3D/4D Echocardiography—STIC

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Abstract: Fetal cardiac screening is an obligation for everybody performing prenatal ultrasound. The heart, as a small and always moving object, is still the most difficult part of the fetal anatomy evaluation. Knowing this, different methods of improving antenatal screening for congenital heart defects (CHD) were introduced. Spatial temporal image correlation (STIC) is the newest one. Its target was to automatic acquisition of the fetal scan from the abdomen, through 4 chamber view toward the three vessel view and off-line analysis of the anatomy of the fetal cardiovascular system. Is that really possible? Does STIC improve screening of CHD? Would it be helpful in the more precise diagnosis of complicated heart defects? These are still the open questions, which will be discussed in the article.

Keywords: Fetal echocardiography, STIC, fetal heart, 4D echocardiography, heart defects, fetal heart screening.

INTRODUCTION

Visualization of the fetal heart became possible in early 80-es. The pioneers were L Allan,[1] from Great Britain, D Sahn[2] and L Lange[3] from the United States. At the beginning high-risk groups were scanned, but the number of diagnosed fetal heart defects was very small. Such situation forced physicians to find the new method to detect more congenital heart defects in fetuses. Copel JA et al. were the first who published proved necessity of screening toward CHD during routine ultrasound scan, using 4 chamber view.[4] In the same year Gde Vore included color Doppler flow in the screening of CHD[5] – nowadays we could not imagine how to evaluate a fetal heart without color Doppler. However, there are some heart defects, especially conotruncal, which were not detected in 4 chamber view. So, after about 20 years since a fetal heart was possible to visualize, the American College of Obstetricians and Gynecologists in collaboration with several other medical societies published practice bulletin for ultrasonography in pregnancy in which inclusion of outflow tracts during screening fetal exam was recommended.[6]

There were two persons and two institutions in which fetal echocardiography started in Poland in middle 80-ties: Prof M Respondek – Liberska[7] in Lodz and Dr Joanna Dangel[8] in Warsaw. In 2004, they established Polish data base for fetal cardiac abnormalities. In 2004, Polish Gynecological Society included fetal heart screening as a part of ultrasound evaluation of the fetus[9] — 4 chamber view is an obligation, visualization of outflow tracts is recommended. The aim of screening is to distinguish between normal and abnormal fetal hearts. In any suspicion of heart defects full fetal echocardiogram should be performed. According to the guidelines of the American Association of Echocardiography nine views should be obtained to fulfill criteria of the diagnostic fetal echocardiogram.[10]

In spite of all recommendation,[11] teaching and cooperation between obstetricians and cardiologists, detection rate of fetal CHD is still unsatisfactory in many places. So, with developing of the new techniques, especially of 3D and 4D, companies tried to find the new method of fetal heart screening. STIC — Spatial Temporal Image Correlation, GE patented technique that allows clinicians to quickly capture a full fetal heart cycle beating in real-time and save the volume for later analysis, is one of the most promising one.

Before we start thinking about 3D or 4D images it is important to understand that the final picture which will be obtained is prepared digitally from acquired 2D pictures. In all digital methods of visualization pixels are used to produce the normal digital image on the screen. To have a possibility to obtain 3D digital image voxels were introduced – axis Z is added to the axes Y and X.[12]

3D Technique for the Fetal Heart Evaluation

3D technique enables to store a volume which was obtained automatically or manually by mechanical array transducer. Recently mechanical transducers were used. The volume consisted of multiple 2D images which were stacked one behind another through the region of interest (ROI), producing a "volume". This was "non-gated" approach which means, that changes occurring in systole and diastole were omitted. Nevertheless, this technique enabled to produce quite good static image of the fetal heart and to evaluate its anatomy. The image A (X) corresponds to normal 2D view (Fig.1). The B (Y) and C (Z) images were constructed from the volume data. Black and with images, color or high definition flows could be stored using this method (Fig. 2). The image B (Y) is perpendicular to the A, and enables to see the lateral view. The image C (Z) is perpendicular to B — the transverse plane from the top or the bottom can be seen. The quality of the image B and C highly depended on the A (X) image quality. Once the volume is stored, different planes can be analyzed off-line. Each volume data set can be scrolled and evaluated in different depth. In each depth, slices can be rotated around X, Y and Z axis so different views can be obtained. Niche method showed correlation between different planes (Fig. 3). 3D technique is useful for evaluating intracardiac and arches anatomy, as is shown on the Figure 4.

3D together with spin technique can be used for rendering, so the 3D image of the fetal heart can be obtained from the defined region of interest (ROI), as is shown on the Figures 5A and B, where the normal left and right ventricular outflow tracts were reconstructed and displayed in the rendering surface, gradient –light mode.

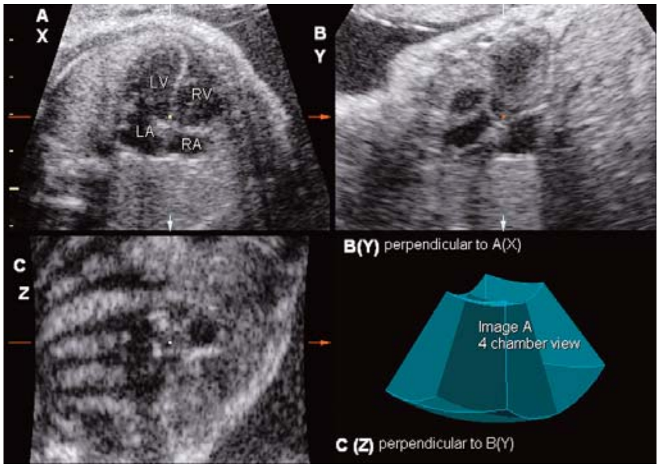


Fig.1: 3D heart static “base” image. Anatomy in different planes can be evaluated. The entire volume is shown in the right lower quadrant, the plane where 4 chamber view from the picture A is shown. RV – right ventricle, LV – left ventricle, RA – right atrium, LA – left atrium

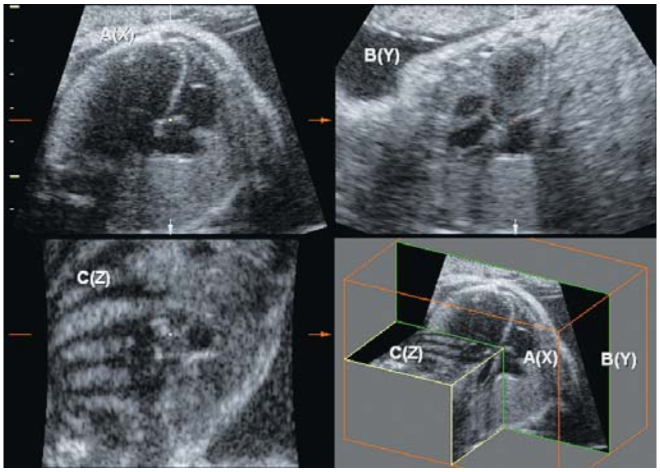
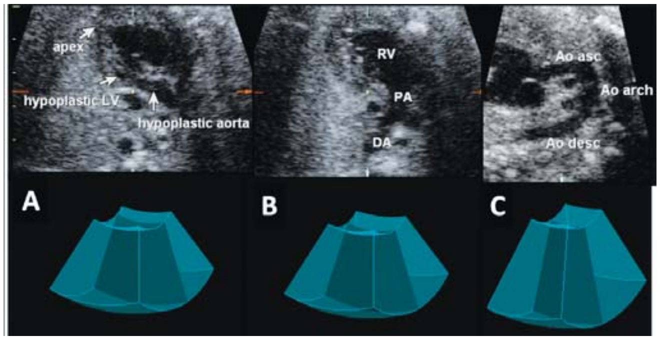
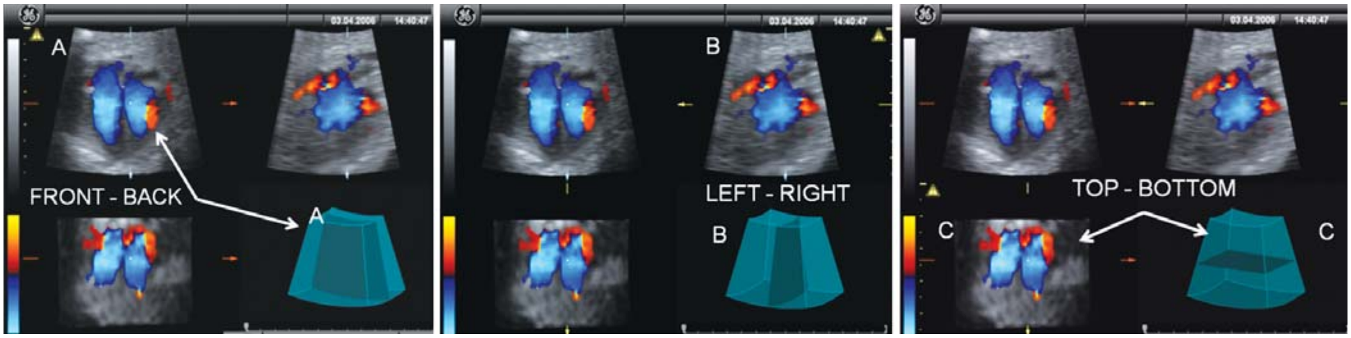


Fig. 3: 3D heart static basic image—Niche technique showed correlations between different planes within the volume

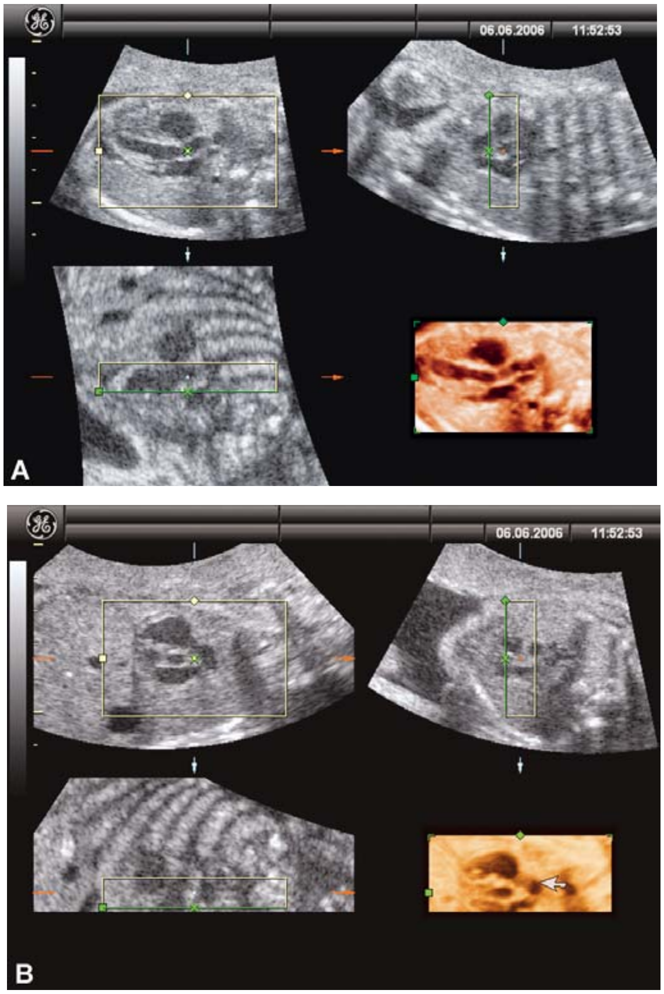


Figs 4A to C: 37 weeks fetus with heart defect: hypoplastic left ventricle and hypoplastic aortic arch, ventricular septal defect, left superior vena cava entering the coronary sinus. Exam performed with VolusonPro USG (Mater Pro Vita, Elblag), diagnosis (proved after birth) was possible after off-line analysis of 3D volume data set. Upper panel: reconstructions from the 3D sectional planes, lower panel – planes showed in the upper panel. Different planes are obtained due to back and forth moving and Y axis rotation

A: modified long-axis left ventricle view, big right ventricle (RV) and severely hypoplastic left ventricle with the patent left ventricular outflow tract and small aorta. The apex is built by the right ventricle. B: right ventricle outflow tract with normal pulmonary artery (PA) and arterial duct (DA). C: hypoplastic aortic arch which is two times smaller than the pulmonary artery



Figs 2A to C: 3D heart static 4 chamber view with color Doppler flow. A: basic 4 chamber view, atria are up, ventricles down, diastole; B: the plane perpendicular to A; C: the plane perpendicular to B. Images B and C are constructed digitally from the image A



Figs 5A and B: Rendering of the 3D image of left (4A) and right (4B) outflow tracts in the 24 weeks fetus. Gradient – light rendering mode was used. 4B image was obtained by the clock-wise rotation of the 4A image

4 D–Spatial Temporal Image Corelation (STIC)

To obtain a good quality 4D image of the beating, heart gating is necessary. After birth it is easy to do so using ECG. But how to obtain real time image of the fetal heart when ECG is not available? Spatial Temporal Image Correlation (STIC) is a GE patented technique that allows clinicians to quickly capture a full fetal heart cycle beating in real-time and save the volume for later analysis. It was introduced in 2002 in the ultrasound machine VOLUSON 730 Expert (at the moment it is available in GE E8 machine too). Triggering is done automatically and "plane" M-mode (B-mode) technique is used to capture 2D images at the same cardiac cycle (Fig. 6A). The machine identifies rhythmic movements of the fetal heart and derives the heart rate from the periodicity. Thus, end-systole or end-diastole can be recognized. B-mode frame rate during acquisition is very high, approximately 150 frames/s. Assuming a volume acquisition time of 10 seconds and the angle of 25°, 1500 B-mode images are stored one after another in the volume memory.[13] As the fetal heart does not beat at an absolutely precise rate, the STIC algorithm was introduced to detect and minimalize changes in the heart rate, which is necessary to create really optimal volume data set. The average heart rate is computed, beat to beat changes with a variability of about ±10% are detected and 2D images are rearranged to make sure, that only those from the same time during the cardiac cycle are merged into the volume (Fig. 6B). As the volume is stored automatically, experience for the fetal heart evaluation is less important. The specialist in fetal echocardiography can evaluate this volume having not only 2D image, but all frames (about 1500 as was mentioned above) recorded in the volume. As a consequence, the fetal heart exam can be evaluated and it is likely that the final diagnosis can be made off-line, without a patient. This method was already checked by several institutions. Its success rate for fetal cardiac screening was about 90% for all cardiac structures, 100% for 4 chamber view with recognition of right and left ventricle and 96% of crossing the arteries.[14]

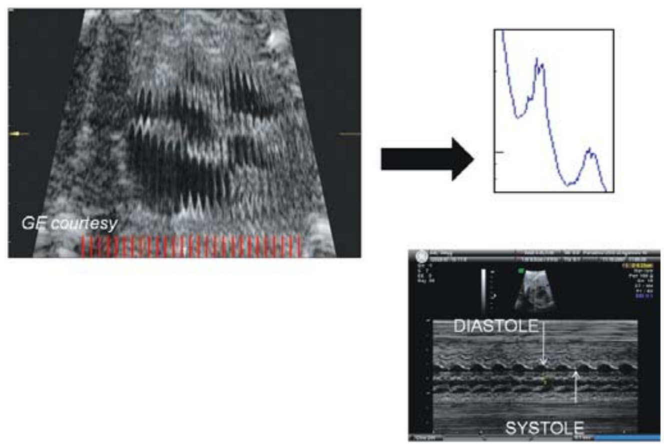


Fig. 6A: STIC technique: gating is possible due to systole and diastole which are stored as wall motion, about 1500 plane 2D are stored to built the entire volume

Fig. 6B: The fetal heart built as a volume – spatial view of the heart is seen inside the automatic acquired volume (GE courtesy)

To capture and store the volume properly several rules must be followed. The main is: **the better quality of 2D image the better volume can be acquired**. Different time and different angle can be used. Time for acquisition varies from 75 to 15° sec. and the angle from 15° to 40° degrees. Practically, the angle and the time must be adjusted individually, according to the fetal movements, mother's movements and the week of pregnancy. In the earlier pregnancy, when the fetus is more active and the heart is smaller, shorter time and smaller angle should be used. In the later pregnancy the angle should be bigger but the fetus is usually less active so time can be longer – up to 15 sec. Practically, in the second trimester acquisition time is between 10 and 12.5 sec., and in the third trimester 12.5 to 15 sec. The longer time and the smaller the angle the better image quality should be obtained.

The cardiac volumes consist of more than 1000 2D images which produce one heart beat displayed in an endless cine-loop, so there is an impression of the real time cardiac motion. The volume data set can be played in different ways. The first one is the **sectional planes**. The rule is exactly the same as for 3D volumes, but additionally we can see the moving heart and analyze systole and diastole. The image from the picture 7A can be played in the normal, slow or frame by frame motion. It can be enlarged, and its quality can be improved if necessary (Figs 7A and B). It can be moved in different directions (front and back, right and left, top and bottom) to obtain the best views for the cardiac anatomical evaluation. The image can be rotated around Y, X and Z axis. Obtaining all this it is possible to get all necessary views which constitute screening echocardiogram. It is called the "spin" technique[15] (Fig. 7B).

As we have the volume, **rendering** can be produced to show spatial 3D appearance of the fetal heart. Surface mode and gradient – light rendering is the best method to obtain a high quality 3D cardiac image. It is very good teaching method, as the heart anatomy is seen more precisely than in the plain 2D picture (Fig. 8). All important parts of the heart are seen, which can be helpful in making the diagnosis in some dubious cases (Fig. 9).

Color Doppler (CD) or **High Definition (HD) Flow** can be used in 4D STIC technique. It is helpful in evaluation function of the fetal heart, as well as its detailed anatomy.[16] Color Doppler is the classical Doppler and it is always used in fetal cardiology — it is not possible to perform full fetal echocardiogram without this technique. High definition is based on power Doppler flow enabling to define the direction of blood flow. Using this technique minor flow lesions can be seen.

Tomographic Ultrasound Imaging (TUI) automatically slices 3D/4D volume datasets, providing simultaneous visualization of up to eight or nine parallel planes in a single screen. Such software produces a series of tomographic images, akin to display methods used by diagnostic imaging professionals to review computerized tomography and magnetic

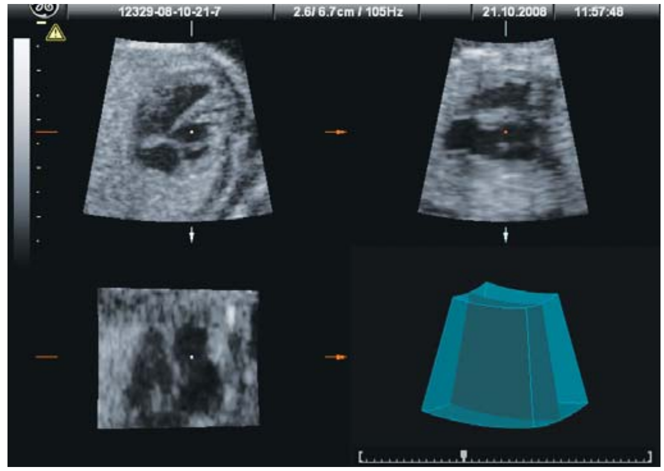


Fig. 7A: 22 weeks fetus, acquired volume from the apical 4 chamber view. A – basic, real time image

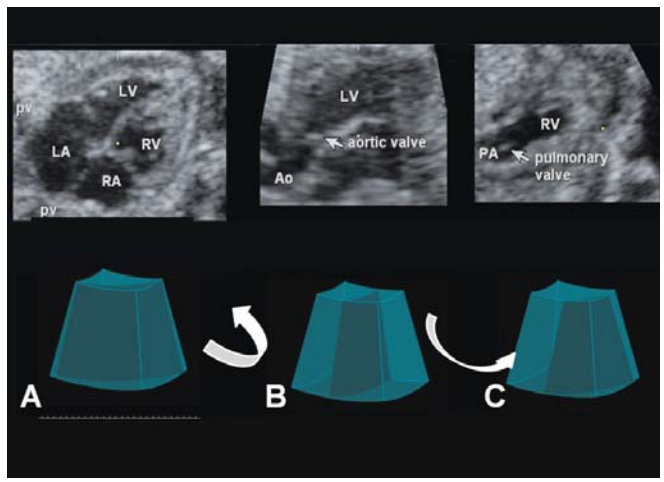


Fig. 7B: The image A from the Fig. 7A is enlarged and its quality is improved using 4D View program, "spin" technique for fetal outflow tract examination is used
A: basic 4 chamber view, enlarged and improved quality. RV – right ventricle, RA – right atrium, LV – left ventricle, LA – left atrium, pv – pulmonary veins.
B: rotating the image counter-clock-wise around the Y axis and moving the image slightly anteriorly aorta (Ao) arising from the left ventricle (LV) is seen.
C: moving the image anteriorly pulmonary artery (PA) from the right ventricle (RV) is seen

resonance studies. It was proved by several authors, that this method can be useful in off-line analysis of the normal hearts[14] as well as for evaluation of fetal cardiac defects.[17] It must be kept in mind that obtaining diagnostic images is not always possible and the volume must be 'adjusted" to be "cut" in defined planes by moving it along Y, X or Z axis (Fig. 10). Color Doppler and HD Doppler can be used with TUI, and the whole screening exam can be performed off-line using 4D View

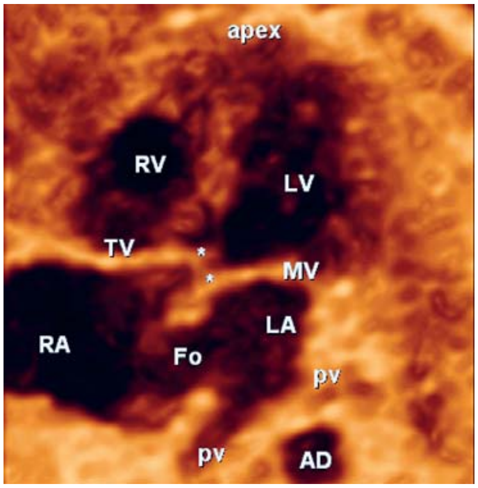


Fig. 8: Rendering of the 4 chamber view in 22 weeks fetus. Small stars showed differential insertion between mitral and tricuspid valve

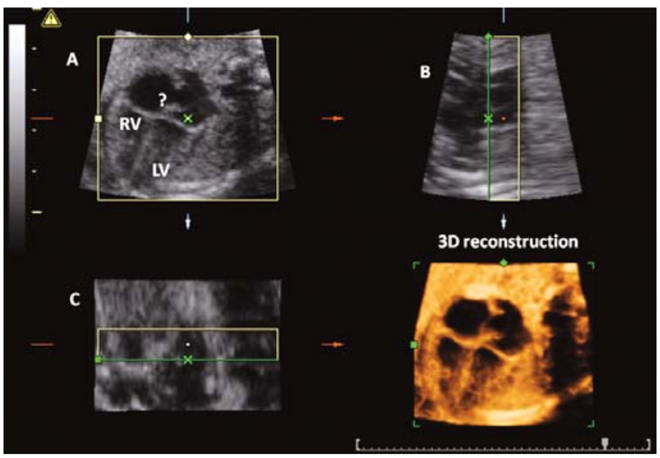


Fig. 9: 25 weeks fetus. In 2D image the {?} is put in the place where the lower part of the atrial septum should be seen. Atrioventricular valves seemed to be at juxtaposition (the same level), so the question was if it is ASD I. After rendering 3D view showed normal anatomy of the interatrial septum and atrioventricular valves

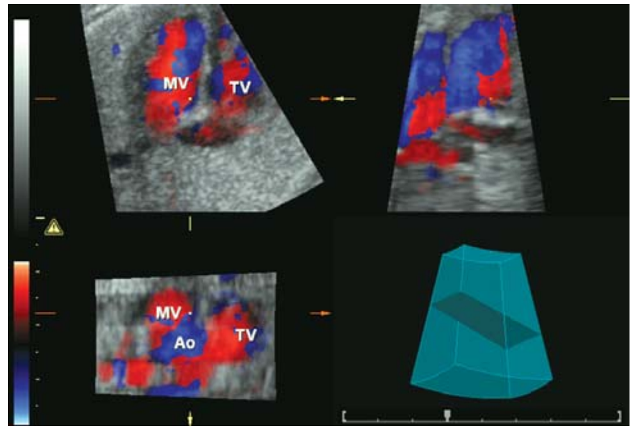
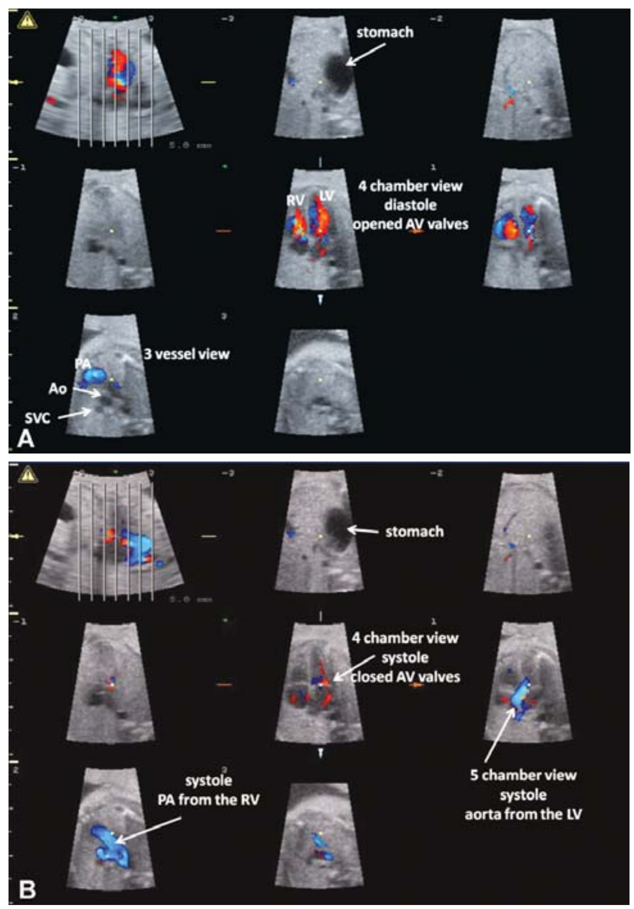


Fig. 10: Color Doppler in STIC technique. Detailed anatomy can be evaluated, as well as function of cardiac valves. C-plane showed the aorta (Ao - blue) which is wedged between mitral (MV – red) and tricuspid valves (TV – red). This is the view from above – atrioventricular orfices are seen in the short axis, blood is going up toward the transducer into the ventricles, and away from the transducer to the aorta



Figs 11A and B: TUI with color Doppler – three important "screening" pictures were obtained from the 4 chamber view: stomach on the left side, 4 chamber view and three vessels view. (A) TUI - diastole – filling of the both ventricles is seen. (B) TUI - systole – left and right ventricular outflow tracts are visualized

program. STIC analysis can be performed in systole (Fig. 11A) and in diastole (Fig.11B).

TUI can be helpful in the diagnosis of congenital heart defects. Difference of the size between the right and the left ventricle, the pulmonary artery and the aorta in the fetus with aortic coarctation is shown on the single screen (Fig.12).

Another method which can be used with STIC is called **inversion mode.**[18] This is the technique in which cardiac chambers and lumen of the vessels are displayed (Figs 13 to 14).

Final Remarks

When the new technique arrived many people started to doubt if they are really necessary. Screening examination of the fetal heart in majority of cases can be performed just using 2D exams.

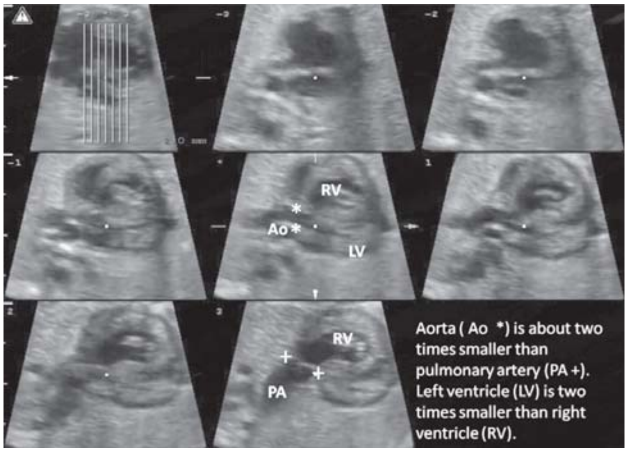


Fig.12: TUI in 26 weeks fetus with aortic coarctation (proved after birth), lateral view. Right ventricle (RV) is two times bigger than left ventricle (LV). Aorta (Ao *) is two times smaller than pulmonary artery (PA +)

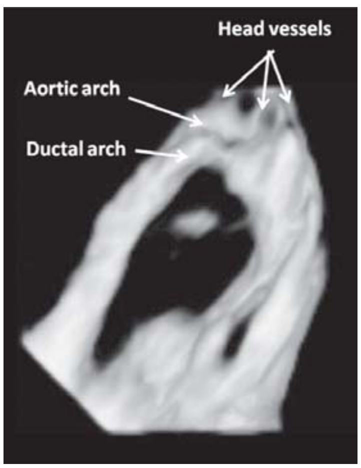


Fig.13: Reconstruction of the aortic and ductal arch in a normal fetus in inversion mode

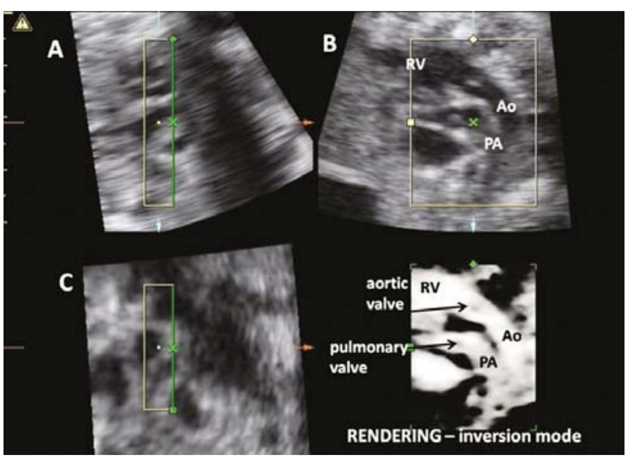


Fig.14: Reconstruction of the left and right ventricle tracts in the 26 weeks fetus with transposition of great arteries. The image is reconstructed from the apical 4 chamber view, both arteries are visualized and rendering in inversion mode to show the anatomy

However, as it was mentioned in the introduction, fetal heart is still the most difficult part of the prenatal ultrasound screening, so new methods of improving the detection rate of CHD seemed to be necessary. People started to search prospectively if 3D and 4D methods could improve screening and there are already some data proving this theory.[19,20]

In spite of screening improvement, there are some additional advantages with 3D and 4D STIC. It is possible to change and select scan planes and obtained views which could not be seen with 2D method. The exam quality can be improved off-line from 3D volume dataset. Such method is important in poor scanning circumstances, like mother's obesity.

Volumetric analysis can be done off-line, without a patient, so time for a patient exam is shorter. However, it must be remembered that it did not mean that time for the full exam is really shorter, as analyzing volumes is time consuming especially with complicated heart defects or poor image quality. 3D rendering images of the fetal heart are much better using STIC than the real time 4D, which is very poor in fetuses due to lack of proper triggering. STIC is an excellent teaching tool which enables to explain spatial correlation within the fetal body in a very friendly way, showing all directions with the third dimension which is often difficult to imagine for the beginners in fetal scanning. Different rendering modes helped to show complicated anatomy of the normal hearts, and complicated heart defects. This is important for students, and in many cases helped to make a proper decision concerning perinatal care, for example better evaluation of the size of defects and cardiac

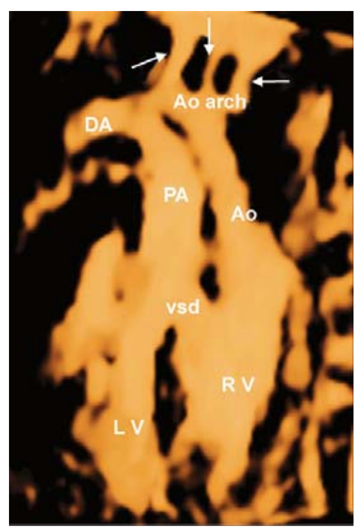


Fig. 15: Reconstruction of the intracardiac anatomy and the outflow tracts in the 21 weeks fetus with Taussig – Bing anomaly (double outlet right ventricle, transposition of the great arteries, ventricular septal defect VSD) in inversion mode. Pulmonary artery (PA) overrides the interventricular septum and is filled from the left (LV) and right (RV) ventricles, there is subpulmonary VSD, aorta (Ao) arises in front from the right ventricle (RV) and is smaller than the PA. Arrows showed the head vessels from the aortic arch

chambers. It was suggested that it is a perfect archive format. STIC volumes are not small, but they contained more information than 2D images of the same size. They are smaller if just sectional planes, without rendering, are stored on disk.

There are some disadvantages as well. STIC is off-line analysis, not real time. Until now it is not very useful in the first trimester. It cannot be used in fetuses with arrhythmia. Volume quality is highly dependent on fetal and mother's movement, but this problem can be solved with some scanning experience.

In spite of some disadvantages, as an experienced fetal cardiologist I must conclude, that 4D STIC is an excellent method which gave us many new possibilities for examining and imaging the fetal heart and after two years of working with volumes it is hard to believe that reference fetal cardiology unit can work without this tool.

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REFERENCES

1. Allan LD, Tynan M, Campbell S, Wilkinson JL, Anderson RH. Echocardiographic and anatomical correlates in the fetus. Br Heart J 1980;44:444-51.
2. Sahn DJ, Lange LW, Allen HD et al. Quantitative real-time cross-sectional echocardiography in the development of normal human fetus and newborn. Circulation 1980;62:588-95.
3. Lange LW, Sahn DJ, Allen HD, Goldberg SJ, Anderson C, Giles H. Qualitative real-time cross-sectional echocardiography imaging of the unborn human fetus during the second half of pregnancy. Circulation 1980;62:799-806.
4. Copel JA, Pilu G, Green J, Hobbins JC, Kleinman CS. Fetal echocardiographic screening for congenital heart disease: the importance of the four-chamber view. Am J Obstet Gynecol 1987;157(3):648-55.
5. DeVore GR, Horenstein J, Siassi B, Platt LD. Fetal echocardiography. VII. Doppler color flow mapping: a new technique for the diagnosis of congenital heart disease. Am J Obstet Gynecol 1987;156(5):1054-64.
6. ACOG Committee on Practice Bulletins. ACOG Practice Bulletin No. 58. Ultrasonography in pregnancy. Obstet Gynecol 2004;104(6):1449-58.
7. Respondek– Liberska M. Prenatal Cardiology–for obstetricians and pediatric cardiologists. Lublin 2006, Czelej, Pol.
8. Szymkiewicz– Dangel J. Fetal Cardiology– principles of diagnosis and therapy 2007, Poznan, OWN, Pol.
9. http://www.gpsk.am.poznan.pl/ptg/rekomendacje/rekomendacjausg.htm
10. Rychik J, Ayres N, Cuneo B, Gotteiner N, Hornberger L, Spevak PJ, Van Der Velde M. American Society of Echocardiography guidelines and standards for performance of the fetal echocardiogram. J Am Soc Echocardiogr 2004;17(7):803-10.
11. L Allan, JDangel, VFesslova, JMarek, MMellander, IOberhansli, ROberhoffer, GSharland, JSimpson, SESonesson. Recommendations for the practice of fetal cardiology in Europe. Cardiol Young 2004;14:109-14.
12. Vienna International School of 3D Ultrasonography, 2004.
13. De Vore GR, Falkensammer P, Sklansky MS, Platts LD. Spatio-temporal image correlation (STIC): New technology for evaluation of the fetal heart. Ultrasound Obstet Gynecol 2003;22:380-87.
14. 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.
15. DeVore GR, Polanco B, Sklansky MS, Platt LD. The "spin" technique: a new method for examination of the fetal outflow tracts using three-dimensional ultrasound. Ultrasound Obstet Gynecol 2004;24:72-82.
16. Chaoui R, Hoffman J, Heling KS. Three-dimensional (3D) an 4D color Doppler fetal echocardiography using spatio-temporal image correlation (STIC). Ultrasound Obstet Gynecol 2004;23(6):535-45.
17. Paladini D, Vassallo M, Sglavo G, Lapadula C, Martinelli P. 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.
18. Goncalves LF, Espinoya J, Lee W, Mayor M, Romero R. Three- and four-dimensional reconstruction of the aortic and ductal arches using in version mode: A new rendering algorhithm for visualization of fluid-filled anatomical structures. Ultrasound Obstet Gynecol 2004;24(6):696-98.
19. Rizzo G, Capponi A, Muscatello A, Cavicchioni O, Vendola M, Arduini D. Examination of the fetal heart by four-dimensional ultrasound with spatiotemporal image correlation during routine second-trimester examination: The 'three-steps technique'. Fetal Diagn Ther 2008;24(2):126-31.
20. Abuhamad A, Falkensammer P, Reichartseder F, Zhao Y. Automated retrieval of standard diagnostic fetal cardiac ultrasound planes in the second trimester of pregnancy: A prospective evaluation of software. Ultrasound Obstet Gynecol 2008;31(1):30-36.