Four-chamber view and ‘swing technique’ echo: a novel and simple algorithm to visualize standard fetal echocardiographic planes

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KEYWORDS: congenital heart disease; fetal heart; four-dimensional; prenatal diagnosis; STIC; ultrasound

ABSTRACT

Objective To describe a novel and simple algorithm (four-chamber view and swing technique (FAST) echo) for visualization of standard diagnostic planes of fetal echocardiography from dataset volumes obtained with spatiotemporal image correlation (STIC) and applying a new display technology (OmniView). Methods We developed an algorithm to image standard fetal echocardiographic planes by drawing four dissecting lines through the longitudinal view of the ductal arch contained in a STIC volume dataset. Three of the lines are locked to provide simultaneous visualization of targeted planes, and the fourth line (unlocked) ‘swings’ through the ductal arch image (‘swing technique’), providing an infinite number of cardiac planes in sequence. Each line generates the following plane(s): (a) Line 1: three-vessels and trachea view; (b) Line 2: five-chamber view and long-axis view of the aorta (obtained by rotation of the five-chamber view on the y-axis); (c) Line 3: four-chamber view; and (d) ‘swing line’: three-vessels and trachea view, five-chamber view and/or long-axis view of the aorta, four-chamber view and stomach. The algorithm was then tested in 50 normal hearts in fetuses at 15.3-40 weeks’ gestation and visualization rates for cardiac diagnostic planes were calculated. To determine whether the algorithm could identify planes that departed from the normal images, we tested the algorithm in five cases with proven congenital heart defects.

Results In normal cases, the FAST echo algorithm (three locked lines and rotation of the five-chamber view on the y-axis) was able to generate the intended planes (longitudinal view of the ductal arch, pulmonary artery, three-vessels and trachea view, five-chamber view, long-axis view of the aorta, four-chamber view) individually in 100% of cases (except for the three-vessel and trachea view, which was seen in 98% (49/50) and simultaneously in 98% (49/50). The swing technique was able to generate the three-vessels and trachea view, five-chamber view and/or long-axis view of the aorta, four-chamber view and stomach in 100% of normal cases. In the abnormal cases, the FAST echo algorithm demonstrated the cardiac defects and displayed views that deviated from what was expected from the examination of normal hearts. The swing technique was useful for demonstrating the specific diagnosis due to visualization of an infinite number of cardiac planes in sequence.

Conclusions This novel and simple algorithm can be used to visualize standard fetal echocardiographic planes in normal fetal hearts. The FAST echo algorithm may simplify examination of the fetal heart and could reduce operator dependency. Using this algorithm, inability to obtain expected views or the appearance of abnormal views in the generated planes should raise the index of suspicion for congenital heart disease. Copyright © 2011 ISUOG. Published by John Wiley & Sons, Ltd.

INTRODUCTION

Congenital heart disease has a prevalence of 8 per 1000 live births1, and is a major cause of infant and...
childhood mortality2. However, only 6–35% of congenital heart defects are identified prenatally1,3–14. Indeed, recent evidence indicates that despite almost universal access to sonographic screening during pregnancy, only 28% of major congenital heart defects were detected prenatally15. Anatomical defects of the fetal heart remain difficult to diagnose due to the complex structure of the organ and the high degree of expertise required for a thorough examination16–18. Prenatal detection of major forms of congenital heart disease may improve preoperative conditions19–23, survival after surgery21,24–28, and neurologic outcomes27. Therefore, the development of algorithms to facilitate examination of the fetal heart could increase detection rates of congenital heart disease and reduce associated perinatal morbidity and mortality.

Two-dimensional sonography of the fetal heart relies on obtaining standard anatomic planes, including the four-chamber view, left and right outflow tracts and three-vessels and trachea view28–33. However, successfully obtaining these views is highly dependent on operator skills and experience. A solid body of evidence34–60 indicates that three-dimensional (3D) and four-dimensional ultrasonography (4D-US) with spatiotemporal image correlation (STIC) can facilitate visualization of standard cardiac diagnostic planes, reducing operator dependency. Four-dimensional STIC technology allows the acquisition of a volume dataset from the fetal heart, and displays a cine loop of a complete single cardiac cycle in motion. OmniView® (GE Medical Systems, Kretztechnik GmbH, Zipf, Austria) is a new display technology for 3D- and 4D-US that allows interrogation of volume datasets and the simultaneous display of up to three independent (non-orthogonal) planes by manually drawing straight or curved lines from any direction or angle. This is in contrast to tomographic ultrasound imaging (TUI), which allows volume datasets to be automatically sliced, displaying multiple parallel images. However, the lines that produce these slices are rigid, equidistant from each other, and cannot be rotated or drawn manually.

We describe herein a novel and simple algorithm (using STIC and OmniView) to visualize the standard diagnostic planes of fetal echocardiography: the Four-chamber view And Swing Technique (FAST) echo. The potential diagnostic value of the FAST echo algorithm is also illustrated in five cases of congenital heart defect.

METHODS

Using STIC technology (Voluson 730 Expert, Voluson E8 Expert; GE Medical Systems, Kretztechnik GmbH, Zipf, Austria), 4D volume datasets of the fetal heart were acquired from an apical four-chamber view with hybrid mechanical and curved array transducers (2–5 or 4–8 MHz) by transverse sweeps through the fetal chest in patients examined at our unit. Acquisition time ranged from 7.5 to 15 s, and the angle of acquisition ranged between 20° and 40°, depending on fetal motion and gestational age. All patients had been enrolled in research protocols approved by the Institutional Review Board of the National Institute of Child Health and Human Development and by the Human Investigation Committee of Wayne State University. All women had provided written informed consent for the use of ultrasound images for research purposes.

Volume datasets considered by the investigators to be of adequate quality were selected: the fetal spine was positioned between the 5- and 7-o’clock positions, minimizing the possibility of shadowing from the ribs or spine, and minimal or no motion artifacts were observed on the sagittal plane. Volume datasets that did not contain the upper mediastinum were excluded. Only one volume dataset per patient was included in the study.

A standardized algorithm was developed from normal fetal hearts for the analysis of volume datasets to obtain the standard diagnostic planes of fetal echocardiography. This was accomplished by retrospectively reviewing datasets offline using 4D View (Version 9.1.1.0; GE Healthcare, Waukesha, WI, USA) and applying OmniView technology. The algorithm was then tested in 50 normal hearts in fetuses at 15.3–40 weeks’ gestation. OmniView allows interrogation of volume datasets (3D or 4D) and the simultaneous display of up to three independent (non-orthogonal) planes by manually drawing straight or curved lines from any direction or angle. The lines that can be selected are: ‘line’, ‘curve’, ‘polyline’ and ‘trace’. Once the line is complete, it may be rotated or moved through any part of the image. Therefore, using OmniView to dissect volume datasets has the following features: multiple independent planes can be generated which are not necessarily parallel to each other; the planes can be targeted to display the anatomical areas of interest; informative views are easier to obtain than with other methods involving complex manipulation of volume datasets, and the informative planes are visualized immediately; ‘virtual’ planes can be generated that cannot be obtained by using TUI or the standard multplanar display because curvilinear planes can be imaged; images may be displayed as a plane, or in conjunction with volume contrast imaging (VCI) (GE Medical Systems, Kretztechnik, Zipf, Austria), an application of 3D-US that displays a thin slice from an acquired volume where the slice thickness can be adjusted to improve contrast resolution; and through VCI, images can be viewed from either side of the section plane.

Representative volumes from normal fetuses at 26, 28 and 30 weeks’ gestation were used to illustrate the FAST echo algorithm for this paper. Additionally, the algorithm was applied to volume datasets from five fetuses with congenital heart defects (confirmed postnatally by echocardiography, surgery, or during autopsy): tricuspid atresia with ventricular septal defect (hypoplastic right ventricle) (21 weeks’ gestation); tetralogy of Fallot (33 weeks’ gestation); complete atroventricular canal defect/transposition of the great vessels (30 weeks’ gestation); transposition of the great vessels with normal four-chamber view (20 weeks’ gestation); and hypoplastic left heart/double outlet right ventricle/transposition of great vessels/heterotaxy (19 weeks’ gestation).
RESULTS

Description of FAST echo algorithm

The acronym ‘FAST’ represents the acquisition of all STIC volume datasets from the four-chamber view – the ‘swing technique’ – and also refers to the performance speed of the algorithm. The algorithm consists of drawing four dissecting lines through the longitudinal view of the ductal arch image; three of the lines are locked to provide simultaneous visualization of targeted planes, and the fourth line (unlocked) ‘swings’ through the ductal arch image (‘swing technique’), providing an infinite number of cardiac planes in sequence. Using this algorithm, the following planes are visualized: longitudinal view of the ductal arch; pulmonary artery; three-vessels and trachea view; five-chamber view; long-axis view of the aorta; four-chamber view; and stomach.

All STIC volume datasets are displayed using the multiplanar modality, which demonstrates three orthogonal planes (panels A, B, and C). The FAST echo algorithm was performed in the following steps:

1) Volume datasets are adjusted to display the apical four-chamber view in panel A, where the cross-section of the aorta is aligned with the crux of the heart (6 o’clock position) (Figure 1). The left ventricle is always oriented towards the left side of the image.

2) The reference dot is positioned in the lumen of the aorta, which allows visualization of a coronal view of the descending aorta in panel C (Figure 1). The image is rotated in panel C so that the aorta is imaged in a vertical or semi-vertical position in order to visualize the longitudinal view of the ductal arch in panel B (Figure 2). The next step is to place the reference dot in the crux of the heart (panel A) (Figure 3).

3) The speed of the STIC cine-loop is then decreased to 50% to facilitate drawing of the independent lines and visualization of the diagnostic planes when using the swing technique. The longitudinal view of the ductal

Figure 1 Volume datasets are adjusted to display the apical four-chamber view in panel A, where the cross-section of the aorta is aligned with the crux of the heart (6 o’clock). The left ventricle is always oriented towards the left side of the image. The reference dot is positioned in the lumen of the aorta, and this allows visualization of a coronal view of the descending aorta in panel C.
arch image in panel B (Figure 3) is selected, and the OmniView option is activated. Three independent lines (Lines 1–3) are drawn through the ductal arch image from the top to the bottom of the image, and then locked into place, so that the ‘lollipop’ is oriented downwards. Each of the lines is activated by clicking first on their respective button in 4D View. To ensure that the lollipop is oriented downwards, the arrowhead pointing to the right (located in the ‘Orientation’ panel of 4D View) should be clicked. At the starting point of each of the lines, the mouse should be clicked only once and released, and a cursor will appear at the inferior end of the line. This allows the operator to visualize the line as it is being drawn, as well as the corresponding image simultaneously. Lines are locked by clicking the mouse again, and the cursor will become a lollipop. Once the lines are locked, they can be rotated or moved through any part of the image. The end result is that each line will generate various cardiac diagnostic planes.

The following is a step-by-step description of the images generated by each line:

1) Three-vessels and trachea view: Line 1 (yellow) is a diagonal line drawn through the center of the pulmonary artery parallel to and equidistant from the walls, until it reaches the level of the descending aorta or below (Figure 4). Once Line 1 has been completed, it is locked into place by clicking the mouse. The pulmonary artery, aorta, superior vena cava and trachea will be visualized (Figure 4A).

2) Five-chamber view: Line 2 (fuchsia) is a vertical line (6 o’clock position) drawn through the right ventricle, center of the aorta (cross-section), left atrium and descending aorta (Figure 4). Once Line 2 has been completed, it is locked into place by clicking the mouse. The five-chamber view (both atria, both ventricles, aortic root) will be visualized (Figure 4B).

3) Four-chamber view: Line 3 (turquoise) is a vertical line (6 o’clock) drawn through the right ventricle, right external edge of the aorta (cross-section), left atrium and...
Figure 3 The reference dot is placed in the crux of the heart (panel A). Panel B shows the ductal arch.

and descending aorta (Figure 4). Once Line 3 has been completed, it is locked into place by clicking the mouse. The four-chamber view will be visualized (Figure 4C).

4) When the three lines are complete, the three-vessels and trachea view, five-chamber view and four-chamber view will be simultaneously visualized (along with the original longitudinal view of the ductal arch/pulmonary artery) (Figure 4) as a continuous cine-loop (Videos S1, S2).

5) Long-axis view of the aorta: ‘Rotation Y’ option is selected by clicking on the bar, and the five-chamber view is rotated by scrolling on the y-axis (to the right) until the long-axis view of the aorta can be seen (Figure 5). Next, a scroll on the y-axis (back to the left) is performed until the original views (three-vessels and trachea view, five-chamber view and four-chamber view) are again simultaneously visualized. The next step will be performance of the swing technique.

6) Swing technique: any of the three lines (yellow, fuchsia, turquoise) may function as the swing line, and is a matter of preference. At the top of the longitudinal view of the ductal arch image, the swing line is begun approximately above the center of the right ventricle and is fixed (but not locked) on this end only, by clicking the mouse once and releasing it. The line is then drawn from the top to the lower left-hand corner of the image, making sure it is lateral to the ductal arch (Figure 6); however, it should remain unlocked with the cursor (not the lollipop) visualized at its inferior end. The line is then swung like a pendulum unlocked through the entire image from the left to the right side, ending at the lower right-hand corner of the image (Video S3). The swing line may also be moved in the opposite direction (right to left) through the ductal arch image. As a result, the swing technique generates an infinite number of cardiac planes in sequence. The planes having diagnostic value (reported in sequence here from left to right) are: three-vessels and trachea view, long-axis view of the aorta, five-chamber view, four-chamber view and stomach. It is noteworthy that by keeping the line unlocked, the pivot point will remain at the superior end of the line and provide a wide field of view with undistorted images. However, once the line is locked, the pivot point will move to
After activating the OmniView option, the following images are generated by drawing three lines through the longitudinal view of the ductal arch image from top to bottom. (A) Three-vessels and trachea view; (B) five-chamber view; (C) Four-chamber view. Refer to text for a description of the technique.

1) The center of the line, and with line rotation the images may appear unrecognizable and non-informative.
2) Once the FAST echo algorithm has been completed, the cardiac views visualized as a continuous cine-loop include: longitudinal view of the ductal arch, pulmonary artery, three-vessels and trachea view, five-chamber view, long-axis view of the aorta, four-chamber view and stomach. Video S4 demonstrates the entire FAST echo algorithm.
3) Depending on image quality, VCI can be activated with a slice thickness of 2 mm (Figure 7 and Video S5). This allows images to appear smoother and the interface between different tissues to be more apparent.

Visualization rates for echocardiographic planes in normal fetuses

The FAST echo algorithm (three locked lines and rotation of the five-chamber view on the y-axis) was able to generate the intended planes (longitudinal view of the ductal arch, pulmonary artery, three-vessels and trachea view, five-chamber view, long-axis view of the aorta and four-chamber view) individually in 100% of cases (except for the three-vessels and trachea view, which was seen in 98% (49/50)) and simultaneously in 98% (49/50). The swing technique was able to generate the three-vessels and trachea view, five-chamber view and/or long-axis view of the aorta, four-chamber view and stomach in 100% of normal cases. In one case where the three-vessels and trachea view was not seen using the three locked lines, the swing technique was able to generate this plane. Moreover, in 24% (12/50) of cases, the swing technique was able to generate the long-axis view of the aorta; therefore, rotation of the five-chamber view on the y-axis to generate this view was not mandatory. For the 76% (38/50) of cases where the swing technique depicted the five-chamber view (but not the long-axis view of the aorta), rotation of the five-chamber view on the y-axis to generate this view was required.

FAST echo algorithm applied to five cases of congenital heart disease

Tricuspid atresia with ventricular septal defect (hypoplastic right ventricle)

The FAST echo algorithm is illustrated in a fetus with tricuspid atresia and ventricular septal defect (hypoplastic right ventricle) at 21 weeks’ gestation (Figure 5).
**Figure 5** Long-axis view of the aorta. The rotation Y option is selected by clicking on the bar, and the five-chamber view is rotated by scrolling on the y-axis (to the right) until the long-axis view of the aorta is visualized. A scroll on the y-axis (back to the left) is performed until the original views (three-vessels and trachea view, five-chamber view, four-chamber view) are again simultaneously visualized (not shown). The next step will be performance of the ‘swing technique’. LV, left ventricle.

**Figure 6** ‘Swing technique’ (placement of ‘swing’ line). At the top of the longitudinal view of the ductal arch image, the ‘swing’ line is begun approximately above the center of the right ventricle and is fixed (but not locked) on this end only. The line is drawn from the top to the lower left hand corner of the image, making sure it is lateral to the ductal arch. The line should remain unlocked with the cursor (not the ‘lollipop’) visualized at its inferior end.

1. S1 and Video S6). The longitudinal view of the ductal arch appears abnormal, and both this view and the three-vessels and trachea view (Line 1) show a small pulmonary artery, consistent with pulmonic stenosis. Placement of Line 2 shows the aorta arising from the left ventricle and this is also evident with rotation of the
Figure 7 FAST echo algorithm and volume contrast imaging (VCI) applied to a normal fetus at 26 weeks of gestation. All three independent planes are simultaneously visualized (along with the longitudinal view of the ductal arch/pulmonary artery) after placement of three lines. VCI has been activated with a slice thickness of 2 mm and X-ray/surface smooth (Mix 100/0%) render mode applied. VCI allows images to appear smoother and the interface between different tissues to be more apparent. The render direction applies from the solid to the dotted line.

1. five-chamber view on the y-axis. The four-chamber view is abnormal (Line 3), with a large ventricular septal defect and a hypoplastic right ventricle. The tricuspid valve is atretic, while the mitral valve moves normally.

2. Tetralogy of Fallot
3. Figure S2 and Video S7 show a fetus with tetralogy of Fallot at 33 weeks’ gestation. Placement of Line 1 shows evidence of pulmonic stenosis with an abnormally thickened valve with poor motility, while placement of Line 2 shows the overriding aorta. Placement of Line 3 shows an abnormal four-chamber view with a large ventricular septal defect.

4. Complete atrioventricular canal defect, transposition of great vessels
5. The FAST echo algorithm is illustrated in a fetus with complete atrioventricular canal defect and transposition of the great vessels at 30 weeks’ gestation (Figure S3 and Video S8). In the longitudinal view of the ductal arch, the descending aorta is visualized, but not the pulmonary artery. The three-vessels and trachea view (Line 1) is abnormal, and shows the aorta, superior vena cava and trachea; however, the pulmonary artery is not visualized. In the five-chamber view (Line 2), the aorta is visualized anteriorly, while the pulmonary artery (confirmed by its bifurcation) arises leftward from the common ventricular chamber. The four-chamber view (Line 3) shows a common atrioventricular valve and a large septal defect involving both the atrial and ventricular septa.

6. Transposition of great vessels with the appearance of a normal four-chamber view
7. In this fetus with transposition of the great vessels at 20 weeks’ gestation (Figure S4, Video S9), the four-chamber view appears normal (Line 3). However, in the longitudinal view of the ductal arch, the pulmonary...
artery and ductus arteriosus are not visualized. The three-
vessels and trachea view (Line 1) is abnormal, and
shows only the aorta (arising from the right ventricle)
and superior vena cava. After placement of Line 2, the
pulmonary artery (confirmed by its bifurcation) is seen
exiting the left ventricle; with rotation of this image
on the y-axis, the aorta is visualized arising anteriorly
from the right ventricle (also shown by the swing
technique).

Hypoplastic left heart, double outlet right ventricle,
transposition of great vessels, heterotaxy

The FAST echo algorithm is illustrated in a fetus at
19 weeks’ gestation with a complex cardiac defect (Figure
S5 and Video S10). In the longitudinal view of the
ductal arch, the descending aorta is visualized, but the
pulmonary artery and ductus arteriosus are not seen. The
three-vessels and trachea view (Line 1) is abnormal, and
shows the aorta arising from the right ventricle. After
placement of Line 2, the pulmonary artery (confirmed
by its bifurcation) is seen to exit leftwards from the
gonocyst wall of the heart defect by defecting two great vessels
(which are also transposed – pulmonary artery leftwards,
aorta rightwards and anteriorly) exiting only the right
ventricle, and the stomach on the fetal right side.

Swing technique

Addition of the novel swing technique offers several
advantages to that of only drawing three locked lines
through the longitudinal view of the ductal arch image and
rotating the five-chamber view on the y-axis: the stomach
60 can be visualized, provided that the angle of acquisition
of the STIC volume is adequate; the three-vessels and
trachea view was generated only by the swing technique
(n = 1); in 24% (12/50) of cases, the swing technique was
able to generate the long-axis view of the aorta, therefore
rotation of the five-chamber view on the y-axis to generate
this view was not mandatory; and an infinite number of
cardiac planes are generated in sequence, which is useful
in demonstrating congenital heart defects. Moreover, by
using the swing line the operator can freely move the line
back and forth in any direction or at any angle, and at
any speed throughout the longitudinal view of the ductal
arch image according to their preference. And, when navig-
ating with the swing line, the user may lock this line at
any time (once the desired image has been generated) so
that the image can be studied, or stored/printed for the
medical record.

DISCUSSION

In a 1980 seminal study correlating sonographic planes
used in fetal echocardiography with anatomic sections of
the thorax in aborted fetuses at 12–28 weeks’ gestation,
Allan et al.62 reported that the sonographic plane most
easily obtained in the fetus was the four-chamber view
of the heart. Subsequently, the four-chamber view was
introduced as a screening tool for the prenatal detection
of congenital heart disease.63,64 It still remains the primary
screening method65–69, and has been included in the fetal
cardiac examination by regulatory organizations70–72.
Because of this the FAST echo algorithm was developed
based upon the acquisition of all STIC volume datasets
from the four-chamber view.

The use of 4D-STIC to evaluate the fetal heart is advan-
tageous because it allows the user to navigate within
the cardiac volume dataset and obtain all of the stan-
dard image planes necessary for diagnosis, and reduces
operator dependency43. However, retrieving informative
diagnostic planes from a volume dataset that contains infi-
nite planes is difficult. Moreover, many operators examine
the fetal heart without using a systematic approach.
Therefore, algorithms have been developed to systemati-
cally examine 3D/4D volume datasets, so that diagnostic
planes can be displayed in an efficient manner44,73,74.
Others have developed a system for the automated dis-
play of such planes from a volume dataset of the fetal
heart75.

We report here a novel and simple algorithm for the
visualization of standard fetal echocardiographic planes
from dataset volumes obtained by STIC and applying
OmniView technology. Indeed, five short-axis views,
including the three-vessels and trachea view, have been
proposed as a screening method for comprehensive fetal
echocardiography61. These sonographic planes can easily
be obtained by reslicing volume datasets of the fetal
heart obtained with STIC, as shown by the FAST echo
algorithm. In abnormal cases, the algorithm demonstrated
the cardiac defects and displayed views that deviated
from what was expected from the examination of normal
hearts. Moreover, the swing technique was useful in
demonstrating the specific diagnosis in abnormal cases,
due to visualization of cardiac planes in sequence by
moving the swing line through the volume dataset.
This concept has been described by Professor Lindsay
Allan, who reported the technique of performing fetal
echocardiography and obtaining transverse views of the
heart.28 With the fetus in a long-axis projection, the
ultrasound beam can be swept in a horizontal plane
from the stomach upwards to image the four-chamber
view, the aortic outflow tract, the pulmonary outflow
tract and the transverse view of the aortic arch in
sequence. Professor Allan showed that by using a manual
approach, a small change in the transducer angle can
produce all of these cardiac views, and will usually
demonstrate all the features necessary to define a normal
heart28.

It is important to stress that the FAST echo algorithm
will not be successful if: the quality of the STIC volume
dataset is inadequate; the volume dataset does not contain
information about the cardiac diagnostic planes; and a
true four-chamber view is not depicted in panel A (e.g. true
cross-section of the thorax, proper alignment in the axial
plane, etc.). Therefore, proper acquisition of STIC volume
datasets is essential in order to perform the algorithm. The algorithm may also be applied to a 3D static acquisition. However, this is not the optimal approach and there are important potential limitations; valvular motion and color Doppler sonography cannot be assessed, and because of cardiac motion static acquisition will combine information from different phases of the cardiac cycle, which may result in artifact and poor resolution/definition of key anatomic structures required for diagnosis (e.g. valves may appear blurred). Thus, by applying our algorithm to 3D static acquisitions, the success rate of visualizing standard fetal echocardiographic planes may be affected. Moreover, using STIC volume datasets allows the operator to select the part of the cardiac cycle where interrogation is to be undertaken, thus optimizing image quality (e.g. peak-systole will result in a well-defined image of the outflow tracts). This is the optimal method of examination of normal and abnormal fetal hearts.

The introduction of new display techniques, such as the one proposed herein, may simplify examination of the fetal heart and could reduce operator dependency. Even if one operator acquires the STIC volume dataset, it is possible for another operator to apply the FAST echo algorithm to it. Moreover, we found that the algorithm improves understanding of the 3D anatomy of the fetal heart, and therefore may be useful as a teaching tool. Using the FAST echo algorithm, inability to obtain expected views or the appearance of abnormal views in the generated planes should raise the index of suspicion for congenital heart disease. Studies to test the reproducibility and agreement of this algorithm are in progress.

ACKNOWLEDGMENTS
This research was supported by the Perinatology Research Branch, Division of Intramural Research, Eunice Kennedy Shriver National Institute of Child Health and Human Development, NIH, DHHS.

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Figure S1 FAST Echo algorithm applied to a fetus with tricuspid atresia and ventricular septal defect (hypoplastic right ventricle) at 21 weeks of gestation. The longitudinal view of the ductal arch appears abnormal, and both this view and the three-vessels and trachea view (Line 1) show a small pulmonary artery, consistent with pulmonic stenosis. Placement of Line 2 shows the aorta arising from the left ventricle. The four chamber view is abnormal (Line 3) with a large ventricular septal defect (asterisk), and a hypoplastic right ventricle. AO, aorta; LA, left atrium; LV, left ventricle; PA, pulmonary artery; RV, right ventricle; SVC, superior vena cava.

Figure S2 FAST Echo algorithm applied to a fetus with tetralogy of Fallot at 33 weeks of gestation. Placement of Line 1 shows evidence of pulmonic stenosis with an abnormally thickened valve. Placement of Line 2 shows the overriding aorta. Placement of Line 3 shows an abnormal four-chamber view with a large ventricular septal defect. AO, aorta; P, pulmonary artery; SVC, superior vena cava; VSD, ventricular septal defect.

Figure S3 FAST Echo algorithm applied to a fetus with complete atrioventricular canal defect and transposition of great vessels at 30 weeks of gestation. In the longitudinal view of the ductal arch, the aorta is visualized, but not the pulmonary artery. The three-vessels and trachea view (Line 1) is abnormal, and shows the aorta, superior vena cava, and trachea; however the pulmonary artery is not visualized. In the five-chamber view (Line 2), the aorta is visualized anteriorly, while the pulmonary artery (confirmed by its bifurcation) arises leftward from the common ventricular chamber. The four-chamber view (Line 3) shows a common atrioventricular valve (arrow) and a large septal defect involving both the atrial and ventricular septa. AO, aorta; PA, pulmonary artery; SVC, superior vena cava.

Figure S4 FAST Echo algorithm applied to a fetus with transposition of great vessels at 20 weeks of gestation. The four-chamber view appears normal (Line 3). In the longitudinal view of the ductal arch, the pulmonary artery and ductus arteriosus are not visualized. The three-vessels and trachea view (Line 1) is abnormal, and shows only the aorta (arising from the right ventricle) and superior vena cava. After placement of Line 2, the pulmonary artery (confirmed by its bifurcation) is seen exiting the left ventricle. AO, aorta; PA, pulmonary artery; RV, right ventricle; SVC, superior vena cava.

Figure S5 FAST Echo algorithm applied to a fetus with hypoplastic left heart, double outlet right ventricle, transposition of great vessels, and heterotaxy at 19 weeks of gestation. In the longitudinal view of the ductal arch,
the descending aorta is visualized, but the pulmonary artery and ductus arteriosus are not seen. The three-vessels and trachea view (Line 1) is abnormal, and shows the aorta arising from the right ventricle. After placement of Line 2, the pulmonary artery (confirmed by its bifurcation) is seen to exit leftwards from the right ventricle. The four-chamber view (Line 3) shows the hypoplastic left heart. AO, aorta; LV, left ventricle; PA, pulmonary artery; RV, right ventricle.

Video S1 FAST Echo applied to a normal fetus at 30 weeks of gestation. All three independent planes are simultaneously visualized (along with the longitudinal view of the ductal arch/pulmonary artery) after placement of three lines. The swing technique’ is not shown here. The three planes are: (a) three-vessels and trachea view (Line 1); (b) five-chamber view (Line 2); and (c) four-chamber view (Line 3).

Video S2 FAST Echo applied to a normal fetus at 28 weeks of gestation. All three independent planes are simultaneously visualized (along with the longitudinal view of the ductal arch/pulmonary artery) after placement of three lines. The swing technique’ is not shown here. The three planes are: (a) three-vessels and trachea view (Line 1); (b) five-chamber view (Line 2); and (c) four-chamber view (Line 3).

Video S3 swing technique’ applied to a normal fetus at 26 weeks of gestation. The swing’ line is fixed (but not locked) at the top of the longitudinal view of the ductal arch image, and is drawn from the top to the lower left hand corner of the image, so that it is lateral to the ductal arch. The line should remain unlocked, with the cursor (not the ‘lollipop’) visualized at its inferior end. In this example, the line is swung like a pendulum throughout the entire image from the left to the right side, and then vice versa. Swinging from left to right, the following cardiac planes are generated in sequence: three-vessels and trachea view, long-axis view of the aorta, five-chamber view, four-chamber view, and stomach.

Video S4 The entire FAST Echo algorithm applied to a normal fetus at 30 weeks of gestation.

Video S5 FAST Echo and Volume Contrast Imaging (VCI) applied to a normal fetus at 26 weeks of gestation. All three independent planes are simultaneously visualized (along with the longitudinal view of the ductal arch/pulmonary artery) after placement of three lines. With rotation of the five-chamber view on the y-axis, the long-axis view of the aorta is seen. VCI has been activated with a slice thickness of 2 mm and X-ray/surface smooth (Mix 100/0%) render mode applied. VCI allows images to appear smoother and the interface between different tissues to be more apparent. The render direction applies from the solid to the dotted line.

Video S6 FAST Echo applied to a fetus with tricuspid atresia and ventricular septal defect (hypoplastic right ventricle) at 21 weeks of gestation. The longitudinal view of the ductal arch appears abnormal, and both this view and the three-vessels and trachea view (Line 1) show a small pulmonary artery, consistent with pulmonic stenosis. Placement of Line 2 shows the aorta arising from the left ventricle, and this is also evident with rotation of the five-chamber view on the y-axis. The four-chamber view is abnormal (Line 3) with a large ventricular septal defect (asterisk), and a hypoplastic right ventricle. The tricuspid valve is atretic, while the mitral valve moves normally. AO, aorta; LV, left ventricle; PA, pulmonary artery; RV, right ventricle; SVC, superior vena cava.

Video S7 FAST Echo applied to a fetus with tetralogy of Fallot at 33 weeks of gestation. Placement of Line 1 shows evidence of pulmonic stenosis with an abnormally thickened valve with poor motility. Placement of Line 2 shows the overriding aorta. Placement of Line 3 shows an abnormal four-chamber view with a large ventricular septal defect present. AO, aorta; P, pulmonary artery; SVC, superior vena cava; VSD, ventricular septal defect.

Video S8 FAST Echo applied to a fetus with complete atrioventricular canal defect and transposition of great vessels at 30 weeks of gestation. In the longitudinal view of the ductal arch, the descending aorta is visualized, but not the pulmonary artery. The three-vessels and trachea view (Line 1) is abnormal, and shows the aorta, superior vena cava, and trachea; however the pulmonary artery is not visualized. In the five-chamber view (Line 2), the aorta is seen anteriorly, while the pulmonary artery (confirmed by its bifurcation) arises leftward from the common ventricular chamber. The four-chamber view (Line 3) shows a common atrioventricular valve (arrow) and a large septal defect involving both the atrial and ventricular septa. AO, aorta; PA, pulmonary artery, SVC, superior vena cava.

Video S9 FAST Echo applied to a fetus with transposition of great vessels at 20 weeks of gestation. The four-chamber view appears normal (Line 3). In the longitudinal view of the ductal arch, the pulmonary artery and ductus arteriosus are not visualized. The three-vessels and trachea view (Line 1) is abnormal, and shows only the aorta (arising from the right ventricle) and superior vena cava. After placement of Line 2, the pulmonary artery (confirmed by its bifurcation) is seen exiting the left ventricle; with rotation of this image on the y-axis, the aorta is visualized arising anteriorly from the right ventricle (also shown by the swing technique’). AO, aorta; PA, pulmonary artery; RV, right ventricle; SVC, superior vena cava.
Video S10 FAST Echo applied to a fetus with hypoplastic left heart, double outlet right ventricle, transposition of great vessels, and heterotaxy at 19 weeks of gestation. In the longitudinal view of the ductal arch, the descending aorta is visualized, but the pulmonary artery and ductus arteriosus are not seen. The three-vessels and trachea view (Line 1) is abnormal, and shows the aorta arising from the right ventricle. After placement of Line 2, the pulmonary artery (confirmed by its bifurcation) is seen to exit leftwards from the right ventricle. The four-chamber view (Line 3) shows the hypoplastic left heart. The swing technique demonstrates the congenital heart defect by depicting: (a) two great vessels exiting only the right ventricle which are also transposed (pulmonary artery leftwards, aorta rightwards and anterior); and (b) the stomach on the fetal right side. AO, aorta; LV, left ventricle; PA, pulmonary artery; RV, right ventricle.
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AQ4 By ‘almost universal access’ I assume that you are referring to the ‘developed’ world; if so, would it be worth mentioning?
AQ5 TM mark added here – is that correct?
AQ6 Should ‘lollipop’ be described/defined?

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