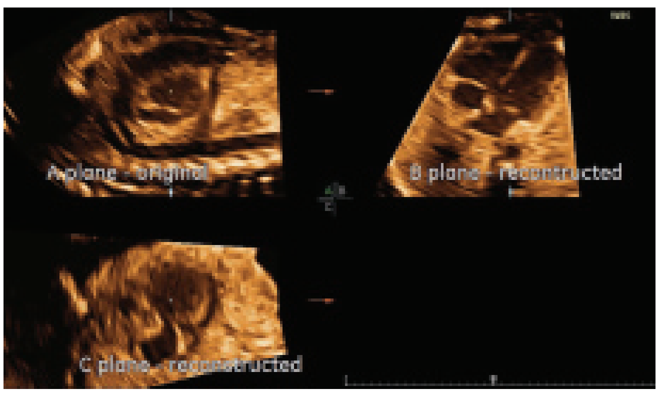


Figure 21.5: Sagittal volume acquisition. The A plane is the original acquisition plane; the B plane is a transverse plane, which is reconstructed from the A plane; the C plane is a coronal plane, which is reconstructed from the A plane

you can easily identify structures that will help you to recognize that you are in a true transverse section of the fetus **(Fig. 21.4)**.

Of note: It is also possible to obtain a STIC acquisition from a sagittal section through the fetal chest.[6] The acquisition plane A then has sagittal sections, plane B reconstructed transverse sections and plane C reconstructed coronal sections **(Fig. 21.5)**.

Selection of Insonation Angle

An optimal insonation angle should simultaneously assure the correct visualization of the chambers of the heart, outflow tracts and the interventricular septum. This is best done by assuring an angle between the beam and the interventricular septum of approximately 45°.[6] This may entail a sweep, which begins at the apex of the heart and sweeps towards the base or vice versa **(Fig. 21.6)**.

Selecting an Acoustic Window Free of Shadowing

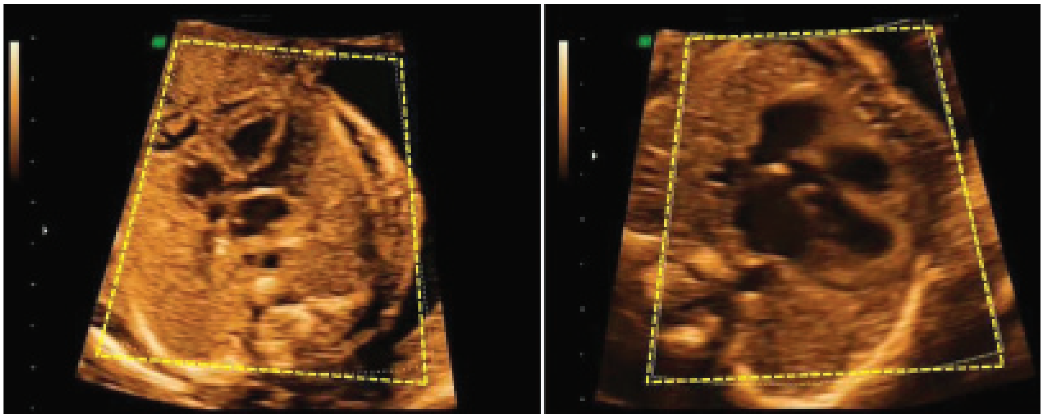
"Escaping" from acoustic shadows is of utmost importance and every sonologist must assure that shadows are not encountered in any section of the heart. So before the STIC acquisition is initiated, it is prudent to make a 2D sweep through the heart imitating the STIC acquisition. If on some sections shadows are visible, one should seek a better acoustic window. Shadows from 2D images will always be rewritten on the 3D dataset.

Selecting Suitable Image Zooming and Framing

The image area, which is to be utilized in the STIC acquisition should always be properly framed. Beginners at STIC should frame the image so that the acquisition area includes not only the fetal heart but also the chest in transverse section, including the fetal ribs and spine. Including this additional information into the STIC volume will allow for easier manipulation of the dataset as the spine and ribs will serve as landmarks for the examiner. In experienced hands, the frame can be limited to the heart and the transverse section through the descending aorta. The image should also be zoomed to an appropriate level so the structures can be easily seen **(Figs 21.7A and B).**

STIC Adjustments

Now that you have chosen an appropriate probe and selected a proper acoustic window it is time to make decisions regarding two important STIC parameters, the STIC volume angle and the STIC acquisition time.



Figures 21.7A and B: The 2D image preparation for STIC acquisition—framing and zooming. (A) A frame covers the whole chest with small magnification; (B) A frame covers only the heart and includes the descending aorta and the spine, high magnification

The STIC volume angle refers to the length of the sweep. You must determine how large is an area that you want to acquire information within. The decision to set the volume angle is dependent on the size of the heart. The greater the size of the heart (gestational age of the fetus) the greater volume angle you will need. A rule of thumb for setting the degree of the angle coincidently coincides with the gestational age in weeks of the fetus.

When acquiring your volume from a transverse plane pick a volume angle that is the same as the gestational age in weeks. For example, an angle of 20° is a good choice for a 20 week fetus. Use a 30° angle for a 30 week fetus.

When acquiring your volume from a sagittal plane pick a volume angle that is the same as the gestational age in weeks plus 5°. For example, an angle of 25° is a good choice for a 20 week fetus. Use a 35° angle for a 30 week fetus.

Of course these numbers need to be adjusted larger in cases of cardiomegaly. A minimum angle size, which is acceptable for use is 15° and a maximum angle size is 40°.

The STIC acquisition time determines the length of the duration of the acquisition. Your choice in setting the acquisition time should depend on how active the fetus is at the time that you are trying to do your STIC acquisition. A longer time will create a sweep, which has more time to obtain information, thus adding to the quality of the volume dataset. However, with a longer time there comes more opportunity for the fetus to move creating motion artifacts. Always choose the longest acquisition time that you think the fetus will cooperate with. You of course will have the opportunity to delete the volume and try again if the fetus moves during the acquisition. A minimum time for a STIC acquisition is 7.5 seconds and a maximum time is 15 seconds.

Finding the Optimal Original Plane of Acquisition (OPA) for a STIC Acquisition

The term original plane of acquisition or OPA refers to the center point of the volume of information, which you are trying to create. It is the midpoint of the volume angle. The OPA is the place on the image that you locate from which the sweep will back up half the distance of the angle that you have decided on and begin the sweep. The sweep will begin, come to the midpoint (the OPA) and continue past the OPA for another half of the sweep angle. This is the same way in which classic 3D volume acquisition is performed (**Fig. 21.8**).

The recommended OPA location for acquisitions done in the transverse plane is the five-chamber view. The five-chamber view is optimal because it is at the midpoint of the manual sweep across the fetal heart that one should acquire for an STIC volume dataset. The five-chamber view is not to be confused with the left ventricular outflow tract (LVOT) view, which is actually an oblique view of the heart and if used as an OPA it will not assure a suitable amount of information, which is included in the STIC dataset. It was proposed by some authors to use the four-chamber view as the OPA in the transverse plane however, if used, the aortic arch may not be included in the volume dataset (**Figs 21.9A and B**).[2,3,6]

The recommended OPA for acquisitions done in the sagittal plane is the ventricular short axis view just below the level of the atrioventricular valves (**Figs 21.10A and B**).

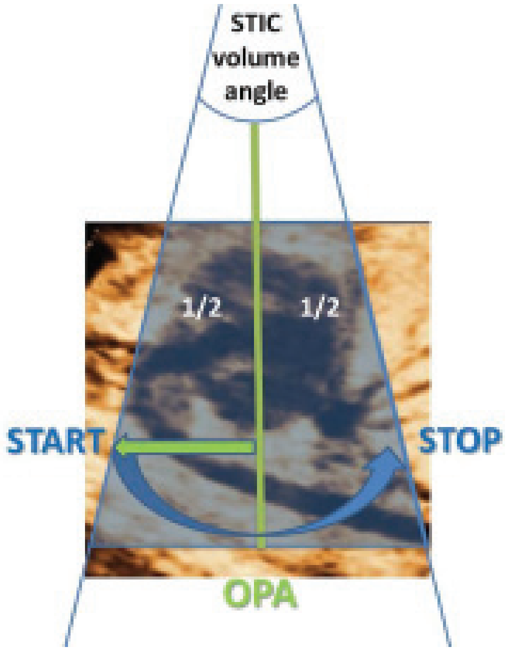
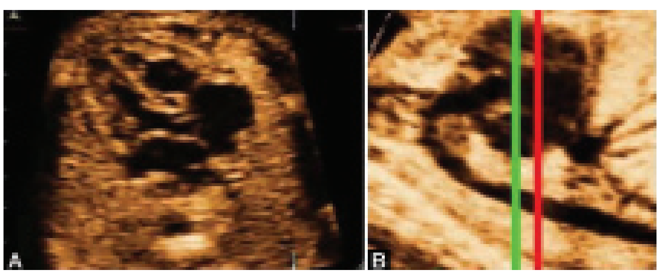


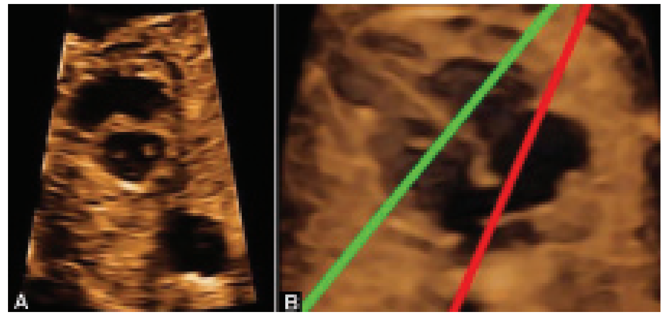
Figure 21.8: Volume acquisition. The original plane of acquisition (OPA) is the mid point of the selected volume angle and thus the central section of the volume dataset. The OPA is chosen and the transducer automatically sweeps 50% of the chosen volume angle away from the OPA. The sweep then begins acquiring information towards the OPA, the sweep continues past the OPA and ends at the equidistance away from the OPA at which it began



Figures 21.9A and B: The original plane of acquisition (OPA) in transverse STIC technique. (A) The five- chamber view; (B) A reconstructed image of the heart in the sagittal plane. The green line demonstrates the level of the OPA for the transverse STIC acquisition, which is the level of the five-chamber view. The red line demonstrates the level of the four-chamber view. As you can see, the green line (the five-chamber view) depicts the midpoint of the information which we would like to include in the sweep. The red line (the four-chamber view) is located too inferior

IMAGE QUALITY ASSESSMENT

After the acquisition you have to make a decision on whether or not you will save this volume of information to the machine hard drive for later review and manipulation or discard it and start over. There are three things for you to review in order to make this decision. The first is the preview of the information during the acquisition. The next is checking to see if the machine has made a correct assessment of the fetal heart rate (FHR). The third is a quick review of the volume data block to check for artifacts.



Figures 21.10A and B: The original plane of acquisition (OPA) in sagittal STIC technique. (A) Ventricular short axis view just below the atrioventricular valves; (B) A reconstructed image of the heart in the transverse plane. The green line demonstrates the level of the OPA for the sagittal STIC acquisition, which is at the level of the ventricular short axis view. The red line demonstrates the level of the aortic arch which would be too far to the right for an optimal STIC acquisition

Acquisition Preview

During the acquisition you can watch as the sweep moves through the different levels of the heart. The acquisition is conveniently played at a slow speed so you can watch to make sure the sweep encompassed the stomach on one end and the transverse section of the aortic arch on the other end. You can also watch to see that the fetus did not move and that the proper positioning was maintained to visualize the common views. The experienced eye can detect even the smallest movements of the fetus such as hiccups or respiratory movements, which can cause artifacts **(Figs 21.11 and 21.12)**.

Verifying the Machines Calculation of the Heart Rate

The machine detects the location and timing of each systolic beat and calculates the heart rate. After the acquisition of the volume, a box will appear telling you the machines calculation of the estimated fetal heart rate. The heart rate is used by the machine in order to calculate an algorithm by which to separate the B-mode frames into a new order depending on their temporal

Figure 21.11: The static illustration of the preview in progress of the transverse, transabdominal STIC acquisition. The viewing permits the examiner to watch each transverse section of the fetal heart during the acquisition and to check whether or not artifacts occurred. (Abd) upper abdominal view; (4C) four-chamber view; (5C) five-chamber view; (RVOT) right outflow tract; (3VT) three vessels and trachea view; (TAoA) the transverse section through the aortic arch

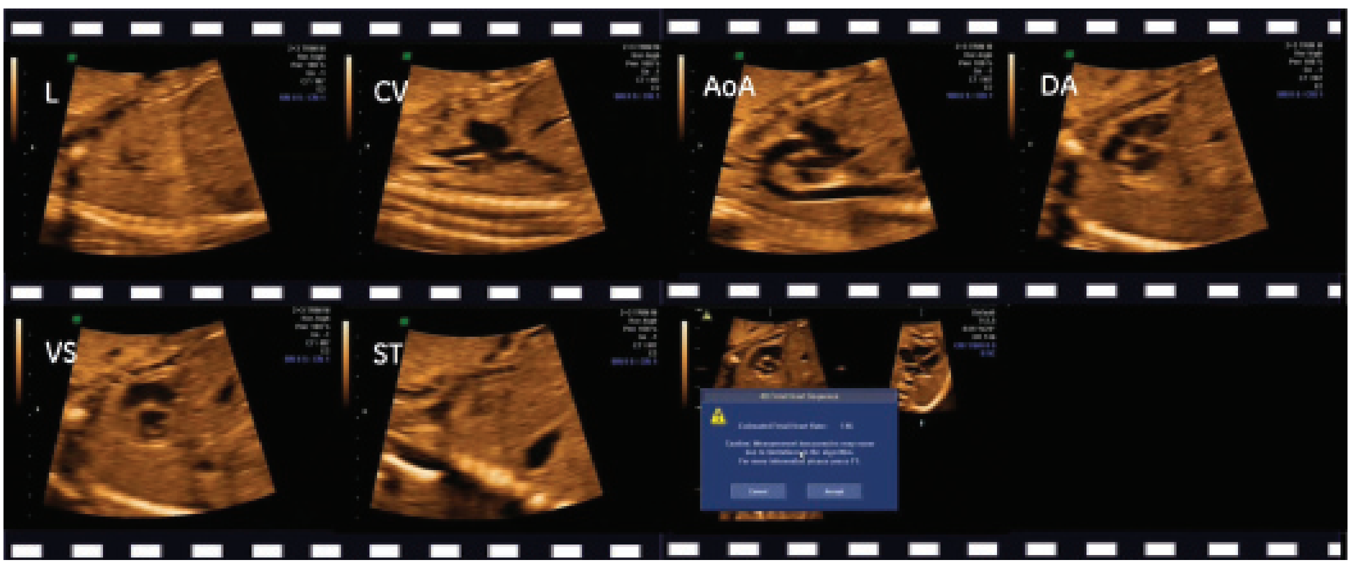


Figure 21.12: The static illustration of the preview in progress of the sagittal, transabdominal STIC acquisition. The viewing permits the examiner to watch each sagittal section of the fetal heart during the acquisition and to check whether or not artifacts occurred. (L) section through right lung; (CV) long axis caval view; (AoA) aortic arch; (DA) ductal arch; (VS) ventricular short axis view; (ST) sagittal section through the fetal trunk at the level of the stomach

event within the heart cycle. The box which appears after the acquisition will ask you to accept or cancel the machines calculation. If the machines estimated heart rate is not consistent with what you observed while imaging the heart you must cancel the acquisition and try again **(Fig. 21.13)**.

Initial Review of the Volume Dataset

A third and last element of the estimation of the quality of a newly acquired dataset is the quick review of the volume block. You will be looking for any reason to reject this particular volume dataset or to decide

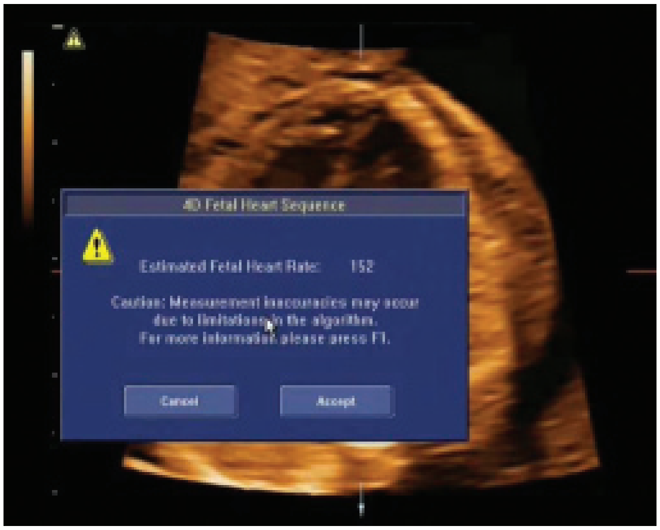


Figure 21.13: This box will appear after the acquisition asking you to accept the machine's estimation of the fetal heart rate

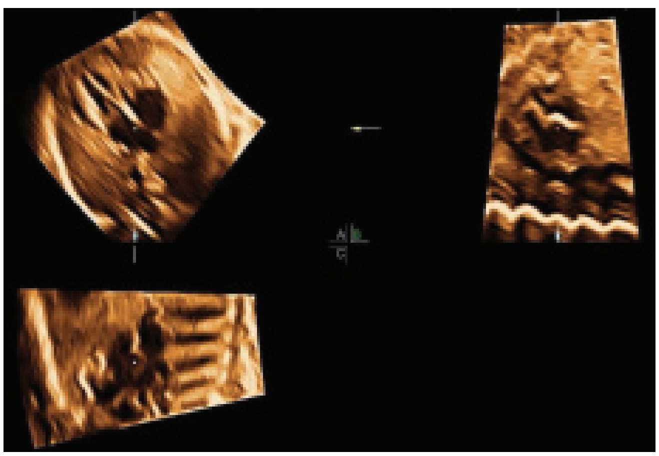
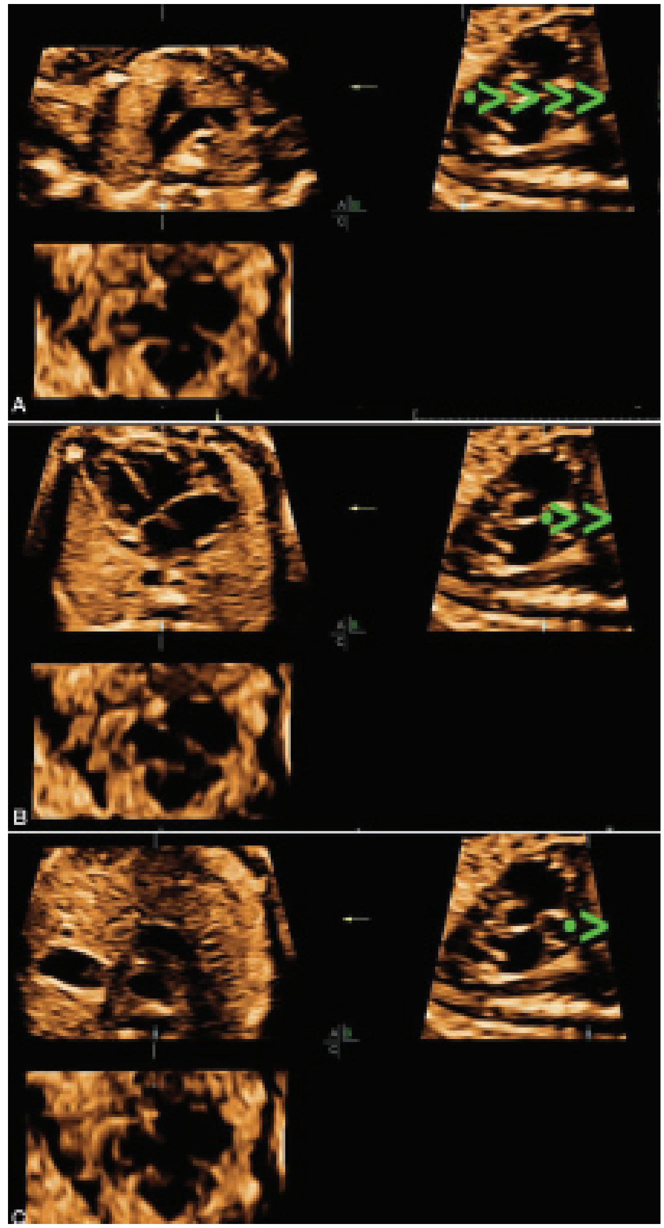


Figure 21.14: Quality rating of a new STIC dataset—motion artifacts. The multiplanar view of the fetal heart. Reference images B and C demonstrate numerous breaks in the reconstruction signifying motion of the fetus during the progress of acquisition

whether or not you will save it to the machine hard drive for later review and manipulation. The most obvious reasons for rejection of the dataset are motion and/or shadowing artifacts. This quick review is easily done by using the multiplanar imaging option. Here you will want to activate the reference image B and look for breaks in the reconstruction, which signify motion by the fetus during the acquisition **(Fig. 21.14)**.

Then, within the same reference image B, which is the sagittal plane, one can move the pivot point horizontally, to the right and left, while watching the A plane. Each of the recommended views from the transverse aortic arch to the level of the stomach in the abdomen will come into view and can be evaluated for motion or shadowing artifacts, or any other undesirable quality **(Figs 21.15A to C)**.



Figures 21.15A to C: Quality rating of a new acquired STIC volume—The series of multiplanar images illustrate the horizontal movement of the pivot point in reference image B and the visualization in the A plane of all recommended cardiac views. The ideal block contains sections from the upper abdominal view to the transverse section of the aortic arch

If after previewing the quality of the volume dataset and verifying that the fetal heart rate is correct then the

STIC volume dataset should be stored to the hard drive of the ultrasound machine. If you forget to store the volume this information will be unavailable later for review and manipulation.

ORIENTATION

Orientation of a STIC Volume

Similarly as in 2D, 3D fetal echocardiography is based on standardized cardiac sections.[2,6-8] An innovation and advantage in STIC is the ability to always review the STIC images in the identical orientation from one exam to the next, one institution to the next and even one country to the next. This is possible due to the ability to manipulate the images by means of rotational knobs, which are standardized among equipment manufactures. This takes away the variability of fetal lie and promotes a continuity and unification of the prenatal diagnoses of congenital heart disease by the use of STIC.

The orientation of STIC volumes is a completely new sonographic skill.[9] It exists in the consistent anatomical arrangement of every heart, stored in STIC mode, according to the same repeatable rules, so as to prepare the volume block for review in a well-organized and reproducible manner.

Foundations of the 3D orientation of the fetal heart were laid in 2001 by Bega and co-authors on static 3D volumes.[2] In the following years it was refined by other authors.[3-6,8]

For the correct orientation of STIC volumes, knobs are available, which rotate images on the x, y and z axis. Coupled with the parallel shift control knob virtually any acquired position of the fetal heart can be manipulated into standard orientations. The image below represents a correctly oriented volume data block of the heart, ready for review and interpretation **(Fig. 21.16)**.

Above is a multiplanar view of a STIC volume dataset. The examiner has arranged the anatomy in the standard viewing planes first described by Bega and co-workers, which is in the A plane, with the apex of the heart to the left of the screen.[2] If the heart is normal, the B plane will show the aortic or ductal arch to the left of the image also. Some others have proposed orientating STIC images with the apex of the heart to the right rather than the left. We believe that orientation with the apex to the left of the image is a good standard and will use this orientation throughout the remainder of this chapter.

Orientating a STIC volume is the process of image orientation in which the operator utilizes the x, y and z knobs and the parallel shift knob on the machine to twist, rotate or flip the images until they end up in a standardized viewing layout whereas the A plane is a transverse four-chamber image of the heart with the

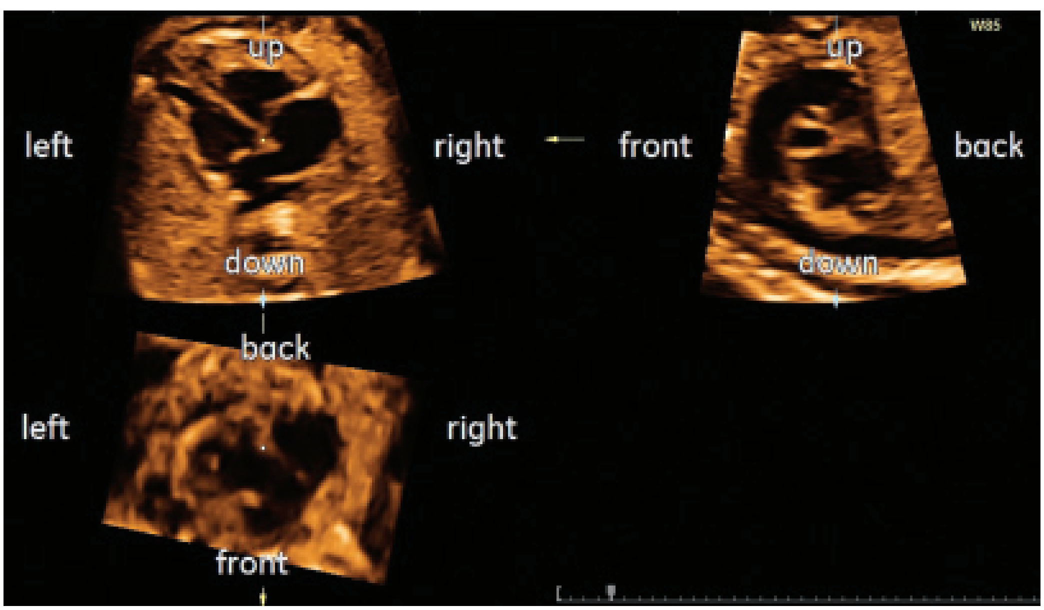
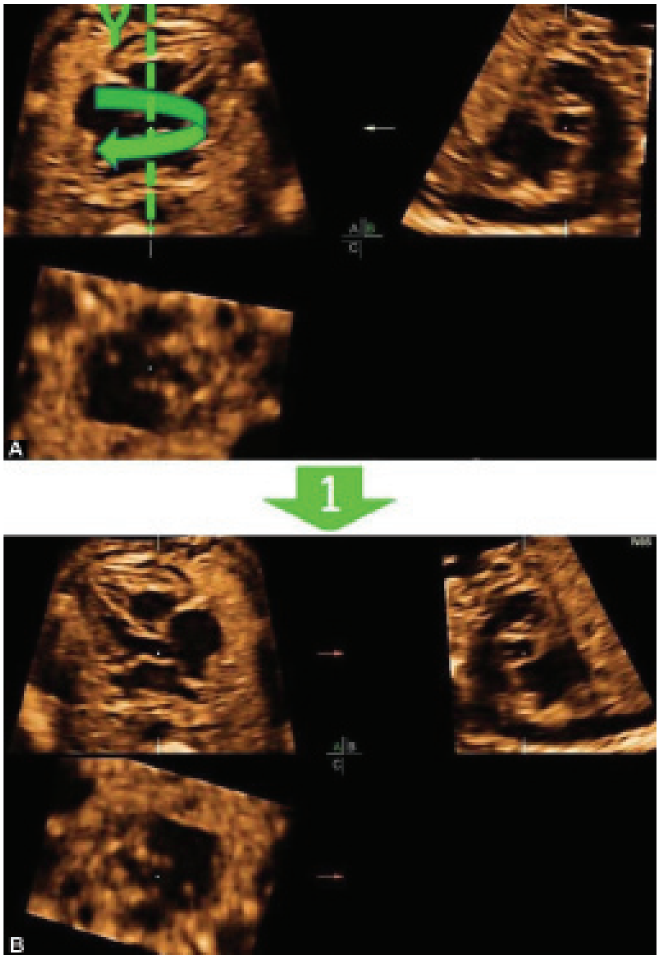


Figure 21.16: The multiplanar view of the fetal heart with the correct arrangement of viscera (situs solitus). This is a properly oriented volume dataset. In the A plane (upper left image) the axis of the heart is directed to the left. In the B plane, the section is through the ductal arch



Figures 21.17A and B: (A) The dataset in the top picture was acquired with the apex of the heart to the right of the image. Since we always want to view our volumes with the apex to the left one must turn the image of 4CV in the reference plane A by 180 degrees using the Y-axis rotation knob; (B) The result is the bottom picture

apex to the left of the image. The B plane is a reconstructed sagittal image showing superior to the left and inferior to the right and the C place is a reconstructed coronal image. This will place the images in planes, which will make review and manipulation easy and predictable.

There are several ways to arrive at this standard orientation of the apex to the left in the A plane. These methods are based on the utilization of linear structures, situated in the anatomical neighborhood of the heart. These structures include the spine, the descending aorta, the interventricular septum and the ductal arch. The orientation should be always performed in the multiplanar view. In multiplanar mode each image has a small dot, which is called the pivot point. By utilizing

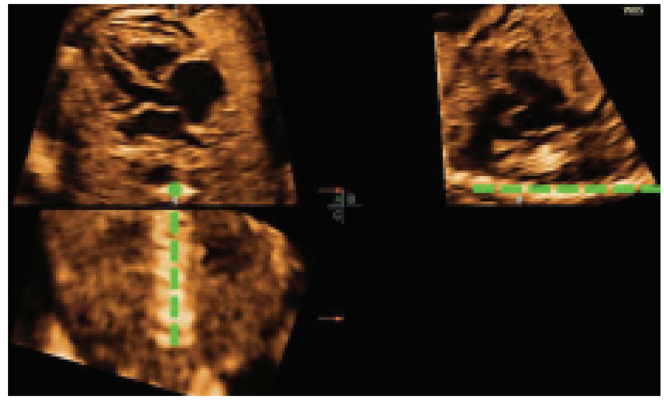


Figure 21.18: The pivot point in the A plane on the spine. The spine was used in the B and C planes to line up the images horizontally in B and vertically in C. This resulted in an optimal orientation of the volume, which can now be reviewed

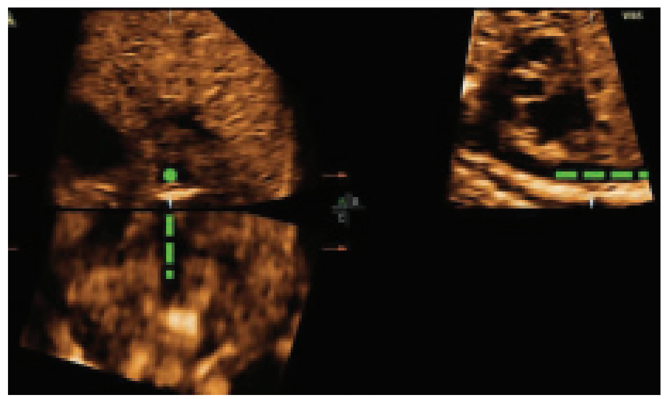


Figure 21.19: The descending aorta was used in like manner as the spine

the x, y and z knobs, the image will rotate on this pivot point allowing you to align structures within the image to a standardized orientation.

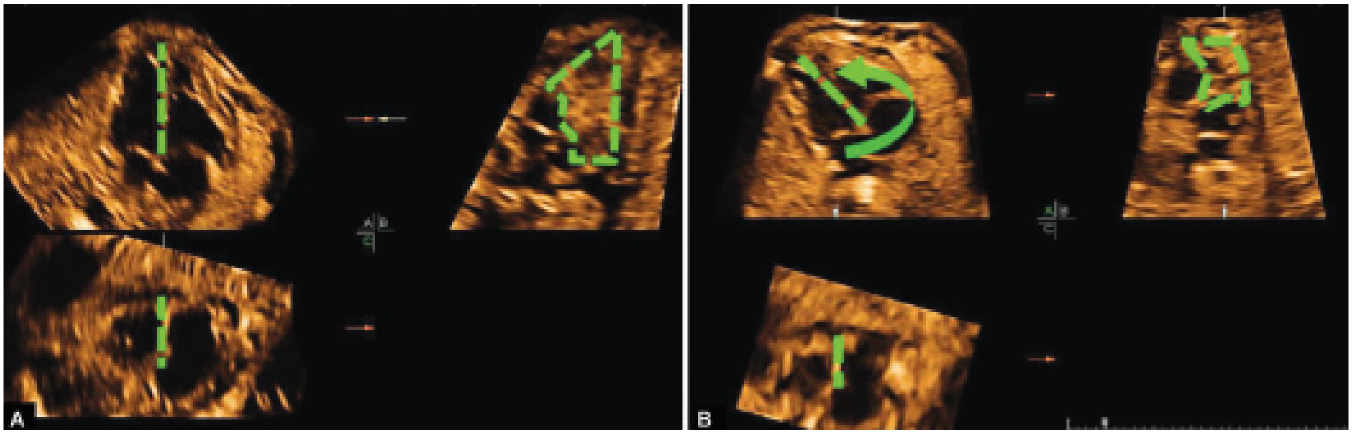
In Figures **21.17 to 21.21** manipulation of the images into a standard viewing orientation is shown.

Any of the above methods will work to manipulate the volume into the standard viewing orientation in which the apex of the heart is on the left in the A plane.

REVIEW

STIC Volume Review and the Spectrum of Viewing Options

Once proper orientation of the volume is obtained it is ready for review and interpretation. When the volume is put into motion in the format of a clip, it represents one full heart cycle played over and over again. It is



Figures 21.20A and B: (A) Orientation of the volume by using the interventricular septum placed along Y-axis in the A plane, the B plane shows the 'IVS in-plane view' and in the C plane the 'ventricular short axis view' comes into plane; (B) A z rotation is used to again turn the axis of the heart to the left in the A plane

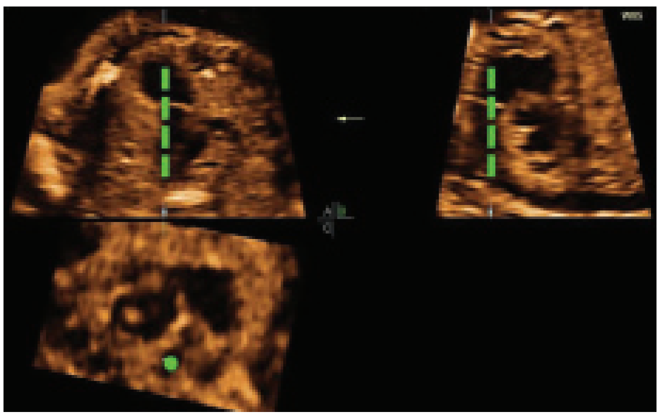
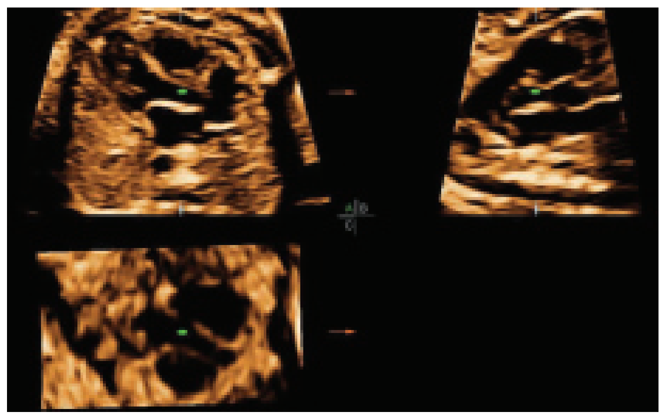


Figure 21.21: The ductal arch was aligned vertically along the Y-axis in the A plane

possible to slow down the speed of the clip to about 50%, which creates superb spatial orientation for review. It is also possible to utilize the frame-after-frame review option. There are many STIC volume 3D viewing options availalbe. These will be discussed below.

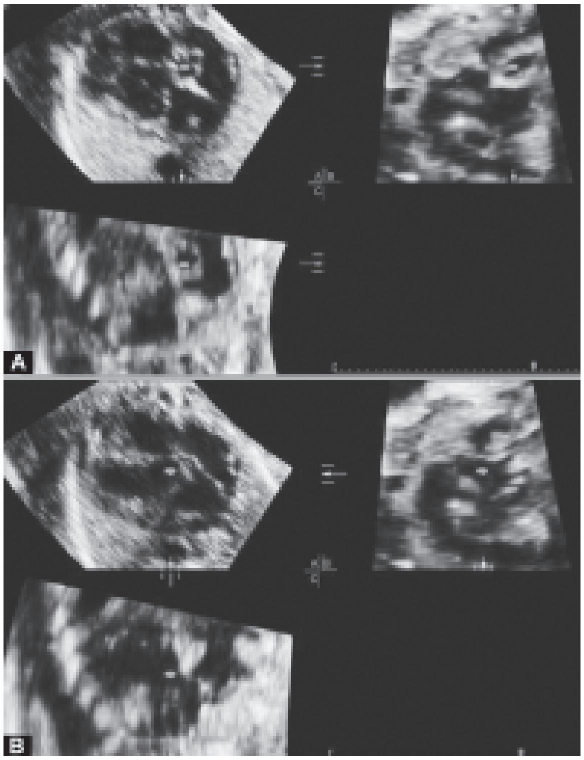
Multiplanar View

Perhaps the most important and most basic of all viewing options is the multiplanar view.[2,5,6,10,11] In this view three planes are shown, which are perpendicular to each other. They have in common one point, the pivot point, which is represented on the screen by a dot. The location of this point in the reference image of plane A, e.g. the root of the aorta, identifies the same structure in the B and C planes. Important tools in the multiplanar view are a parallel shift control, which allows for navigating through the image in a layer-after-layer manner in any of the three planes. Other tools are the x, y and z axis rotational knobs used for volume manipulation **(Figs 21.22A to C)**.



Figures 21.22A to C: (A) Multiplanar view showing the pivot point in the aortic root in the A plane; (B) This same geographic location is represented again by the pivot point in the aortic root, now in a sagittal view, in the B plane; (C) The coronal view of the aortic root is represented again in the C plane

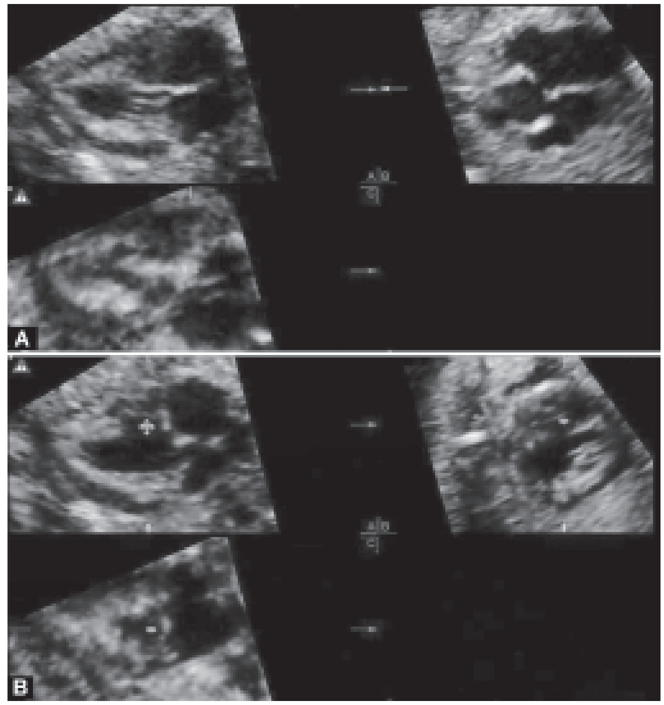
In the picture below a clinical example of the use of the multiplanar imaging is shown. The anomaly in this case is a congenital aneurysm of the right aortic Valsalva sinus which during the two-dimensional investigation imitated the root of the aorta. The detailed multiplanar evaluation gave the clear picture of this rare abnormality. With two-dimensional imaging it is not possible to obtain this type of spatial correlation in three orthogonal planes **(Figs 21.23A and B and 21.24A and B)**.



Figures 21.23A and B: (A) An aneurysm of the right aortic Valsalva sinus (green dot) appears to be the aortic root however this structure is actually at the level of the right atrium; (B) The true aortic root is found at a more anterior level in its normal position

Tomographic Ultrasound Imaging

Another viewing option for a STIC volume is ultrasound tomography. It has many advantages and is utilized often by many examiners.[7,12-14] Tomography allows for the viewing of multiple slices of the same image, by means of 1, 3, 5, 8, 11 or 15 sections on one screen along with a reference image, which is perpendicular to the tomographic sections with an overlay of the tomographic lines of slices. The distance between the slices can be set with equal or any distances. The mid slice is represented on the overlay by an asterisk. Slices to the left of the center line are described by negatives slice numbers and slices to the right of the center line are represented by positive slice numbers. This makes identification of the slices in comparison to the reference image easy. By using three standardized tomographic planes, the plane of the four-chamber view, the plane of the five-chamber view and the right ventricular outflow tract view, most of the abnormalities of the heart can be recognized. In cases of complex defects of the heart ultrasound tomography is an excellent way to illustrate the margins of the defect on one screen. As shown in the picture both a normal heart and a heart with Tetralogy of Fallot is illustrated with the use of tomographic imaging **(Figs 21.25 to 21.29)**.



Figures 21.24A and B: A case with a large ventricular septal defect. (A) The pivot point is placed at the level of the crux; in the A plane a papillary muscle mimics the presence of an intact IVS; (B) By moving the pivot point in the C plane more to the front it becomes clear that there is a large septal defect

OmniView

OmniView (GE) or Oblique View (Medison) technique allows for drawing arbitrary straight or curved sections from the reference image and displaying those sections next to the reference image **(Figs 21.30A to D and 21.31A to D)**.

Rendering

A completely different kind of volume viewing option, which can be utilized in STIC is rendering. This is a technique of 3D reconstruction from flat multiplanar images.[6,14-17] Surface rendering gives the impression of depth, causing the final images to resemble autopsy sections. The surface which one wishes to examine can be chosen and applied by the use of a rendering box. Because we are using volumes of information a direction that one wishes to look from can be chosen from any plane. The thickness of the box determines the "depth" of tissue that one wants to see in the rendered image **(Fig. 21.32)**.

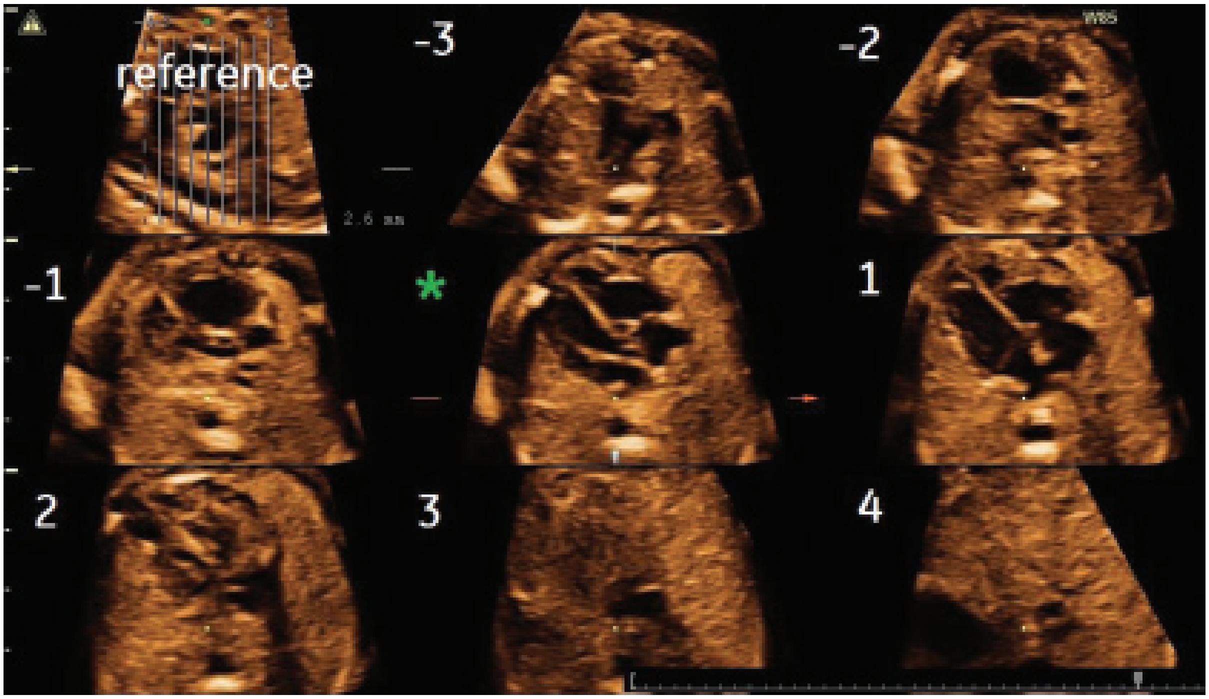


Figure 21.25: Tomographic ultrasound imaging in a STIC volume in diastole in a normal heart. In the top left section, the overlay image is presented, which is perpendicular to the tomographic layers, demonstrating section levels

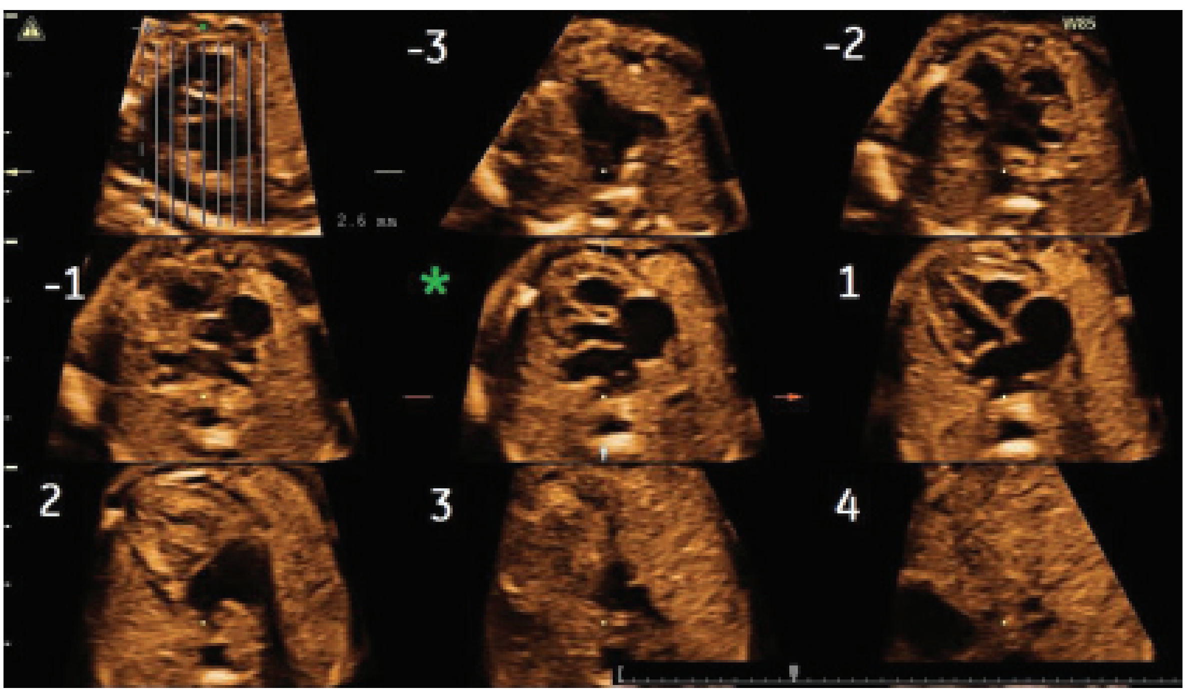


Figure 21.26: Ultrasound tomography in systole in a normal heart

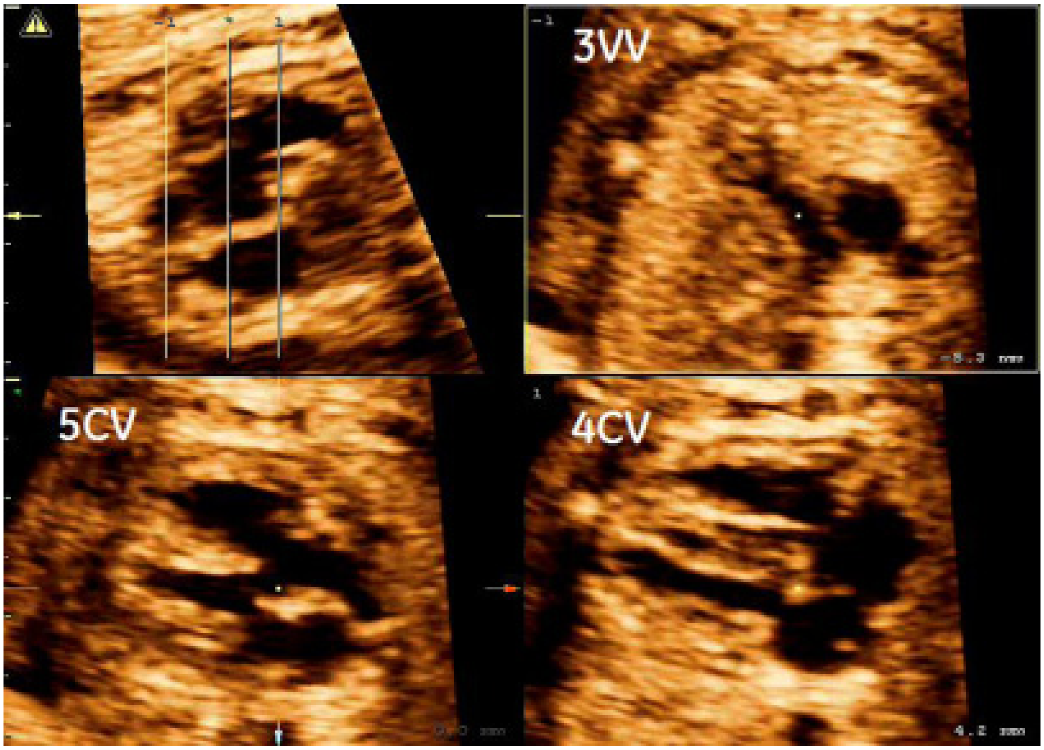


Figure 21.27: Tetralogy of Fallot in Tomographic Ultrasound Imaging. Levels of four-chamber view (4CV); five-chamber view (5CV) and three vessel view (3VV) are presented

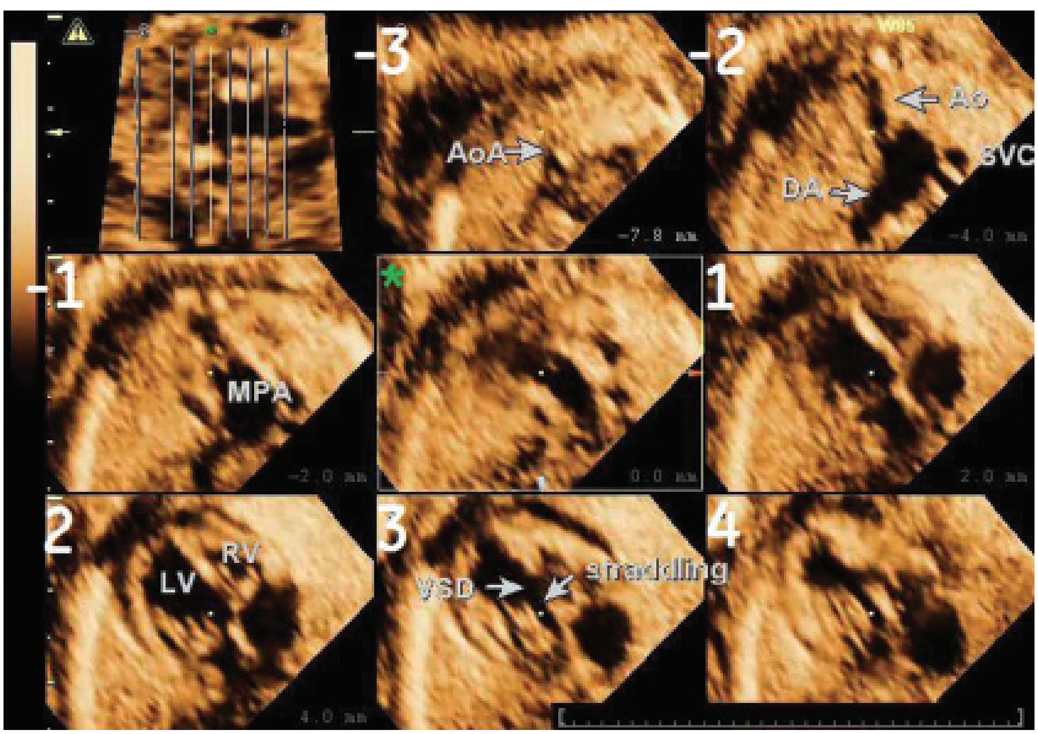


Figure 21.28: Presentation of a complex congenital heart defect (d-therapeutic goods administration + large ventricular septal defect + hypoplastic aortic arch) in systolic tomographic sections

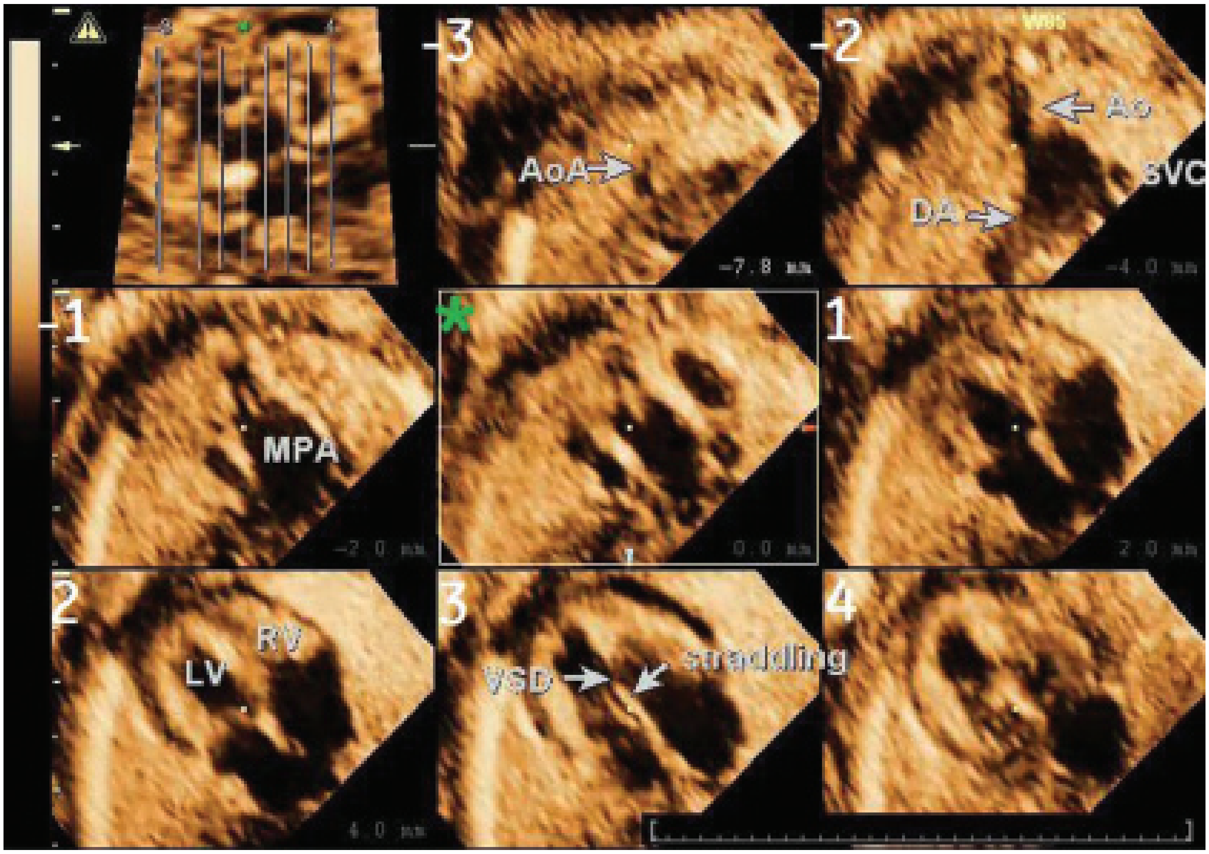
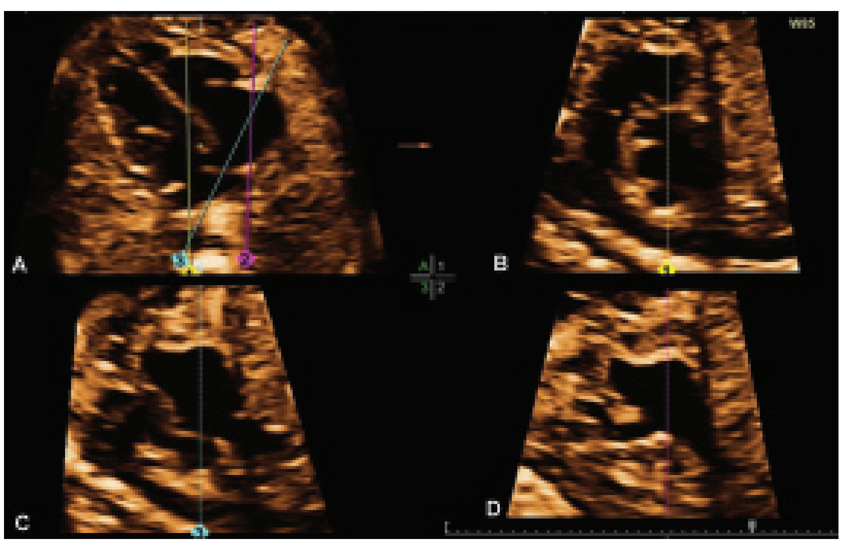
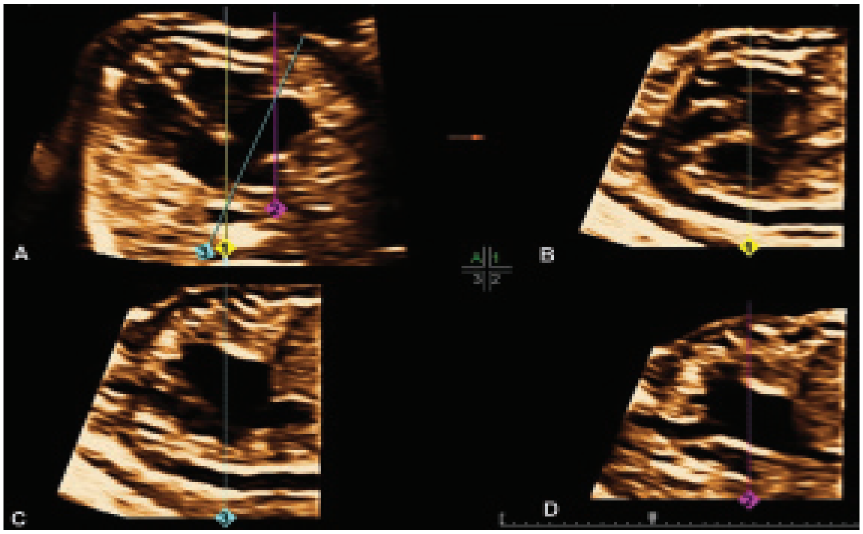


Figure 21.29: Presentation of a complex congenital heart defect (d-therapeutic goods administration + ventricular septal defect + hypoplastic aortic arch) in tomographic ultrasound at the phase of diastole. Section (3): ventricular septum defect and straddling of the tricuspid valve; section (-1): broad vessel arising from the left ventricle and bifurcating; section (-2): triangular arrangement at the level of three vessel view with a narrow and anteriorly positioned aorta (Ao); section (-3): hardly visible transverse section through aortic arch



Figures 21.30A to D: OmniView imaging in a normal fetal heart. (A) Colored lines are arbitrarily placed on the reference image; (B) A perpendicular plane to the yellow line on the reference image (the ductal arch sagittal view); (C) A perpendicular plane to the purple line on the reference image (the long axis caval view); (D) A perpendicular plane to the blue line on the reference image (the aortic arch view)



Figures 21.31A to D: (A) OmniView imaging of a heart with d-transposition of great arteries; colored lines are arbitrarily placed on the reference image; (B) A perpendicular plane to the yellow line on the reference image (the parallel course of the great arteries is seen here); (C) A perpendicular plane to the purple line on the reference image (the long axis caval view); (D) A perpendicular plane to the blue line on the reference image (in this case a nondiagnostic image)

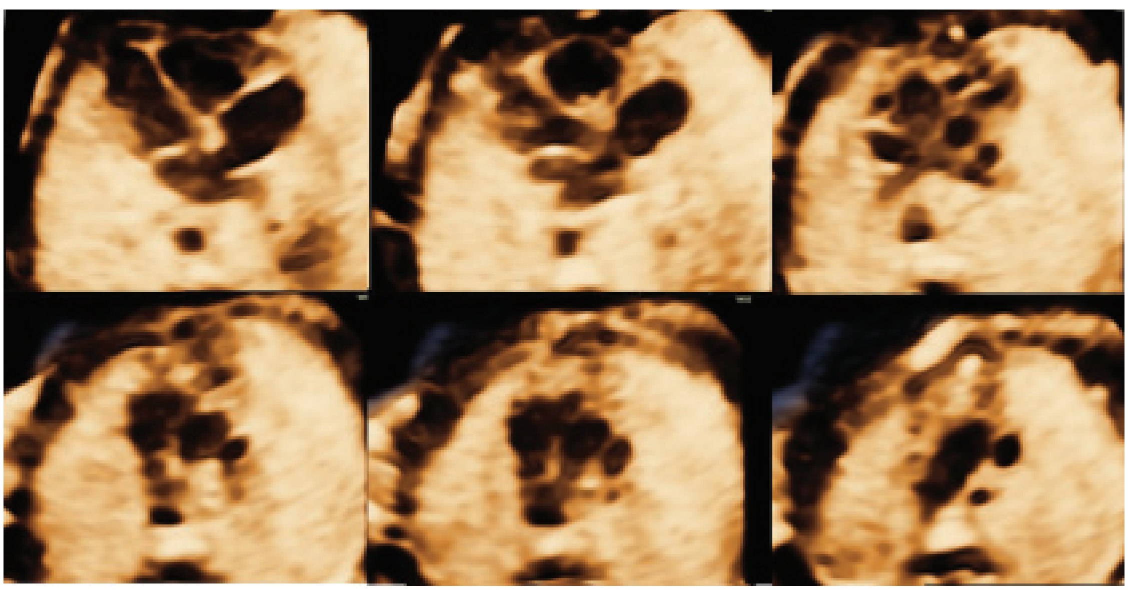


Figure 21.32: Surface rendering of the fetal heart from a STIC volume obtained at 21 weeks of gestation. Rendering direction which was applied is front to back. Subsequent cardiac views are represented starting from the four-chamber view through the five-chamber view, the three vessel view, the transverse section through ductal arch, the three vessel and trachea view and the transverse section through aortic arch. In all the presented images, the effect of depth is clearly seen

Surface rendering takes place on comparatively narrow thicknesses of the region of interest **(Fig. 21.33)**.

Most of the rendering directions can be applied in the STIC mode from the volumes obtained by a transverse acquisition technique **(Figs 21.34 to 21.37)**.

In surface rendering of the fetal heart, the options available for optimization are very important. We have found excellent results with the use of gradient light mode mixed with surface with very low levels of threshold low and transparency **(Figs 21.38 to 21.42)**.

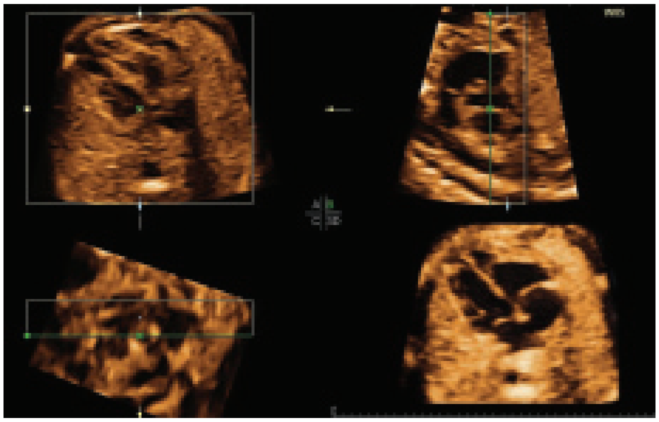


Figure 21.33: Multiplanar view of the fetal heart along with 3D rendering. In the B and C reference images a narrow region of interest is chosen, which is essential for surface rendering of the heart

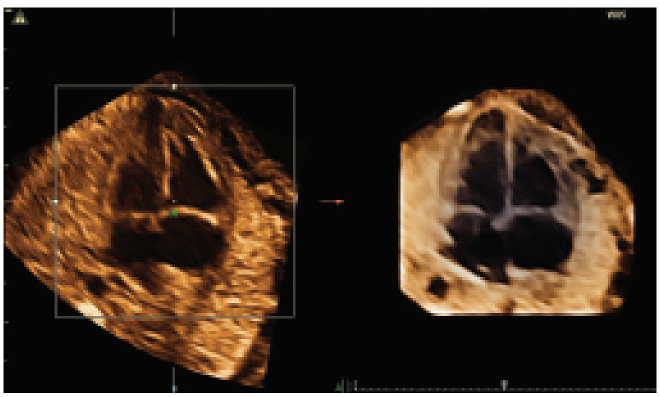


Figure 21.34: Rendering directions in surface rendering of the fetal heart: a four-chamber rendered view using a front to back render direction

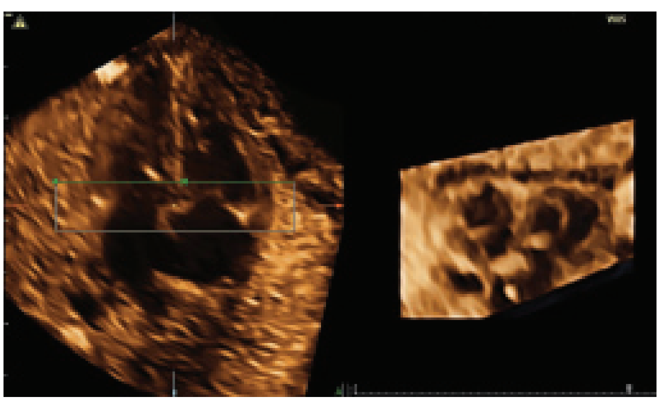


Figure 21.35: Rendering directions in surface rendering of the fetal heart: a rendering direction of up to down is used here for the evaluation of the atrioventricular valves

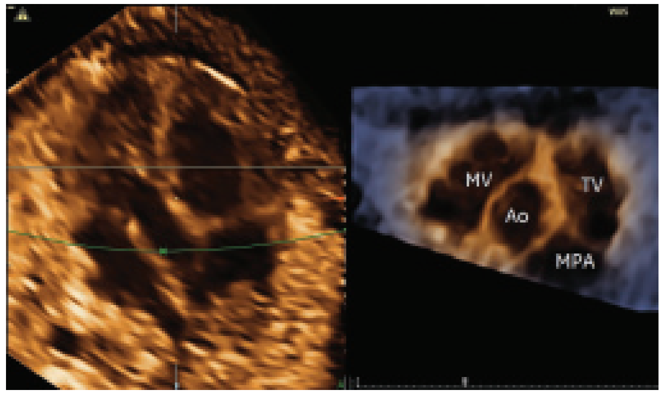


Figure 21.36: Rendering directions in surface rendering of the fetal heart: analyses of the base of the heart is rendered here from a down to up direction

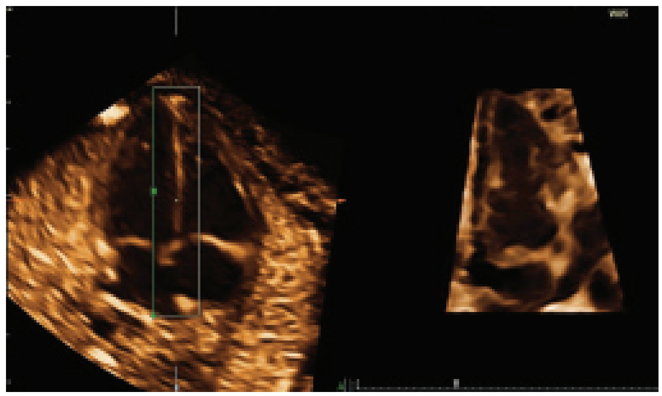
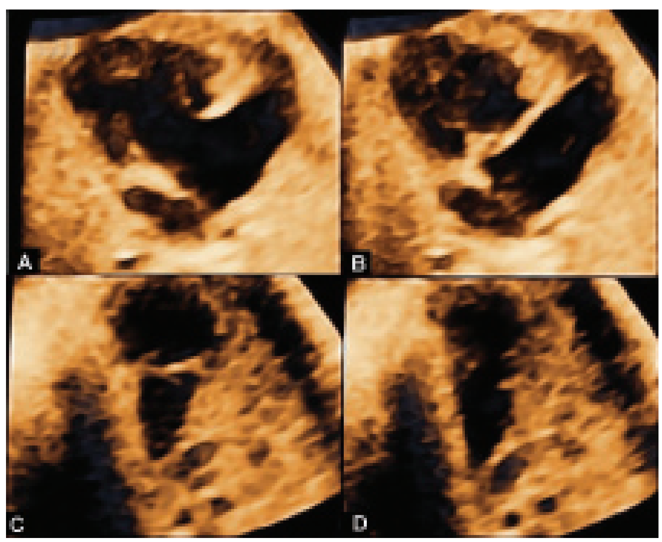
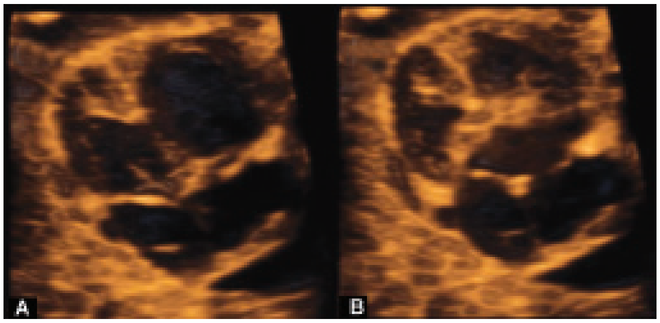


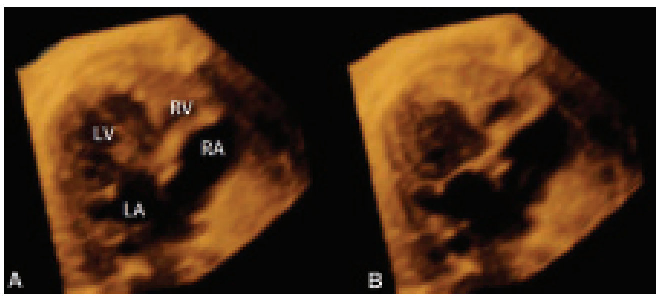
Figure 21.37: Rendering directions in surface rendering of the fetal heart: a unique view of the interventricular septum is shown here from the left-to-right direction



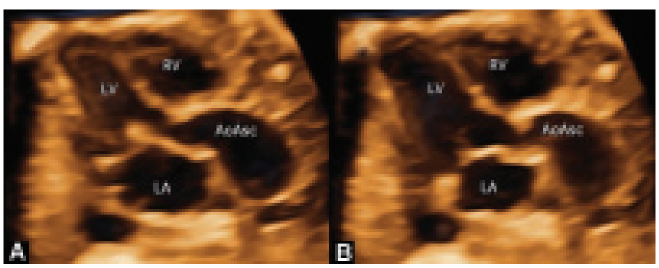
Figures 21.38A to D: Hypoplastic left heart syndrome (HLHS) shown in render mode. (A) Four-chamber view in diastole; (B) Four-chamber view in systole; (C) Three vessel view and trachea in diastole; (D) Three vessel view and trachea in systole



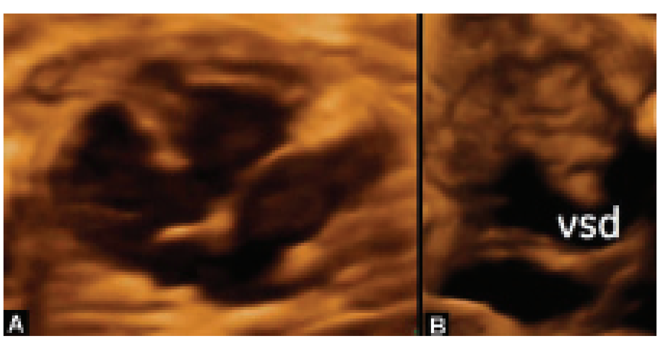
Figures 21.39A and B: Atrioventricular septal (AVSD) in render mode. (A) Systole; (B) Diastole



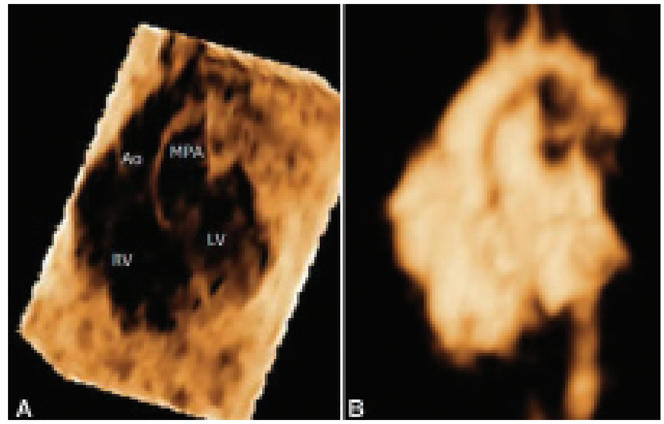
Figures 21.40A and B: Tricuspid atresia with ventricular septum defect in render mode. (A) Diastole; (B) Systole



Figures 21.41A and B: Valvular aortic stenosis in render mode. (A) Diastole; (B) Systole



Figures 21.42A and B: Large ventricular septum defect (VSD), which involves the inlet and outlet portions of the septum. (A) The VSD is not clear by using a rendering direction of front-back; (B) But is doubtless when a direction of left-right is applied



Figures 21.43A and B: Surface rendering of transposed great arteries. (A) Shows minimum mode; (B) Utilizes inversion mode

For the evaluation of the relationships of the great arteries and evaluation of cardiac chambers minimum transparent mode or inversion mode rendering can be utilized.[18,19] Below is an example of these modes in a case of transposed great arteries. Here the region of interest box has been enlarged so that all of the essential anatomical elements can be seen. The inversion rendering seen on the right image below uses the gradient light mode and an increase of lower threshold and transparency. This is a particularly good combination utilized with a sagittal acquisition **(Figs 21.43A and B to 21.46)**.

In the inversion mode, it is also possible to use a narrow region of interest box, encompassing only the cardiac chambers. This focuses on the relation of the size of the ventricles, their contractility, the cross of the heart, the interventricular septum, the composition of the atrioventricular valves,or the relationship of the outflow tracts **(Figs 21.47 and 21.48A and B)**.

The same viewing options accessible with STIC gray scale datasets are also accessible when using gray scale plus color mapping **(Figs 21.49 and 21.50)**.[20,21]

A rendering modality called "glass body" imaging writes the color information on the background of the grayscale information **(Figs 21.51A and B to 21.53A and B)**.

A STIC acquisition can be done in gray scale with B-mode alone or with the addition of color, power or bidirectional power Doppler mapping (HD flow). Below are the examples of vascular mapping with STIC **(Figs 21.54A to D)**.

An option available with STIC imaging is the use of B-flow imaging. B-flow imaging is an exceptionally sensitive form of coding of the blood flow, allowing visualization of extremely small vessels.[22] It is a Doppler

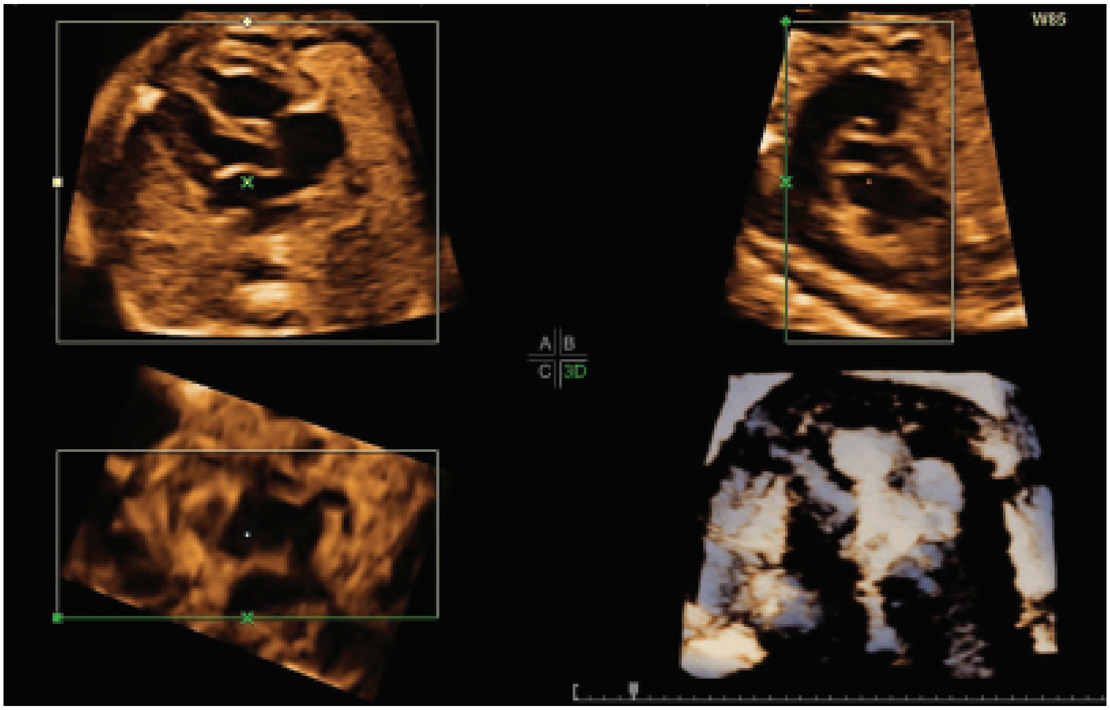


Figure 21.44: Multiplanar view coupled with inversion mode rendering (volume obtained by transverse technique of acquisition). Note the use of a large region of interest box, which can be helpful when using inversion mode

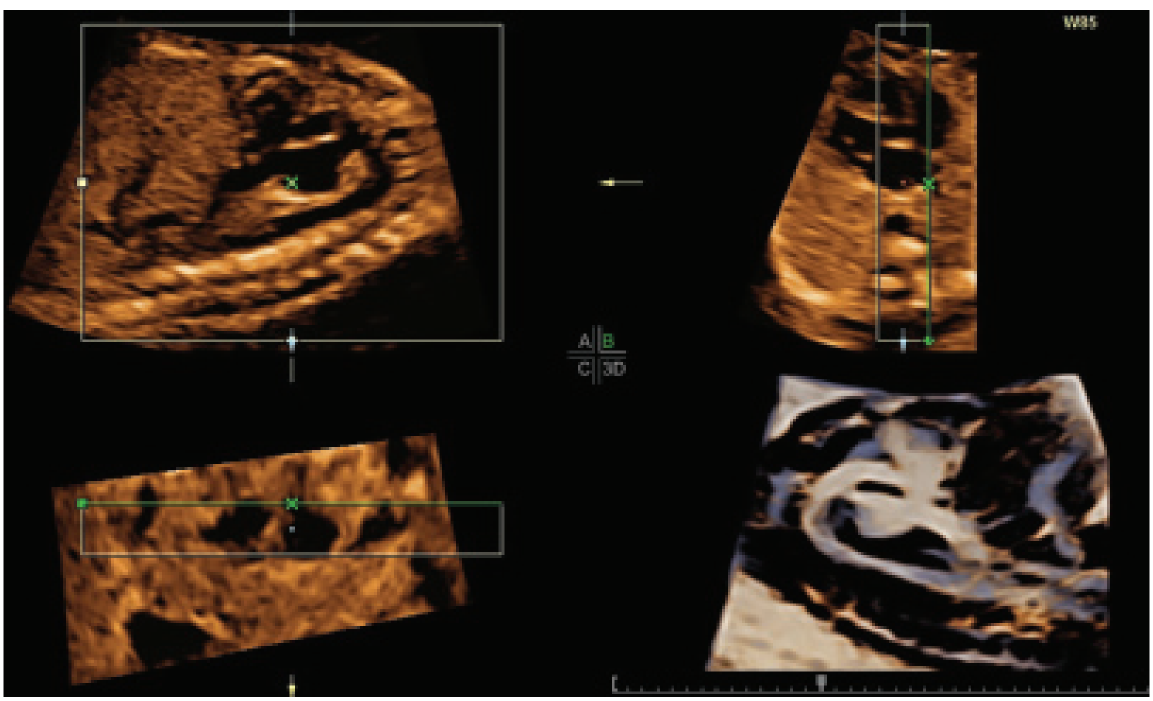


Figure 21.45: Multiplanar view coupled with inversion mode rendering from a STIC volume obtained by a sagittal technique of acquisition

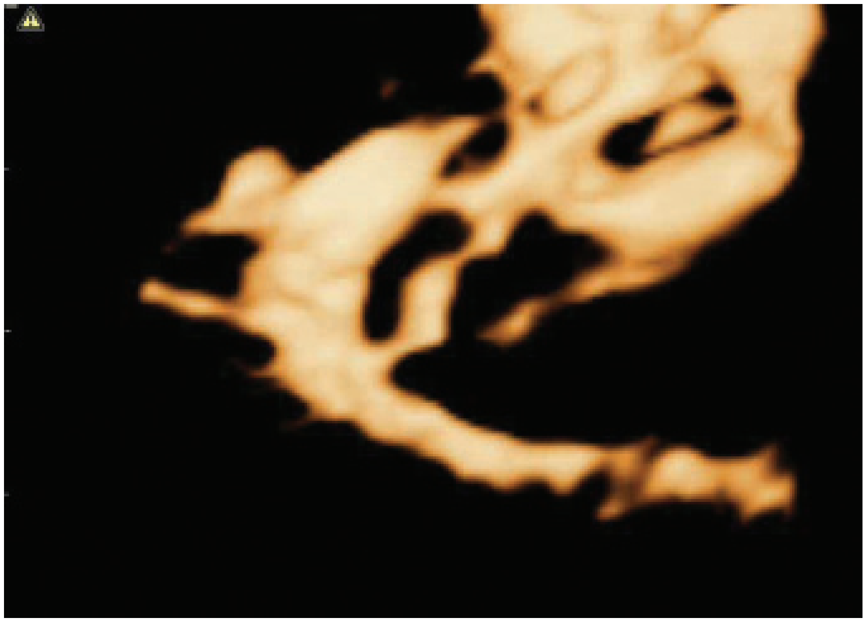


Figure 21.46: Tetralogy of Fallot—aortic arch in inversion mode. Notice the tortuous course of the ductus arteriosus, which attaches to the ventral part of the aorta

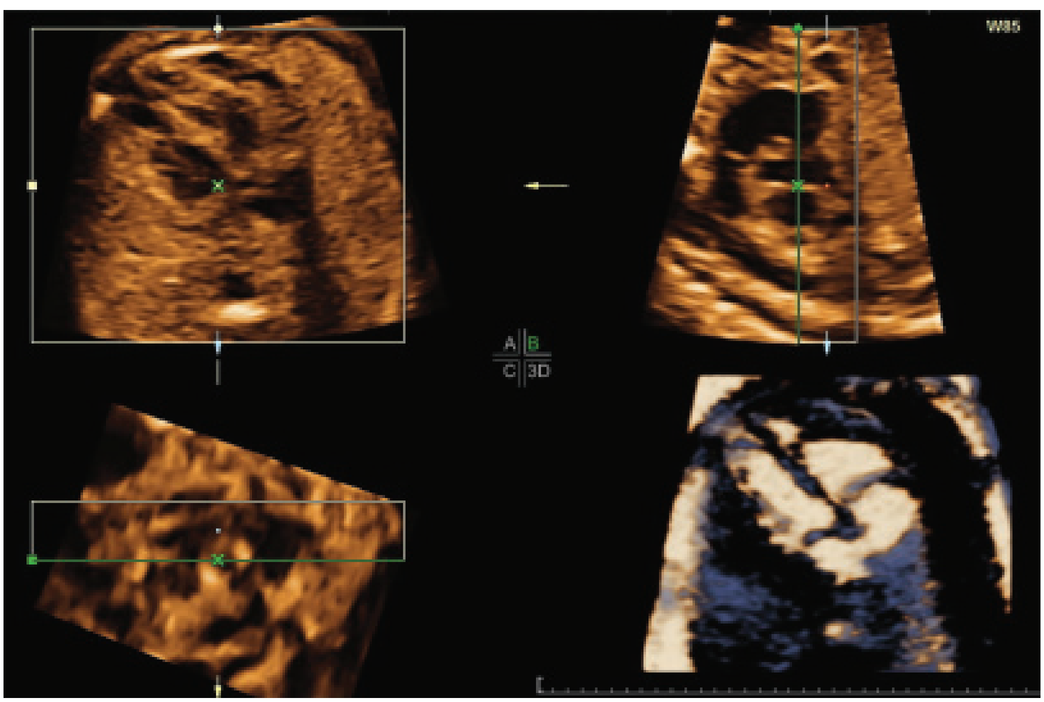
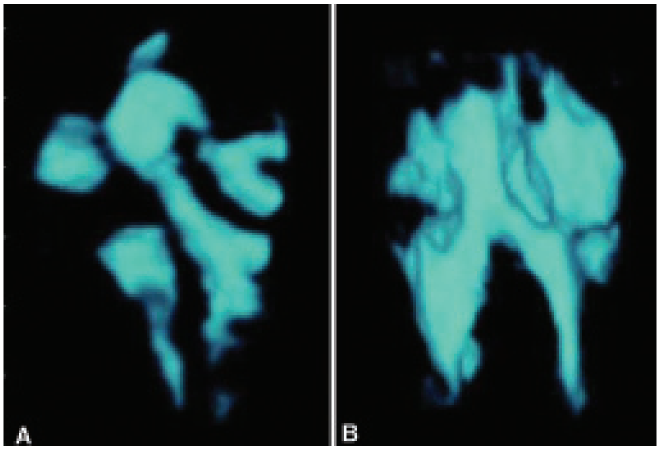


Figure 21.47: Multiplanar view coupled with inversion mode rendering from a STIC volume obtained by a transverse technique of acquisition. A narrow region of interest is utilized in the B and C planes. The relationship between cardiac chambers is clearly demonstrated



Figures 21.48A and B: Inversion mode rendering with the application of a narrow region of interest box focused on the left outflow tract. (A) An overriding aorta; (B) A normal left outflow

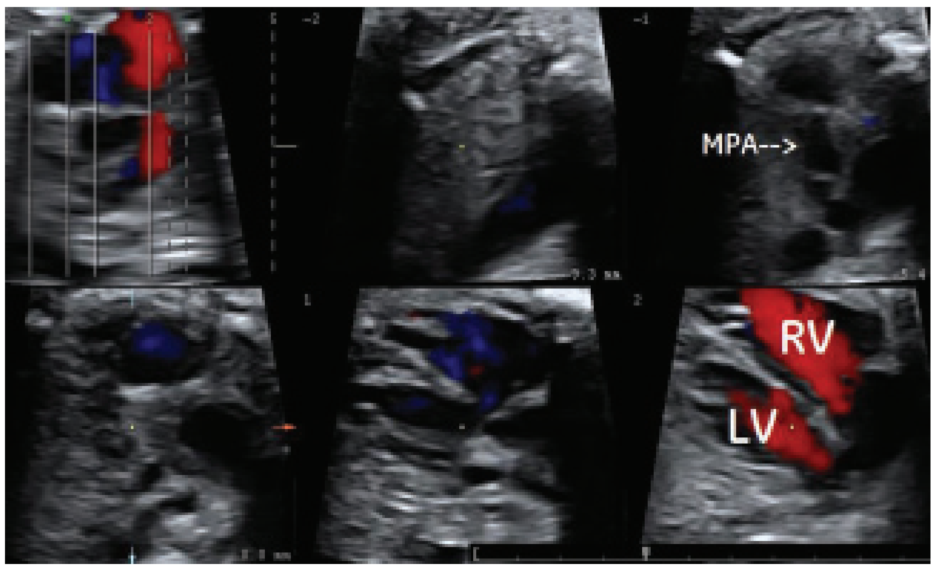


Figure 21.49: Pulmonary atresia with ventricular septum defect in tomographic ultrasound imaging in diastole (LV=left ventricle; RV=right ventricle; MPA=main pulmonary artery)

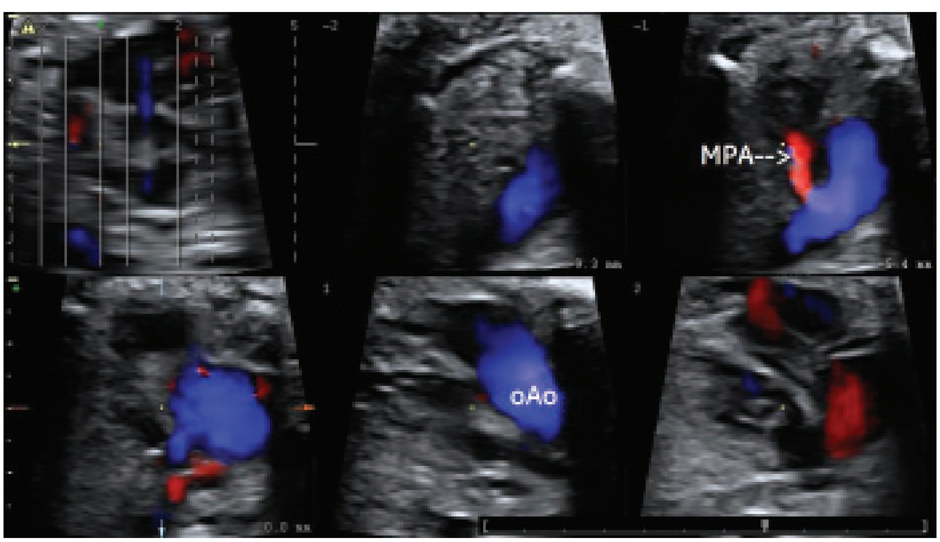
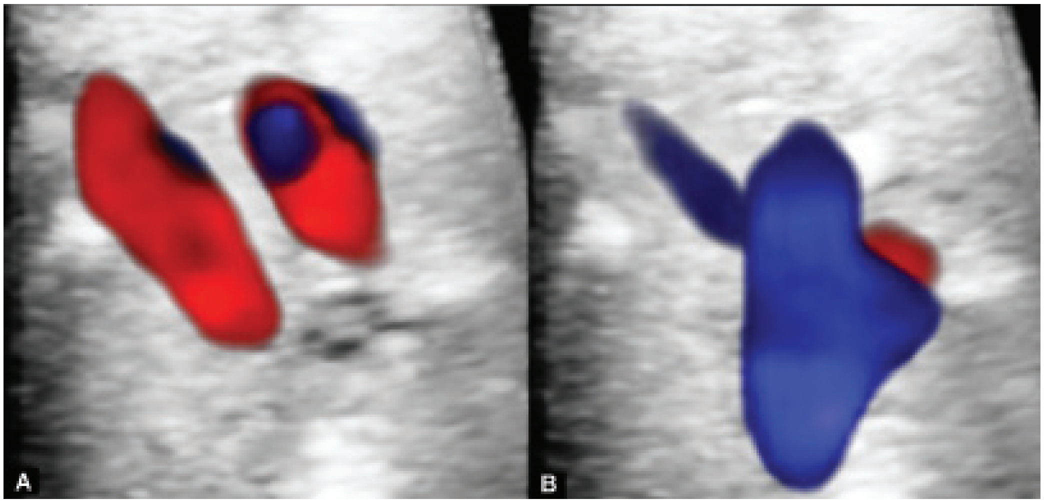


Figure 21.50: Pulmonary atresia with ventricular septum defect in tomographic ultrasound imaging in systole (MPA=main pulmonary artery; oAo=overriding aorta)



Figures 21.51A and B: Glass body rendering using a deep region of interest box

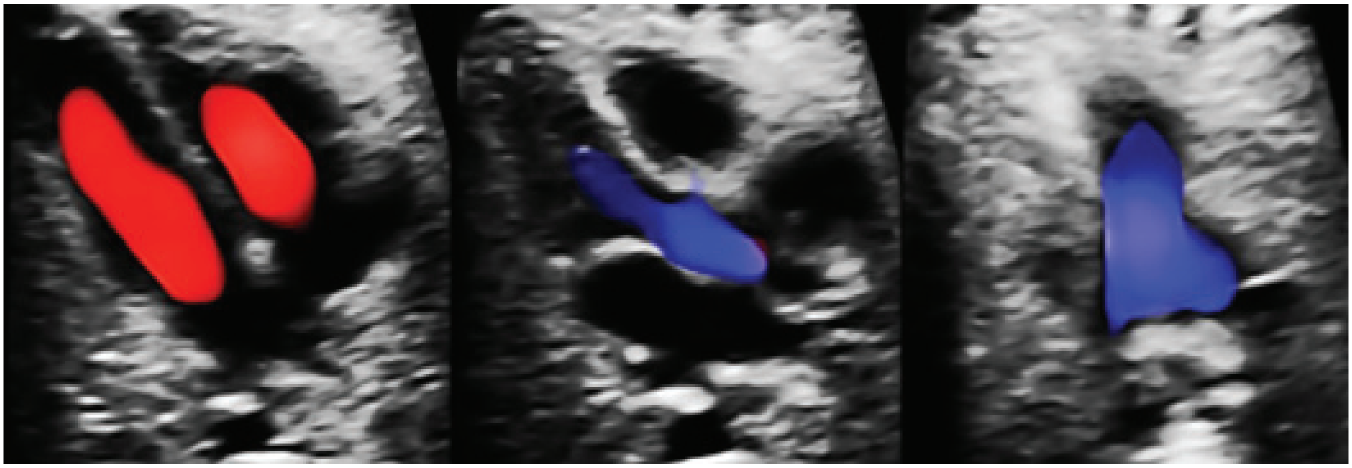
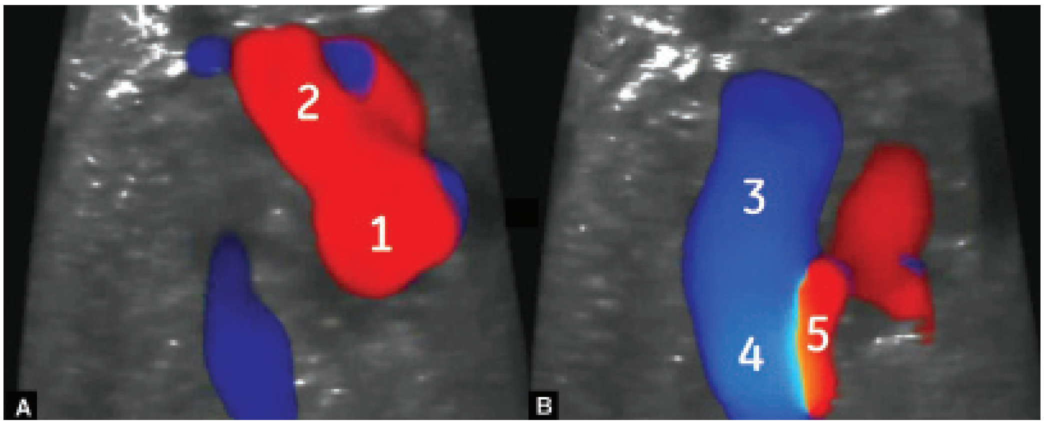
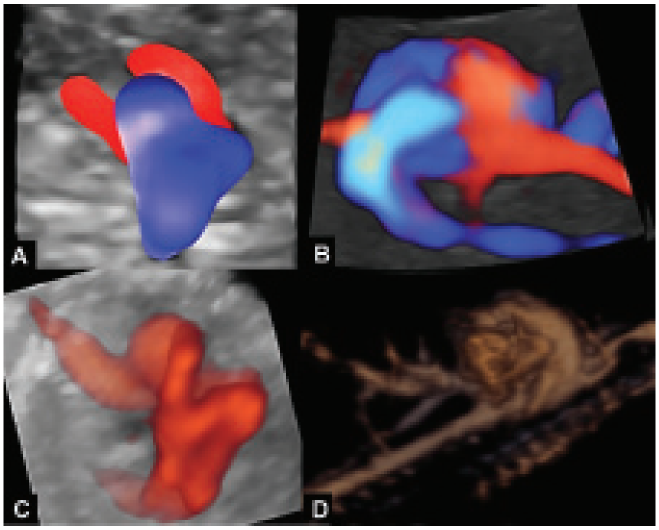


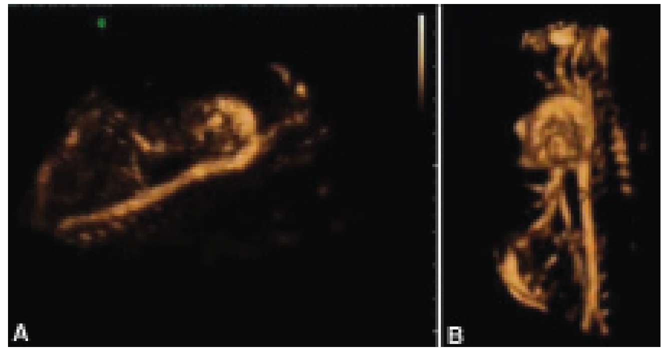
Figure 21.52: Glass body rendering using a shallow region of interest box



Figures 21.53A and B: Hypoplastic left heart in glass body rendering mode. (A) Diastole—no inflow to the left ventricle is noted (1-right atrium; 2-right ventricle); (B) Systole (3-main pulmonary artery; 4-ductus arteriosus; 5-transverse section through aortic arch demonstrating retrograde flow)



Figures 21.54A to D: Three-dimensional images of the fetal heart showing the variety of flow mapping modalities. (A) Spatial and temporal image correlation (STIC) color Doppler; (B) STIC HD flow (bidirectional Power Doppler) displayed in transparent glass body rendering mode; (C) STIC Power Doppler displayed in transparent glass body rendering mode; (D) STIC B-flow



Figures 21.55A and B: B-flow imaging. (A) A fetal heart and surrounding vessels in two-dimensional B-flow mapping during the process of STIC acquisition; (B) Three-dimensional image of the same fetal heart after acquisition of a STIC volume dataset

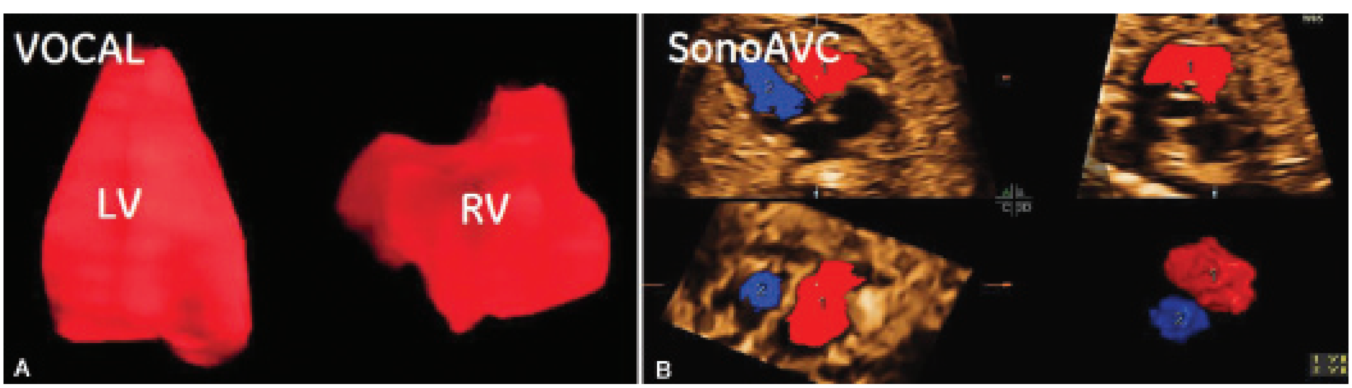
independent B-mode option based on the use of the highest frequencies transmitted by the probe allowing for the enhancement of signals representing blood flow while simultaneously ignoring signals from stationary tissue. This allows for the visualization of vascular information independent of tissue information **(Figs 21.55A and B)**.

VOCAL, SonoAVC

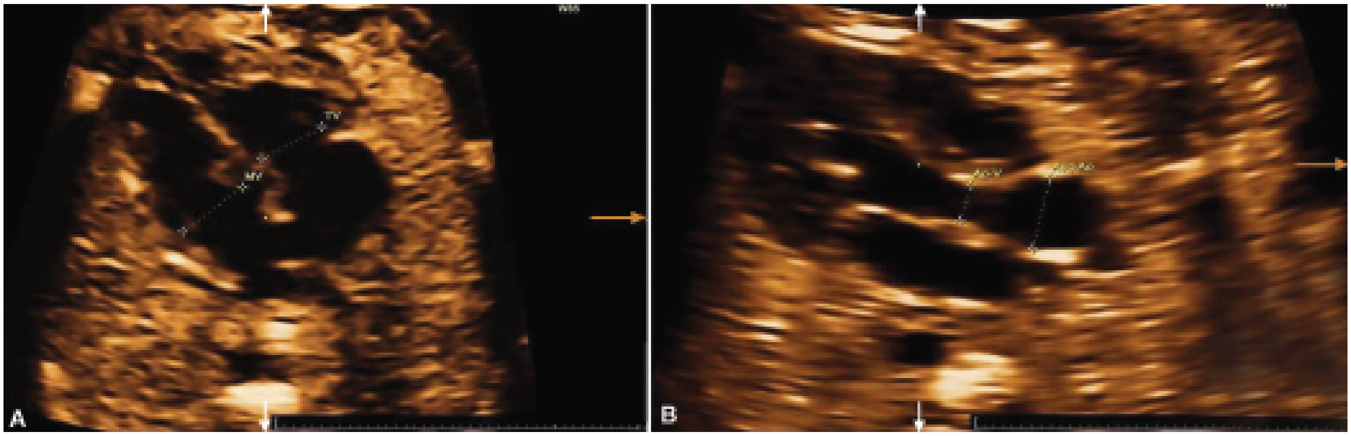
Vocal and SonoAVC are both methods, which are available for volumetric calculations with STIC.[23,24] An application of this is to assess cardiac chamber volumes in various phases of the cardiac cycle. The calculations of these algorithms have been validated on artificial models. The use of the VOCAL method requires mechanical tracing by the examiner of whatever structure one wishes to perform a volumetric measurement of. SonoAVC is also utilized for volume calculation however it is a machine-derived volume, which can only be used for volume measurements of fluid structures. When volumetric measurements are performed in both systole and diastole, calculations of cardiac stroke volume can be easily derived **(Figs 21.56A and B)**.

Z-scores

Measurements can be made from STIC volumes in the same manner as classic 2D measurements. Since 2006, Z-score measurements have been available for use in relating cardiac measurements to gestational age. This method simplifies the expression of measurements providing the examiner with calculations in standard deviations rather than in millimeters in relation to any given gestational age and measured bronchopulmonary



Figures 21.56A and B: Volume calculations of cardiac ventricles. (A) Done with VOCAL; (B) Uses SonoAVC



Figures 21.57A and B: Z-score measurement technique performed in a STIC volume. (A) Normal standard deviations at the level of the atrioventricular valves; (B) Dilatation of the ascending aorta (measurements indicate approximately + 3SD) in a case of valvular aortic stenosis

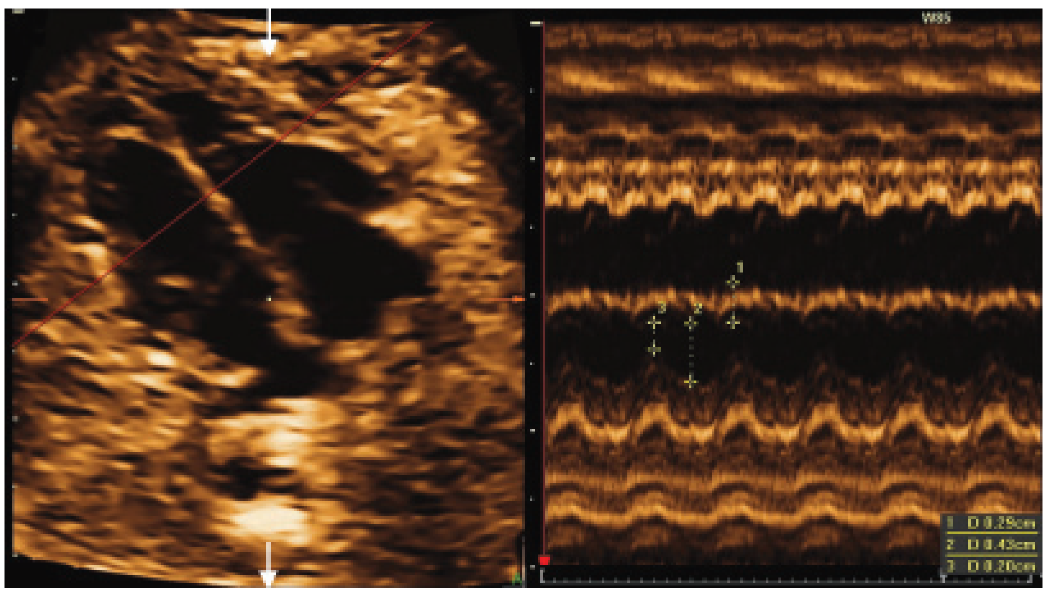


Figure 21.58: STIC M-mode technique has the capability of placing arbitrary anatomic lines allowing for M-mode measurements to be taken from positions that are not available by two-dimensional imaging

dysplasia (BPD) and femur length (FL). It simplifies the precise quantification of the size of fetal cardiac structures **(Figs 21.57A and B)**.[25]

STIC M-mode

In 2009, STIC M-mode was introduced into clinical practice allowing for the capability of placing arbitrary M-mode lines into the volume dataset allowing for M-mode measurements to be taken from positions that are not available by 2D imaging **(Fig. 21.58)**.

Volume Computer-Aided Diagnosis (VCAD)

In 2006, the STIC VCAD technique was introduced for use with fetal heart imaging between 18 and 23 weeks of gestation. In this time period, the heart increases in size as the whole but relationships of the sizes of the main cardiac structures remain similar. Because of this fact an automated system can be used during this time to aid in the identification of basic cardiac views.[26] After a volume is achieved, the examiner must orient the A plane so that the four-chamber view is showing and

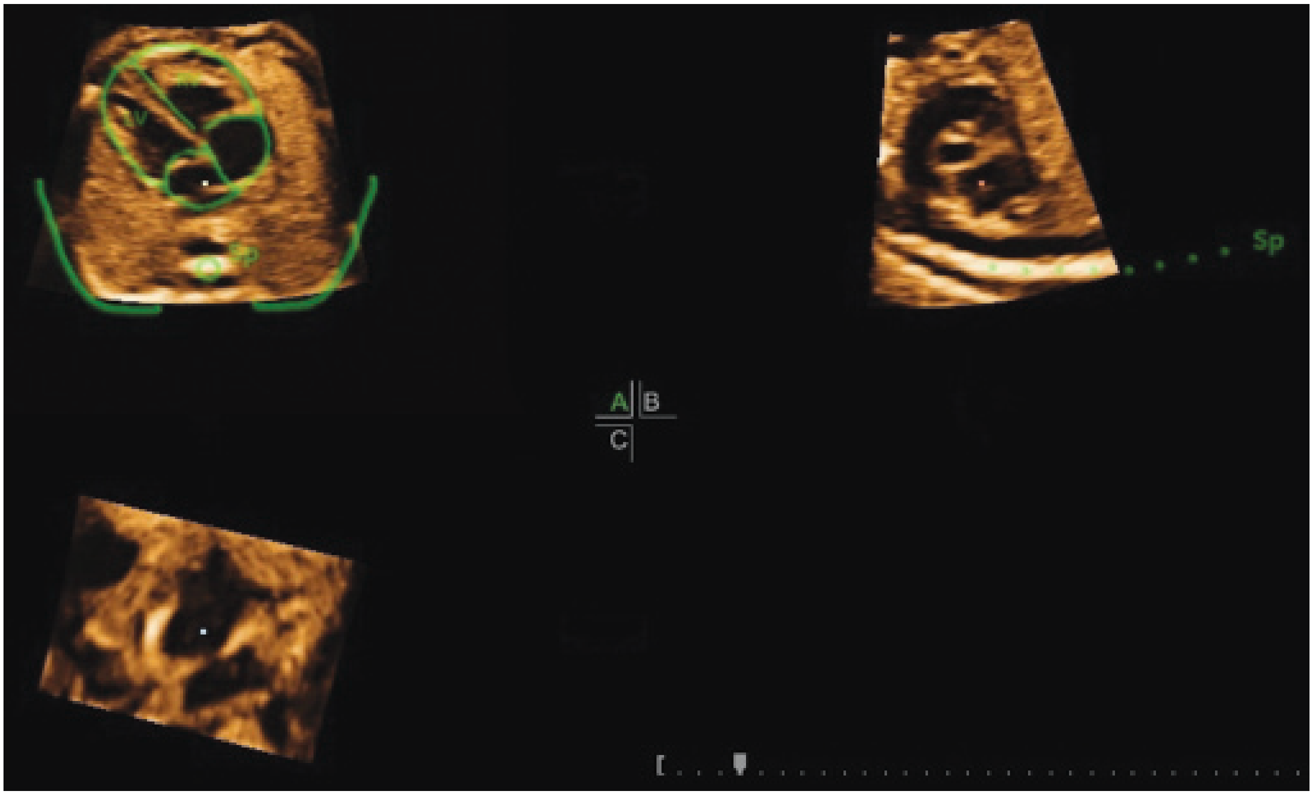


Figure 21.59: Volume computer-aided diagnosis modality. Initial stage after simplified orientation according to templates marked with green line (in reference images A and B)

the apex of the heart is to the left. When VCAD is enabled, a green template of a heart, ribs and spine appears overlying the A plane image and a green dotted line appears on the B plane representing the sagittal spine. The examiner lines up the volume in the A and B planes with the green templates, which essentially orientates the volume into an optimum position **(Fig. 21.59)**.

Because the volume is now in a standardized position, the VCAD algorithm can automatically identify the following cardiac views: left outflow tract (Cardiac 1); right outflow tract (Cardiac 2); upper abdominal (Cardiac 3); long-axis caval (Cardiac 4); ducal arch (Cardiac 5); and aortic arch (Cardiac 6).

The VCAD cannot identify and align views correctly in the cases of cardiac malformations or mediastinal shift **(Figs 21.60A to F)**.

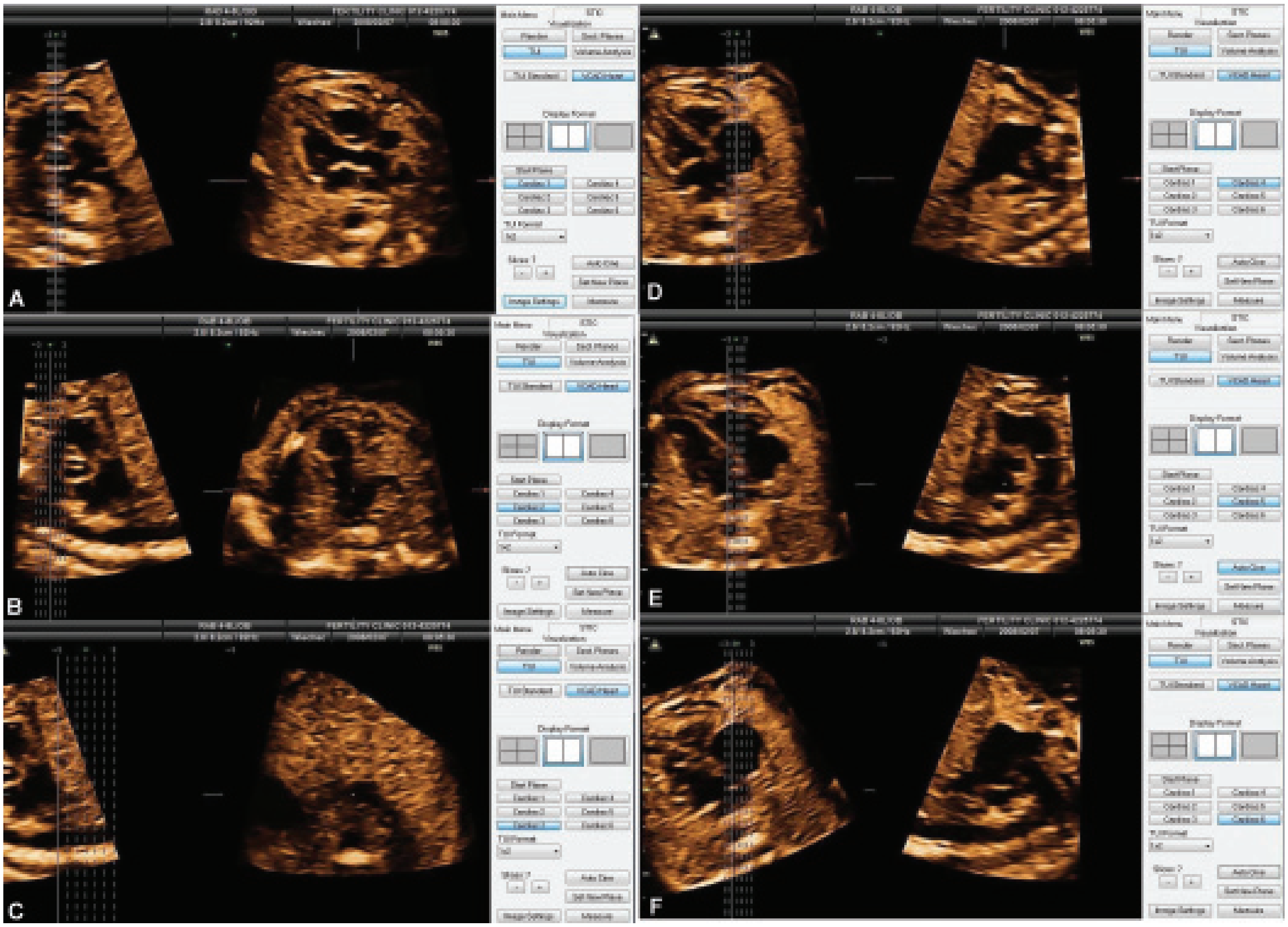
CONCLUSION

Spatial and temporal image correlation is one of the newest diagnostic tools in fetal echocardiography. It adds, both figuratively and literally, another dimension in the prenatal diagnostics of congenital heart disease.

The STIC has a number of advantages over 2D fetal echocardiography, some of which are listed below:

- The spatial evaluation of cardiac structures in multiplanar, tomographic imaging and rendering
- The ability to store spatial images of the fetal heart in a dynamic form, cine loop, accessible for unlimited evaluation from many angles
- Access to the acquisition preview: meaning demonstration of the cardiac views, which are being acquired in real time presented in slow motion. The preview has the advantage in volume acquisition quality assessment
- The ability for multiple consultations without the presence of the patient, including internet and teleconsultations
- The STIC is a good method for image archiving and retrieval
- The STIC is an exceptional teaching tool.[4,5,27]

Like every modality STIC also has its limitations. The STIC is not useful in the evaluation of fetal arrhythmias. This is because of the algorithm that STIC uses.



Figures 21.60A to F: Volume computer-aided diagnosis modality in the final stage. Automated identification of cardiac views. (A) Left outflow tract; (B) Right outflow tract; (C) Upper abdominal view; (D) Long axis caval view; (E) Ductal arch; (F) Aortic arch

Technical limitations include a very active fetus, as STIC has a long acquisition time. Motion artifacts from fetal movements may cause volume datasets to become nondiagnostic. The examiner's patience and experience can overcome some of these limitations by an understanding of appropriate acquisition planes. Training in STIC acquisition should begin with normal cases and only in good scanning conditions. Two-dimensional image optimization and learning how to avoid motion artifacts and shadowing from the ribs and limbs are the basics of training. Unsuccessful acquisitions should be repeated and volume datasets reviewed individually or among team members.

Cardiac 3D imaging and STIC technology have made a great contribution in modern fetal echocardiography. They allow for a detailed segmental evaluation of the fetal heart. A sequential 2D plane-by-plane analysis of the fetal heart was initially proposed by Yoo in 2D imaging.[28] Development of this 2D concept is now similar to the number of publications on STIC.[7,12,29,30] Good quality STIC volumes are ideal for segmental analysis of the fetal heart when the examiner is skilled in this modality. A good example is a publication by Vinals and co-workers, which summarized and simplified an approach to the diagnosis of d-transposition of the great arteries based on the planes of the four-chamber, five-chamber, three-vessel, and three vessels and trachea views obtained from a STIC volume.[28] Before the segmental technique, oblique sections were commonly used for prenatal cardiac diagnosis, which was confusing in some cases as it was highly operator dependent. For most congenital heart defects, a sequential segmental analysis is now recommended. In one of the first studies on STIC, 94.2% of various fetal cardiac views and structures were identified in the datasets.[3] Our discussion on STIC however would not be complete without reporting that one article did not find STIC to be helpful. Wanitpongpan and co-workers showed inferior quality of STIC volumes and poor measurement accuracy of great vessel diameters acquired by a general obstetrician when compared with 2D fetal echocardiography performed by a pediatric cardiologist.[31] Conclusions from this study may have come from the use of large acquisition angles of 30° in STIC mode for fetal hearts between 17 and 21 weeks of gestation and preacquisition 2D settings. The introduction of STIC widened the horizons of fetal echocardiography, improved the detection of congenital heart defects and increased the education in cardiac scanning. To conclude, STIC, like other 3D techniques, is nothing more than the rewriting of 2D information into volume datasets. The better the 2D imaging the better the quality of STIC volumes. We encourage the use of STIC as a routine element of the standard fetal cardiac evaluation.

REFERENCES

1. Meyer-Wittkopf M, Cooper S, Vaughan J, et al. Three-dimensional (3D) echocardiography analysis of congenital heart disease in the fetus: comparison with cross-sectional (2D) fetal echocardiography. Ultrasound Obstet Gynecol. 2001;17(6): 485-92.
2. Bega G, Kuhlman K, Lev-Toaff A, et al. Application of three-dimensional ultrasonography in the evaluation of the fetal heart. J Ultrasound Med. 2001;20(4):307-13.
3. Viñals F, Poblete P, Giuliano A. Spatio-temporal image correlation (STIC): a new tool for the prenatal screening of congenital heart defects. Ultrasound Obstet Gynecol. 2003;22(4):388-94.
4. DeVore GR, Falkensammer P, Sklansky MS, et al. Spatio-temporal image correlation (STIC): new technology for evaluation of the fetal heart. Ultrasound Obstet Gynecol. 2003;22(4):380-7.
5. Yagel S, Cohen SM, Shapiro I, et al. 3D and 4D ultrasound in fetal cardiac scanning: a new look at the fetal heart. Ultrasound Obstet Gynecol. 2007;29(1):81-95.
6. Goncalves LF, Lee W, Chaiworapongsa T, et al. Four-dimensional ultrasonography of the fetal heart with spatio-temporal image correlation. Am J Obstet Gynecol. 2003; 189(6):1792-802.
7. Espinoza J, Romero R, Kusanovic JP, et al. Standardized views of the fetal heart using four-dimensional sonographic and tomographic imaging. Ultrasound Obstet Gynecol. 2008;31(2):233-42.
8. Paladini D. Standardization of on-screen fetal heart orientation prior to storage of spatio-temporal image correlation (STIC) volume datasets. Ultrasound Obstet Gynecol. 2007;29(6):605-11.
9. Abuhamad A. Automated multiplanar imaging: a novel approach to ultrasonography. J Ultrasound Med. 2004; 23(5):573-6.
10. Goncalves LF, Espinoza J, Romero R, et al. Four-dimensional fetal echocardiography with spatiotemporal image correlation (STIC): a systematic study of standard cardiac views assessed by different observers. J Matern Fetal Neonatal Med. 2005;17(5):323-31.
11. DeVore GR, Polanco B, Sklansky MS, et al. The 'spin' technique: a new method for examination of the fetal outflow tracts using three-dimensional ultrasound. Ultrasound Obstet Gynecol. 2004;24(1):72-82.
12. Paladini D, Vassallo, Sglavo G, et al. The role of spatio-temporal image correlation (STIC) with tomographic ultrasound imaging (TUI) in the sequential analysis of fetal congenital heart disease. Ultrasound Obstet Gynecol. 2006;27(5):555-61.
13. Rizzo G, Capponi A, Vendola M, et al. Role of tomographic ultrasound imaging with spatiotemporal image correlation for identifying fetal ventricular septal defects. Ultrasound Med. 2008;27:1071-5.
14. Goncalves LF, Espinoza J, Romero R, et al. Four-dimensional ultrasonography of the fetal heart using a novel tomographic ultrasound imaging display. J Perinat Med. 2006;34(1):39-55.
15. Chaoui R, Heling KS. New developments in fetal heart scanning: three- and four-dimensional fetal echocardiography. Seminars in Fetal and Neonatal Medicine. 2005; 10:567-77.
16. Yagel S, Benachi A, Bonnet D, et al. Rendering in fetal cardiac scanning: the intracardiac septa and the coronal atrioventricular valve planes. Ultrasound Obstet Gynecol. 2006;28(3):266-74.
17. Vinals F, Pacheto V, Giuliano A. Fetal atrioventricular valve junction in normal fetuses and in fetuses with complete atrioventricular septal defect assessed by 4D volume rendering. Ultrasound Obstet Gynecol. 2006;28(1):26-31.
18. Goncalves LF, Espinoza J, Lee W, et al. Three- and four-dimensional reconstruction of the aortic and ductal arches using inversion mode: a new rendering algorithm for visualization of fluid-filled anatomical structures. Ultrasound Obstet Gynecol. 2004;24(6):696-8.
19. Espinoza J, Goncalves LF, Lee W, et al. The use of the minimum projection mode in 4-dimensional examination of the fetal heart with spatiotemporal image correlation. J Ultrasound Med. 2004;23(10):1337-48.
20. Chaoui R, Hoffmann J, Heling KS. Three-dimensional (3D) and 4D color Doppler fetal echocardiography using spatio-temporal image correlation (STIC). Ultrasound Obstet Gynecol. 2004;23(6):535-45.
21. Goncalves LF, Romero R, Espinoza J, et al. Four-dimensional ultrasonography of the fetal heart using color Doppler spatiotemporal image correlation. J Ultrasound Med. 2004; 23(4):473-81.
22. Volpe P, Campobasso G, Stanziano A, et al. Novel application of 4D sonography with B-flow imaging and spatio-temporal image correlation (STIC) in the assessment of the anatomy of pulmonary arteries in fetuses with pulmonary atresia and ventricular septal defect. Ultrasound Obstet Gynecol. 2006;28(1):40-6.
23. Messing B, Cohen SM, Valsky DV, et al. Fetal cardiac ventricle volumetry in the second half of gestation assessed by 4D ultrasound using STIC combined with inversion mode. Ultrasound Obstet Gynecol. 2007;30(2):142-51.

24. Tutschek B, Sahn DJ. Semi-automatic segmentation of fetal cardiac cavities: progress towards an automated fetal echocardiogram. Ultrasound Obstet Gynecol. 2008; 32(2):176-80.
25. Devore GR. The use of Z-scores in the analysis of fetal cardiac dimensions. Ultrasound Obstet Gynecol. 2005;26(6): 596-8.
26. Rizzo G, Capponi A, Cavicchioni O, et al. Application of automated sonography on four-dimensional volumes of fetuses with transposition of the great arteries. J Ultrasound Med. 2008;27(5):771-6.
27. Vinals F, Mandujano L, Vargas G, et al. Prenatal diagnosis of congenital heart disease using four-dimensional spatio-temporal image correlation (STIC) telemedicine via an Internet link: a pilot study. Ultrasound Obstet Gynecol. 2005;25(1):25-31.
28. Yoo SJ, Lee YH, Cho KS, et al. Sequential segmental approach to fetal congenital heart disease.1999;9(4):430-44.
29. Viñals F, Ascenzo R, Poblete P, et al. Simple approach to prenatal diagnosis of transposition of the great arteries. Ultrasound Obstet Gynecol. 2006;28(1):22-5.
30. Goncalves LF, Lee W, Espinoza J, Romero R. Examination of the fetal heart by four-dimensional (4) ultrasound with spatio-temporal image correlation (STIC). Ultrasound Obstet Gynecol. 2006;27:336-48.
31. Wanitpongpan P, Kanagawa T, Kinugasa Y, et al. Spatio-temporal image correlation (STIC) used by general obstetricians is marginally clinically effective compared to 2D fetal echocardiography scanning by expert. Prenat Diagn. 2008;28:923-8.