Some Aspects of Fetal Echocardiogram : 12 Years of Experience

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Abstract

Fetal echocardiogram is a reliable tool for prenatal diagnosis of congenital heart disease. It is an important adjunction to obstetrical ultrasonography in caring for women during pregnancy. With improvement in resolution of 2-D echo images as well as the addition of parameter software, fetal echocardiography has found ever-expanding applications in both the structural and functional assessment of the fetal cardiovascular system.

From the author's 12 years experience in fetal echocardiogram, 1,000 fetal hearts were studied and 12 cases had congenital heart defects (CHD): 4 ventricular septal defects, 1 Ebstein's anomaly, 1 Tetralogy of cantrell, 1 single atrium and single ventricle, 1 Hypoplastic left heart syndrome, 2 abnormal tricuspid valve with tricuspid regurgitation, 1 calcification RV, LV and interventricular septum with hydrops fetalis. Three hydrops fetalis were of unknown cause.

Fetal heart size was evaluated by comparing the heart area/size with the chest area/size. The ventricular dimension was assessed by M-mode and 2-D echo, The ventricular volume could be measured by 2-D echo with a special formula. Evaluation of ventricular function was important and could be evaluated by M-mode, 2-D echo and Tissue Doppler Image (TDI). Pulsed Doppler and Doppler Colour Flow Image gave more information about the hemodynamics.

The assessment of the foramen ovale, ductus venous, ductus arteriosus arteries including the umbilical artery and vein were also important and would be abnormal if the fetal heart had ventricular dysfunction and congestive heart failure. The fetal echocardiographic findings will help the obstetrician for further investigation and/or treatment including termination of pregnancy.

The author would like to recommend that fetal echocardiogram be performed in all pregnant women at 18-22 weeks of gestation. The incidence of CHD in low risk pregnancy is as significant a finding as in high-risk pregnancy.

Key word : Fetal Echocardiogram, Tissue Doppler Image, Myocardial Velocities

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Congenital heart disease (CHD) is one of the most common lethal congenital malformations causing tremendous clinical and psychosocial implications for patients, their families, and for the society as a whole. It accounts for almost half of all prenatal and infant deaths caused by congenital malformations. The early detection of congenital heart disease is very important, not only for proper planning of the treatment, but and also for parental counseling.

Fetal echocardiogram has now been accepted as a reliable tool for prenatal diagnosis of congenital heart disease[1-14]. The indicators for the fetal echocardiogram are the fetal risk factors, maternal risk factors and familial risk factors such as fetal arrhythmia, fetal extra-cardiac anomalies, fetal chromosome anomalies, family history of CHD, maternal disease, abnormal fetal growth and evidence of fetal distress (e.g. hydrops fetalis).

Previous studies revealed the incidence of CHD to be more common in high risk pregnancies[15-18]. But a recent study found that the incidence of CHD was also high in low risk pregnancies[19]. 40 per cent of CHD were associated with chromosome abnormalities and 27 per cent of CHD were isolated. At present, most academic hospitals in Europe especially in France, England and many hospitals in the USA perform fetal heart screening as part of the routine ultrasound screening procedures in both low and high risk pregnancies by well-trained sonographers, obstetricians or pediatric cardiologists.

The Tissue Doppler Imaging (TDI) method, which is a noninvasive modality, has been developed [20-25]. It is based on the conventional colour Doppler imaging, which makes it possible to measure cardiac wall motion velocity as a parameter for quantitative evaluation of heart disease, including ischemic heart disease, myocardial infarction[11-21], cardiomyopathy [22] and ventricular pre-excitation (WPW syndrome) [23] in adults. In children, TDI has been used to evaluate myocardial velocities in normal and abnormal structural heart diseases[24,25] especially in the abnormal origin of the left coronary artery, myocarditis and congestive cardiomyopathy. This method has some limitations due to the whole fetal heart motion as well as the angle between the ultrasound beam and area of measurement[26].

The antenatal medical and surgical interventions for structural heart disease, arrhythmia and congestive heart failure have been reported and are progressing. Some of them have shown good results, such as arrhythmia, but not for congenital complete heart block[27-33]. Direct percutaneous ultrasound guided approaches for valvuloplasty, open fetal cardiac surgery and fetoscopic fetal cardiac intervention have been reported but need further improvement in equipment and methods used[27,34].

Echocariographic machine and fetal heart scanning[1-12]

An echocardiographic machine has now been developed with good resolution. Some machines have special modalities such as Tissue Doppler Imaging (TDI), tissue harmonics, and special formulas for fetal heart measurement including ventricular functions, etc. In addition, these new machines can give a more accurate diagnosis and beneficial information. With transabdominal fetal echocardiogram, the transducer can be used in either linear or phase array with 3.75 to 5 MHz. The fetal heart is scanned using the systematic scanning technique in all standard windows with dynamic recording. Complete fetal echocardiographic study generally involves three methods of investigation: 2-D echocardiogram, M-mode echo, and Doppler interrogation. This will get all the fetal heart information such as heart position, situs arrangement, atrioventricular and ventriculoarterial connections, cardiac chambers sizes, ventricular functions, valvular regurgitation and cardiac defect. Doppler echocardiogram and Doppler Colour Flow Image will give additional information about the hemodynamics. The foramen ovale, ductus venosus, ductus arteriosus and umbilical artery and vein flows are also important which need to be evaluated carefully. The four chamber view is mainly used to measure ventricular sizes and functions. For TDI study, the apical four chambers and the apical or parasternal long axis views, are the standard planes with an appropriate setting of colour-coded tissue velocities superimposed onto the M- mode picture to measure the myocardial velocities.

Detection of congenital heart disease[7-12,34]

The appropriate gestational age for abdominal fetal echocardiogram is 18-22 weeks, but it can be done as early as 16 weeks of gestation, and the transvaginal approach can be performed as early as 12 weeks of gestation. The accuracy and specificity now are high for the detection of CHD especially in significant heart defects due to good machines and more experienced pediatric cardiologists. During the past 12 year period of the author's experience in transabdominal fetal echocardiography (from 1990-2002), fetal echocardiograms were performed on 1,000

fetal heart. 570 were normal (low risk) pregnancies and 430 cases were high risk pregnancies. The gestational ages were 16-39 weeks (mean 26.5 ± 5.6 wks). Twelve of the 1,000 fetal hearts had congenital diseases: 4 ventricular septal defect (VSD) (Fig. 1), 1 Ebstein's anomaly with tricuspid valve regurgitation (TR), 1 Tetralogy of Cantrell (Fig. 2), 1 single atrium and single ventricle, 1 hypoplastic left heart syndrome, 1 artrioventricular septal defect (AV), 2 abnormal tricuspid valves with TR (one associated with hydrops fetalis) (Fig. 3), 1 abnormal calcification of both anterior walls of the right ventricle (RV) and free walls of the left ventricle (LV), and right sided interventricular septum (IVS) with hydrops fetalis.

Ventricular size and function

Fetal cardiac size is considered abnormal or not by comparing the heart area/size with the chest wall area or diameter by drawing the whole cardiac size and the chest wall[35,36]. This method can be inaccurate in mild cases or in lung or thoracic cage abnormality. The author found direct measurements of the internal ventricular cavity area in both the right and left ventricle, during end systole and diastole in four chamber view are helpful and probably more accurate. Ventricular sizes and functions can be evaluated by M-mode echocardiogram which requires good 2-D echo picture quality and accurate cursor line at the acceptable reference point. (Fig. 4)

Fifty normal fetal hearts with gestational ages of 18-38 weeks had performed by M-mode and 2-D echocardiograms to measure ventricular sizes and functions. The results of the study revealed the RV cavity area by 2-D echocardiogram in systole to be 0.502 ± 0.329 cm^2 and in diastole it was 0.925 ± 0.662 cm^2. The LV cavity area by 2-D echocardiogram in systole was 0.944 ± 0.524 cm^2 and in diastole it was 1.459 ± 0.753 cm^2. The RV dimension by M-mode in systole was 0.21-1.07 cm and in diastole it was 0.43 – 1.64 cm. The LV dimension by M-mode in systole was 0.29-1.20 cm and in diastole it was 0.49-1.66 cm. The author found that M-mode was good for the evaluation of the ventricular size, but may not be good for ventricular function due to abnormal interventricular septal motion (flat).

The evaluation of the ventricular functions by 2-D echocardiogram can be done by using children's or adult's formulas but it may not be suitable for fetal hearts especially in the early stage of pregnancy. It has been reported from an experimental study in animals that measuring ventricular volume by using both four chambers and long axis views was accurate[37]. The ventricular size should not be interpreted from only one view. Instead, multiple views such as four chambers, long axis and cross axis must be used. From the author's experience, the right ventricular free wall is noticeably thicker than the left ventricular free wall but the right ventricular cavity is equal to or slightly smaller than the left ventricular

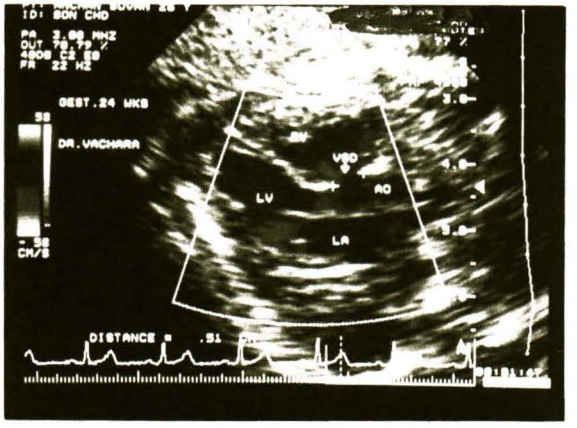

Fig. 1. Long axis view of a fetal heart with ventricular septal defect (VSD).

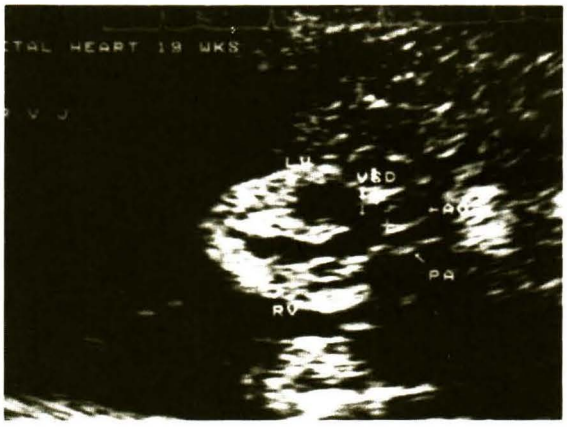

Fig. 2. 2-D Echo picture shows ectopia cordis with structural heart defect (Tetralogy of Fallot).

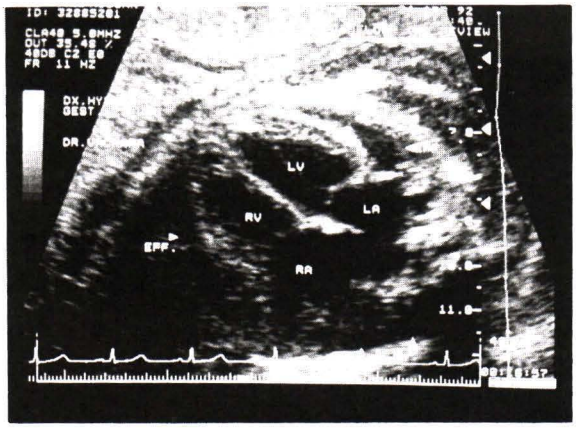

Fig. 3. **Four-chamber view of a fetus with hydrops fetalis with pericardial effusion.**

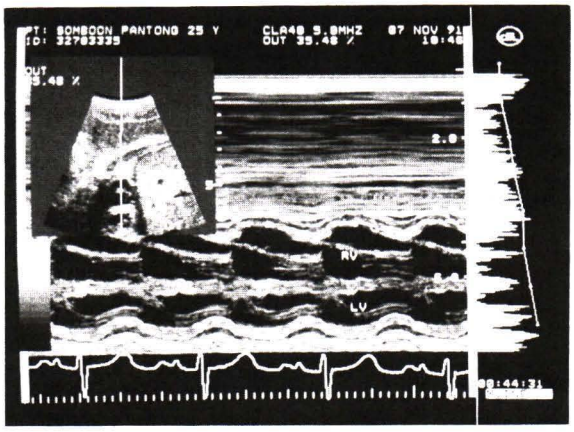

Fig. 4. **M-Mode Echo of right and left ventricle to evaluate ventricular sizes and functions.**

cavity. The anterior wall of the right ventricular contraction is more prominent than the left ventricular posterior wall. The ejection fractions of both right and left ventricles may not he accurate due to abnormal interventricular septal motion.

Evaluation of ventricular function by Tissue Doppler Imaging (TDI)

From 1996 to 2000, Tissue Doppler Imaging (TDI) was performed in addition to fetal heart scanning including hydrops fetalis, to evaluate myocardial function[26].

Fifty four normal fetal hearts with gestational ages of 20-38 weeks (mean 27 ± 14.9 wks) had Tissue Doppler Imaging in addition to M-mode, 2D-echocardiography and Doppler Color Flow Imaging, performed to evaluate the cardiac function by measuring the myocardial velocities of the posterior wall of the LV, anterior wall of the RV, and interventricular septum. The apical four chambers and apical long axis or parasternal long views were the standard planes with the superimposed M-mode, and appropriate color-coded tissue velocities, selected for study. (Fig. 5) The results showed myocardial velocities of the posterior wall of the left ventricle during the early, mid, and late systolic phases to be 1.61 ± 0.71, 1.83 ± 0.85,0.93 ± 0.45 cm/sec and the early, mid, and late diastolic phases were 1.32 ± 0.81, 1.96 ± 0.98, 1.17 ± 0.67 cm/sec respectively. The myocardial velocities of the anterior wall of right ventricle during the early, mid, and late systolic phases were 1.25 ± 0.80, 1.96 ± 1.22,1.31 ± 0.86 cm/sec and the early, mid and late diastolic phases were 1.1 ± 0.6, 1.8 ± 0.7 and 1.5 ± 1.0 cm/sec respectively. The interventricular septal velocities could not be measured due to the abnormal interventricular motion and the total fetal heart motion.

The myocardial velocities of the anterior wall of the RV and the posterior of the LV were not affected by the gestational ages. The use of the TDI to evaluate myocardial velocities of the fetal heart had some limitations due to the whole fetal heart motion and the angle between the ultrasound beam and the area of myocardium being measured

Pulmonary artery and aorta

The pulmonary artery size at the pulmonic valve level was 0.35-0.85 cm (0.532 ± 0.116 cm). The aorta size at the aortic valve level was 0.31-0.72 cm (0.477 ± 0.1-5 cm). (Fig. 6) The pulmonary artery was slightly bigger than the aorta which was probably due to high pulmonary vascular resistance and as it is the route of blood supply to the lower part of the body and extremity *via* ductal arteriosus. This finding was not different from other reports[38-41]. The pulmonic flow velocity was 0.420-0.992 m/sec and the aortic flow velocity was 0.476-0.966 m/sec. The pulmonic flow velocity is not significantly different from the aortic flow except for a more rapid upstroke than the aortic flow. Reed et al[42,43] found that the peak and mean velocities across the pulmonary valve and mean velocity across the aortic valve did not change with

gestational age, but the peak aortic valve velocity increased with advancing gestational age. The aortic isthmus was smaller than the ascending aorta and the thoracic aorta. (Fig. 7) The aortic diameter at the aortic valve level was not significantly different from the aortic diameter at the thoracic or abdominal aorta levels.

Mitral and tricuspid valve inflow velocities

The mitral valve and tricuspid valve inflow velocity patterns were opposite in children and adults by reverse "A" and "E" wave ratios. The "E" wave velocity was higher than the "A" wave velocity[42-44]. The author studied mitral and tricuspid valve inflow velocities of 50 normal fetal hearts and found:

MV inflow velocity: "E" wave was 0.112-0.530 m/sec.
"A" wave was 0.258-0.720 m/sec.
TV inflow velocity: "E" wave was 0.122-0.633 m/sec.
"A" wave was 0.275-0.850 m/sec.

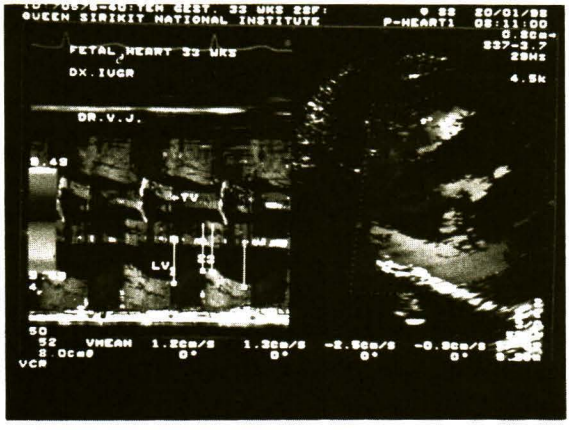

Fig. 5. Four-chamber view of Tissue Doppler Image (TDI) demonstrates endomyocardial velocity.

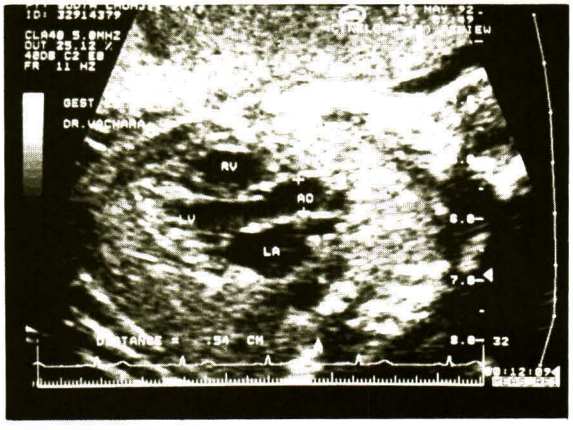

Fig 6. Long axis view of left ventricle in a normal fetal heart shows normal size of left ventricle and aorta.

The average velocities of both "A" and "E" waves were not significantly different during pregnancy. The velocities of "E" wave of both mitral and tricuspid valves were nearly constant from 16 weeks of gestation to birth. This finding suggested impaired ventricular diastolic relaxation.

Umbilical artery and vein flow

The umbilical artery and vein flow were nearly constant during pregnancy. The umbilical vein flow was 0.105-0.175 m/sec (mean 0.138 m/sec). For umbilical artery flow : the pulsatile index (PI) was between 0.870-2.090 (1.329 $\pm$ 0.260). The S/D (maximum/minimal) was 3.436-4.99 (3.560 $\pm$ 0.815) and the resistant index (RI) was 0.560-0.900 (0.727). The pattern and velocity flow of the umbilical vein and/or artery will be changed in significant hemodynamic abnormality due to congestive heart failure or ventricular dysfunction, such as Ebstein's anomaly with severe tricuspid regurgitation and hydrops fetalis[45].

Assessment of foramen ovale

The author found flow across the foramen ovale was a continuous flow like the atrial septal defect (ASD) flow in children but in the opposite direction (Fig 8A and B). The foramen ovale flow was from the right atrium to left atrium (fetal circulation). If it is restricted it can cause right atrial enlargement, right ventricular dilatation and hypertrophy, restricted enlargement of the main pulmonary artery and ductus arteriosus[46].

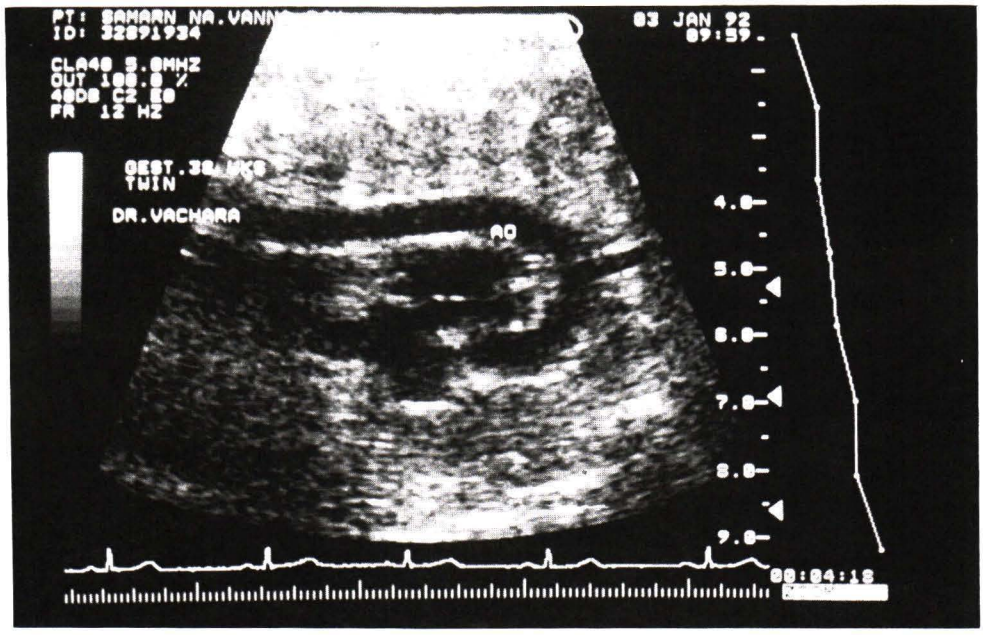

Fig. 7. Long axis view of aorta with normal aortic arch.

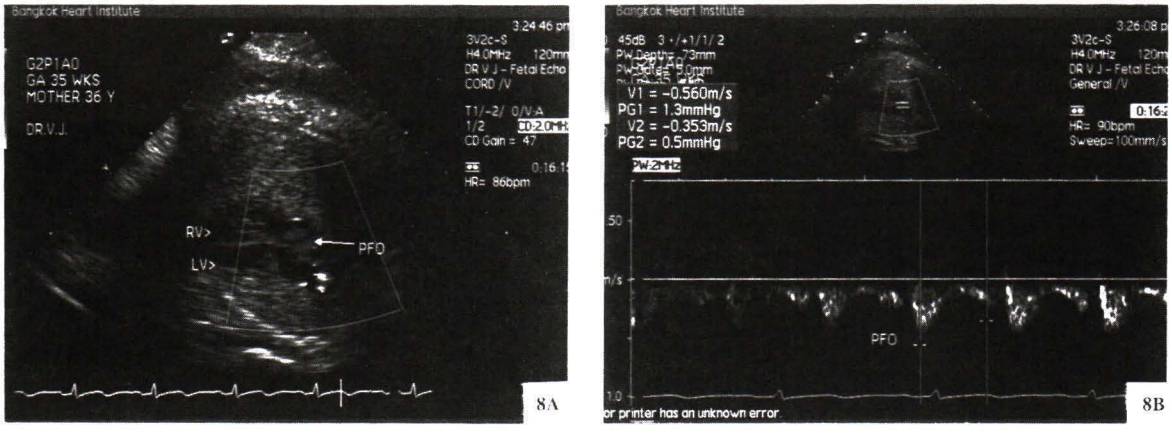

Fig. 8A & B. Doppler Color Flow Image and Pulsed Doppler of foramen ovale with right to left shunt from right atrium to left atrium.

Assessment of ductus arteriosus

Ductus arteriosus is not difficult to visualize and can be seen and evaluated by Doppler and Doppler Color Flow Image in the same way as in the newborn. Constriction of ductus arteriosus can occur in mothers given prostaglandin inhibitor such as Indomethacin which can cause progressive right ventricular pressure overload, hydrops fetalis and fetal demise[47].

Assessment of fetal cardiac arrhythmia

Fetal cardiac arrhythmia is rare[48-54]. If it occurs and persists with a rapid ventricular rate,

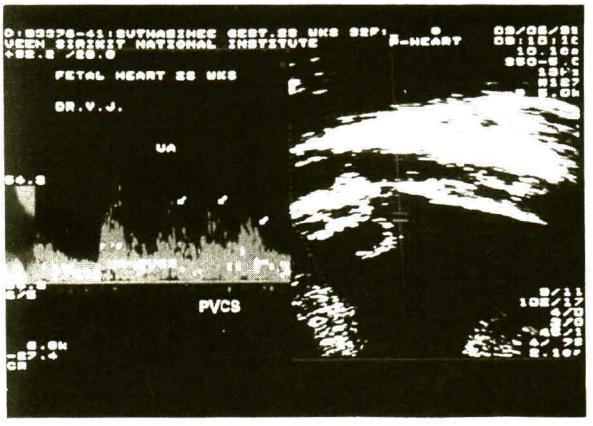

Fig. 9. Pulsed Doppler of umbilical artery shows irregularity of waves from due to premature ventricular ectopic beat.

such as supraventricular tachycardia or atrial flutter with rapid ventricular response it can produce congestive heart failure and a dead fetus *in utero*. This arrhythmia can be treated by medication to the mother such as digitalis, flecainide or verapamil. Complete heart block with a slow ventricular rate (< 50 beats/min) can also produce congestive heart failure and hydrops fetalis with poor prognosis. It is usually resistant to medication. During a 12 year period, the author found only occasional premature atrial ectopic beats and premature ventricular ectopic beats which did not require any medication. (Fig. 9) These are benign arrhythmias and will disappear later.

In the future, fetal echocardiogram will have better pictures, which can allow much more accurate detection of congenital heart defects and heart functions. The 3-D echocardiogram will come in the near future and will give more details of the fetal heart, including any defects of congenital heart disease and ventricular function. There will be more new software programs to measure the ventricular function and volume of the fetal heart. Fetal cardiac intervention will have better results due to improvement in the technique and equipment.

In conclusion, the fetal echocardiogram should be used as routine ultrasound screening in all pregnancies, not only for high risk pregnancies. It will provide supplementary data for the obstetrician to improve care of the fetus and mother[55,56]. It can also be used as a basis for additional studies such as whole fetal scanning to detect extracardiac abnormalities[14], amniocentesis[15], methods of delivery, and immediate delivery care. Finally, the purpose of fetal echocardiography is not only to consider whether to terminate affected pregnancies but to provide improved information and better care for patients.

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ประสบการณ์ 12 ปี ในการวิเคราะห์โรคหัวใจพิการแต่กำเนิดแก่ทารกในครรภ์มารดา

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Fetal echocardiogram เป็นการตรวจวิเคราะห์โรคหัวใจทารกในครรภ์มารดาด้วยเครื่อง Echocardiogram โดยผลการตรวจมีความแม่นยำ และมีประสิทธิภาพไม่เป็นอันตรายต่อทั้งทารกในครรภ์และตัวมารดา ปัจจุบันเครื่องมือนี้ได้มีการพัฒนาก้าวหน้าเป็นอย่างมาก ทำให้ได้ภาพชัดเจนตลอดจนมี parameter ต่าง ๆ ทำให้สามารถทราบถึง hemodynamics และการทำงานของกล้ามเนื้อหัวใจอีกด้วย

จากประสบการณ์ด้านการทำ Fetal echocardiogram นาน 12 ปี ของผู้เขียน ตั้งแต่ปี พ.ศ. 2533-2545 ได้ทำการตรวจวิเคราะห์หัวใจทารกในครรภ์มารดา (Fetal echocardiogram) รวมทั้งสิ้น 1,000 ราย อายุครรภ์ระหว่าง 16-38 สัปดาห์ พบทารกในครรภ์มารดาเป็นโรคหัวใจพิการแต่กำเนิน 12 ราย โดยเป็น Ventricular septal defect 4 ราย, Ebstein's anomaly 1 ราย, Tetralogy of contrell 1 ราย, Single atrium and single ventricle 1 ราย, Hypoplastic left heart 1 ราย, Abnormal tricuspid valve with tricuspid regurgitation 2 ราย, calcification RV, LV and interventricular septum with hydrops fetalis 1 ราย และ Unknown cause ของ hydrops fetalis 3 ราย ซึ่งจากการทราบความผิดปกติของหัวใจทารกในครรภ์-มารดานี้จะเป็นข้อมูลเสริมให้กับสูติแพทย์ในการดูแลการตั้งครรภ์และ Investigation ต่อ รวมทั้งการดูแลทารกหลังคลอดทันทีได้ดียิ่งขึ้น ตลอดจนการพิจารณาหยุดการตั้งครรภ์ สำหรับการวิเคราะห์ว่าหัวใจโตผิดปกติหรือไม่ ทราบได้จากการหาอัตราส่วนของ heart area เทียบกับ chest area นอกจากนี้ขนาดของ right และ left ventricle ทราบได้จาก M-Mode และ 2-D Echo การหา ventricular area และ volume สามารถทำได้และช่วยในการวิเคราะห์ว่าหัวใจทารกในครรภ์มารดา มีขนาดผิดปกติหรือไม่ดียิ่งขึ้น นอกจากนี้ Pulsed Doppler และ Doppler Color Flow Image ช่วยให้ได้ข้อมูลในด้าน hemodynamics ทำให้การวิเคราะห์สมบูรณ์มากขึ้น การ evaluate ventricular functionของหัวใจทารกในครรภ์มารดาสามารถหาได้จาก M-Mode, 2D-Echo และ Tissue Doppler Image (TDI) การ evaluate foramen ovale, ductus venous, ductus arteriosus ตลอดจน umbilical artery และ vein flow ก็มีความจำเป็นและมีประโยชน์ ถ้าเป็นไปได้ควรทำ Fetal echocardiogram ให้แก่หญิงตั้งครรภ์ทุกรายที่อายุครรภ์ระหว่าง 18-22 สัปดาห์ และพบว่าหญิงตั้งครรภ์ปกติ (ความเสี่ยงต่ำ) ก็มีอัตราการเกิดเป็นโรคหัวใจพิการแต่กำเนิดใกล้เคียงกับมารดาที่ตั้งครรภ์มีความเสี่ยงสูงเช่นกัน

คำสำคัญ : การวิเคราะห์โรคหัวใจพิการแต่กำเนิดในครรภ์มารดาด้วย echocardiogram, Tissue Doppler Image (TDI), การวัดความเร็วของกล้ามเนื้อหัวใจ

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