CHAPTER 3

The Examination of the Normal Fetal Heart

Alessandra Toscano, Luciano Pasquini* and Roberta Iacobelli

Department of Pediatric Cardiology and Cardiac Surgery, Bambino Gesu' Hospital, Rome, Italy

Abstract: The heart, anatomically and embryologically, is a segmented structure. The atria, the ventricles and the great arteries are the three major fundamental components. The heart should be examined echocardiographically by Sequential Segmental Analysis from the venous to the arterial poles following the blood flow. Each segment is evaluated independently considering not only the segmental situs (or location into the body) but also the connections of each heart segment to the others. A systematic approach by Sequential Segmental Analysis is a cornerstone of fetal cardiac study. First step is the identification of fetal heart position followed by the identification of position of the heart in relation to the body and the anatomic study of each cardiac chamber, and finally, the study of cardiac rhythms and function. The heart can be observed in infinity of planes, but few sections are the basis of fetal cardiac study. The examination starts with abdominal cross-sectional view for the identification of the viscero-atrial situs. Then the transthoracic four-chamber view should be obtained. This view allows to obtains a large amount of informations specially regarding the atria and ventricles, atrioventricular valves, interatrial and interventricular septum. Ventriculo-arterial connections are well identified by a gentle sweep towards the fetal neck, left ventricular outflow tract and ascending aorta are first visualized and, by further sweeping, also right ventricular outflow tract, branch pulmonary arteries and ductus arteriosus are correctly identified. The three vessel view give us information regarding left or right location of aortic arch. Short axis of the heart is evaluated from the cavo-atrial and ventricular segments to the ductal and aortic arches. Finally the study of heart rate and rhythm and of myocardial function ends the fetal heart examination.

Key Words: Fetal Heart, Ultrasound, Diagnostic Planes, Segmental Analysis

FETAL CARDIAC ANATOMY

The heart should be examined ultrasonographically by sequential segmental analysis starrting from the venous and finishing at the arterial poles [1]. It is helpful to consider the heart as a segmented structure represented by three regions: atria, ventricles, and great arteries [2]. The two connecting cardiac segments are the atrioventricular canal or junction and the infundibulum or conus arteriosus. Each region, in turn, is partitioned into two components, usually right-sided and left-sided. There are only a limited number of possible connections between the three major regions, regardless of their spatial orientations. In practice, each region is evaluated independently, following the direction of blood flow: systemic and pulmonary veins, atria, atrioventricular valves, ventricles and right ventricular outflow tract, semilunar valves, and great arteries. In a systematic manner, right-sided and left-sided structures at each level are evaluated according to their morphology, their positions and connections to segments. The diagnostic problem generated by congenital heart disease is that the morphologically or anatomically right atrium, left atrium, right ventricle, and left ventricle can from the positional standpoint be "anywhere". Morphologic anatomic identification is the cornerstone of accurate diagnosis. It starts with the identification of readily recognizable landmarks and progresses to more subtle findings. The step-by-step approach that we use includes: the identification of the fetal position, the position of the heart in relation to the body, the number of chambers and their connections, and finally, the rhythm.

POSITION OF THE FETUS IN THE UTERUS

Correct prenatal determination of the fetal right/left axis is essential for the diagnosis of fetal malformations, in particular congenital heart anomalies. To assess the cardiac position in the uterus, observe the fetal position: is it cephalic or breech? Then identify the position of the spine and of the cardiac apex (Clip 1).

LOCATION IN THE CHEST

With regard to the position of the heart in the chest, two questions arise that can be answered: where is the heart

***Address correspondence to Luciano Pasquini:** Department of Pediatric Cardiology and Cardiac Surgery, Bambino Gesu' Hospital, Piazza S.Onofrio, 4 - 00165 Rome Italy; Email: pasquini@opbg.net

Giuseppe Rizzo and Domenico Arduini (Eds)

located, and what is the direction of the cardiac apex? Within the thorax, the heart can be described as left-sided (normal), right-sided, or in a midline position. The position of the heart in the mediastinum is affected not only by underlying cardiac malformations but also by abnormalities in adjacent structures. Some hearts are abnormally displaced from their usual position in the anterior left central chest. This abnormal cardiac position can be caused by a diaphragmatic hernia or space-occupying lesion, such as cystic adenomatoid malformation. Position abnormalities can also be secondary to fetal lung hypoplasia or agenesis. Rightward displacement of the heart constitutes dextroposition, a leftward shift represents levoposition, and shifts toward the midline are called mesoposition.

ORIENTATION IN THE CHEST

The left-right orientation of the abdominal organs and of the heart in vertebrate is a non random and highly conserved phenomenon [3], probably controlled by several genes [4,5,6,7]. Levocardia is the normal state and is caracterized by a ventricular apex that is directed leftward, anteriorly and somewhat inferiorly. In Dextrocardia, the apex is directed to the right of midline [8-11]. Mesocardia is the location of the heart with the cardiac base-apex axis directed to the midline of the thorax [12].

THE ATRIA

There are two main type of visceroatrial situs (situs meaning location). Situs solitus, the normal pattern of anatomic organization in which the right atrium is right -sided and the left atrium is left-sided,. In situs inversus is present an inverted or mirror image pattern where the right atrium is left- sided and the left atrium is right- sided. Situs “ambiguus” indicates that the type of visceroatrial situs is anatomically uncertain or indeterminated, and it occurs in the heterotaxy syndrome with asplenia or polysplenia [13-15].

THE VENTRICLES

There are two types of ventricular situs: D-loop ventricles, in which the morphologically right ventricle is typically right-sided, and the morphologically left ventricle is left-sided. L-loop ventricles, that is, inverted or mirror image ventricles in which the right ventricle is typically left-sided and left ventricle is right-sided [16].

THE GREAT ARTERIES

Solitus Normally Related (the usual normal), Inverted Normally Related (mirror image), Malposition of the Aorta (anterior to the pulmonary artery): D (anterior and right), L (anterior and left), A (just anterior) [17].

FETAL ECHOCARDIOGRAPHIC PROJECTIONS

The heart can be observed in infinity of planes, but few sections are the basis on which most of the diagnoses are made [18]. The basic cardiac screening examination relies on at least five transverse images of the heart and vasculature and three sagittal images [19,20].

ABDOMINAL CROSS-SECTIONAL VIEW

The stomach should be seen on the left side of the fetus and just below the heart and diaphragm. It is important to localize the spine and the transverse descending aorta, which is a circle laying anterior to the spine. Usually in a normal fetus the descending aorta is in the left side and points to the left atrium (Clip 2).

TRANSTHORACIC FOUR CHAMBER VIEW

The four-chamber view is generally easy to achieve and is useful for identifying the atria, ventricles, and respective septae [21]. A normal heart is usually no larger than one-third the area of the chest (Clip 3). The majority of the heart is in left chest. The heart is normally deviated about 45 ± 20◦ (2 standard deviations) toward the left side of the fetus (Fig. **1**). Situs abnormalities should be suspected when the fetal heart and/or stomach is/are not found on the left side as well. The atria should have equal size and thickeness. From the standard 4-chamber view, one should

sweep posteriorly to demonstrate the coronary sinus (Clip 4). The right atrium is anteror and the left posterior. The left atrium is related to the descending aorta posteriorly. The morphologic features of the atrial appendages are usually appreciable only when the atria are outlined by excessive pericardial fluid. The interatrial septum is open at the level of the *foramen ovale*. The *foramen ovale* flap is visible in the left atrium, beating toward the left side [22]. The *foramen ovale* occupies about one third of the atrial septum. The flap valve has a biphasic motion during the cardiac cycle, partially closing at end systole and during atrial contraction end diastole. In the right atrium, two thin lines distinct from the interatrial septum can occasionally be seen. The Eustachian valve, a crest between the inferior vena cava and the wall of the right atrium, is located close to the inferior vena cava. The Chiari network is composed of abnormal lacelike strands that attach to the Eustachian_valve and the *crista terminalis*. It results from the incomplete reabsorption of the *septum spurium*, which should be completed by the 3rd month and persists in about 1% of patients. The confluence of the pulmonary venous connections to the back of the left atrium should be identified. Exception: anomalous venous return. In the four-chamber view the most anterior vein is the inferior pulmonary vein; the most posterior is the superior pulmonary vein. To confirm an apparently normal pulmonary venous connection to the left atrium, forward flow from the vein in the pulmonary parenchyma into the atrium should be documented on color flow mapping (Clip 5), and ideally adding pulsed wave doppler. The normal pulmonary venous pulsed Doppler tracing shows forward flow throughout systole and early diastole with occasionally reversal of flow in late diastole. The flow pattern reflects left atrial events, the “suction” effect of atrial relaxation, followed by descent of the mitral valve orifice, late systole, passive opening of the mitral valve, early diastole, and atrial contraction that may cause minimal flow reversal in late ventricular diastole.

In the second trimester, the ventricles should be approximately equal in size, however, it is important to note that in later gestation, the right ventricle becomes slightly larger than left and should not be confused with pathologic right ventricular dilation [23, 24]. The right ventricle is the most anterior structure and closest to the anterior chest wall. The insertion of the tricuspid valve along the interventricular septum is more apical than the insertion of the mitral valve. The right ventricular apex should contain the moderator band, causing the apex to appear “filled in” (Clip 6). In favorable cases one can note the difference in lining of the two ventricles: the right ventricle has a more coarse lining than the left due to a coarser trabeculation. The left side of the interventricular septum is free of papillary muscle while a papillary muscle, implants on the septum in the right ventricle (i.e. the muscle of the septal leaflet of the tricuspid valve). In the left ventricle there are two papillary muscles in the left ventricle, while in the right ventricle three papillary muscles are prensent. The valve follows the ventricle, thus a bicuspid valve is an indicator of left ventricle, while a tricuspid valve marks a right ventricle. In a normal fetus, there is no atrioventricular valve regurgitation.

Doppler echocardiography may prove to be useful as an adjunct to imaging echocardiography for evaluation of fetal cardiac anatomy and function.

Doppler velocity measurements were obtained by placing the Doppler sample volume immediately distal to the valve leaflets in the ventricle. Using pulsed Doppler, there is a typical biphasic shape of the diastolic flow velocity waveform with an early peak diastolic velocity (E) and a second peak during atrial contraction (A-wave); E is smaller than A, and the E : A ratio increases during pregnancy toward 1, to be inversed after birth. Fetal cardiac blood flow patterns differ from those in the neonate and the adult. Flow in the fetus results from simultaneous ejection from both right and left ventricles into the systemic circulation.

The diameters of the mitral and tricuspid valve annuli can be evaluated as well as the lengths of the left and right ventricles. Several reference limits for dimensional measures based on gestational age have been published [25, 26].

The ventricular septum should appear intact. The ventricular septum will appear thin and an area of dropout may been seen just below the atrioventricular valves when imaged from the apex (Clip 7, Fig. **2**). In an apical four-chamber view, caution should be taken not to confuse this artifact with a ventricular septal defect. Imaging from a lateral view perpendicular to the septum will better demonstrate its thickness and continuity. Small septal defects can be very difficult to confirm if the ultrasound imaging system fails to provide a sufficient degree of lateral resolution, especially if fetal size and position are unfavorable.

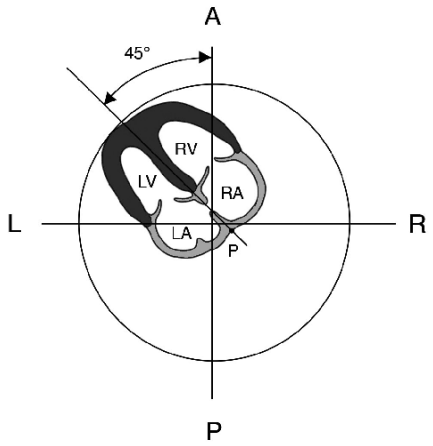

Figure 1: Fetal cardiac axis and position. LA, left atrium, LV, left ventricle, RA, right atrium, RV, right ventricle. The cardiac axis can be measured from a four-chamber view of the fetal heart.

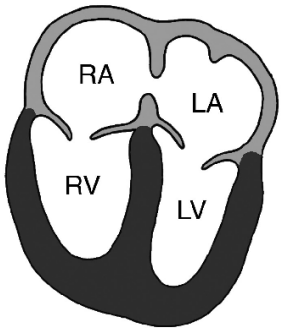

Figure 2: Four- Chamber view of the fetal heart. LA, left atrium, LV, left ventricle, RA, right atrium, RV, right ventricle.

CARDIAC LONG-AXIS VIEW

The long-axis view is aligned with the left ventricular outflow tract (Clip 8, Fig. **3**). Evaluation of outflow tracts can increase the detection rates for major cardiac malformations above those achievable by the four-chamber view alone [27,28]. The four chamber view is inadequate for determining the conotruncus anomaly and in particular Transposition of the Great Arteries, Tetralogy of Fallot, Subaortic Ventricular Septal Defect, Double Outlet Right Ventricle, and Truncus Arteriosus. From the four-chamber view a slight cranial angulation of the transducer should reveal the left ventricular outflow tract the aortic valve and proximal ascending aorta, (also called the five-chamber view) (Clip 9). The left ventricular outflow tract view confirms the presence of a great vessel originating from the left ventricle. The continuity between the mitral and aortic valves and the absence of sub-aortic conus should be noted. The size of the ascending aorta can be measured. The anterior leaflet is in continuity with the posterior wall of the aorta. The anterior wall of the aorta is in continuity with the interventricular septum. The aortic valve and ascending aorta are seen arising centrally from the four- chamber view with the ascending aorta directed toward the right shoulder. The aortic valve moves freely and should not be thickened. For the arterial Doppler studies, the transducer must be positioned so that the sample volume is placed parallel to the flow. With pulsed Doppler, a single peak flow velocity waveform for the aortic valve should be demonstrated. The peak systolic velocity increases from 50 to 110 cm/s during the second half of pregnancy and it is higher across the aortic than the pulmonary valve. Time to peak velocity in the aorta is longer than in the pulmonary trunk. The ventricular output can be calculated by using the product of the valve area and mean velocity of flow, When the left ventricular outflow tract is truly the aorta, it should even be possible to trace the vessel into its arch, from which three arteries originate into the neck. The ventricular septum should appear intact from the apex to crux and from the apex to the anterior wall of the aorta.

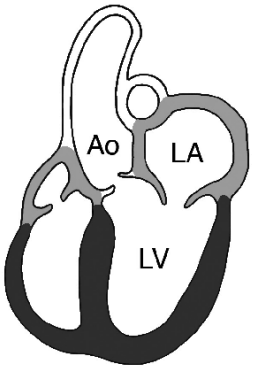

Figure 3: Left ventricular outflow tract. LA, left atrium, LV, left ventricle, Ao, ascending aorta.

FOUR-CHAMBER SWEEP TO THE RIGHT VENTRICULAR OUTFLOW TRACT VIEW

Continuing the sweep toward the fetal neck, a view of the right ventricular outflow tract documents the presence of a great vessel starting from a morphologic right ventricle. The pulmonary artery normally arises from the right ventricle and courses toward the left of the more posterior ascending aorta (Clip 10, Fig. **4**).

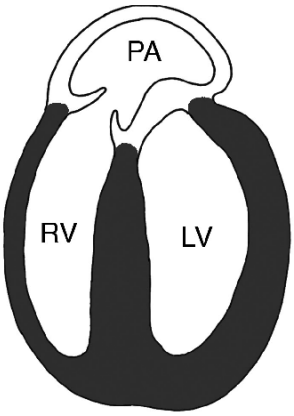

Figure 4: Right ventricular outflow tract. LV, left ventricle, RV, right ventricle. PA, pulmonary artery.

The bifurcation of the pulmonary artery and ductus arteriosus completes this view. The right ventricular outflow tract can be confirmed as a pulmonary artery only if its distal end appears bifurcated. The distal pulmonary artery normally divides toward the left side into a ductus arteriosus that continues into the descending aorta. The right side branch into the right pulmonary artery. The great arteries are similar in size, but the pulmonary artery at the valve ring may be slightly bigger than the aorta. The pulmonary valve is anterior and cranial to the aortic valve. The great arteries cross over at their origin.

THE THREE-VESSEL VIEW

Demonstrates the long axis views of the tranverse aortic arch and ductus arteriosus and the short axis views of the superior vena cava and trachea (Clip 11) [29-33].

THE SHORT AXIS VIEW / THE RIGHT HEART VIEWS

This section demonstrates the right ventricle and the ventricular outflow tract. The main pulmonary artery originates from the anterior ventricle and trifurcates into a large vessel, the ductus going into the descending aorta, and two small vessels, the pulmonary arteries. The pulmonary valve is anterior and cranial to the aortic valve. This is the best section to demonstrate the pulmonary valve (Clip 12, Fig. **5**).

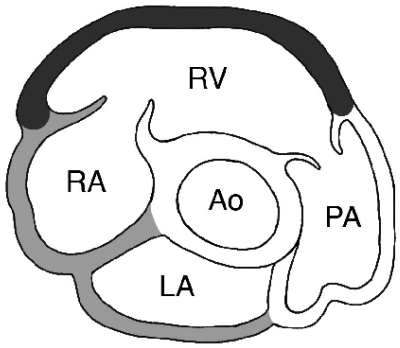

Figure 5: Short-axis view. LA, left atrium, RA, right atrium, RV, right ventricle, PA, pulmonary artery, Ao, aorta.

DUCTAL AND AORTIC ARCH VIEW

In a normal fetus, the aortic arch can be evaluated in both transverse and longitudinal views. The transverse view is more useful because the distal arch can be followed to its connection to the duct, and the two vessels can be directly compared in size, they should be equal in diameter. The longitudinal view shows the tight "hook" shape of the normal arch (Clip 13, Fig. **6**) [34-36]. The aortic arch is obtained with the beam aligned from anterior right of the fetal chest to posterior left of the fetal chest. The side of the aortic arch can be readily shown in fetal life, using the orizzontal view of the arch. The ductal view is obtained when the imaging plane is aligned with the right ventricular outflow tract and main pulmonary artery. In the ductal view, the main pulmonary artery, and ductal arch are well seen and main pulmonary artery size can be easily measured. The ductal arch is formed by the communication of the ductus arteriosus with the descending aorta, appears more flattened than the aortic arch and will have no head and neck vessels arising from it. Note laminar flow, direction, and velocity with color flow and spectral (pulsed wave) Doppler. Normal ductal velocities in 20- to 39-week fetuses range from 50 to 140 cm/sec in peak systole and 6 to 30 cm/sec in peak diastole. Premature ductal constriction is distinguished by either an increase in peak systolic and end diastolic velocities or absolute absence of flow in case of premature closure. Severe constriction leads to progressive right ventricular pressure overload, hydrops, and fetal death. Retrograde flow in the ductus arteriosus should prompt investigation for an right ventricular outflow tract obstruction.

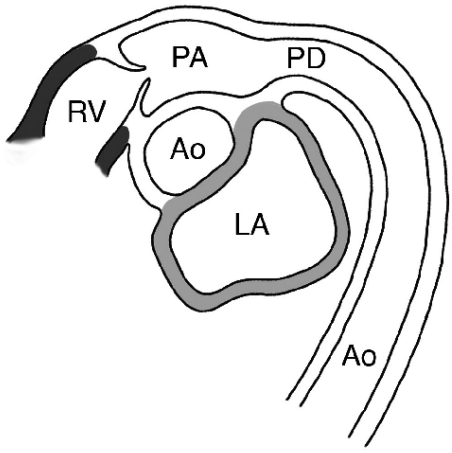

Figure 6: Ductal view and aortic arch view. RV, right ventricle, PA, pulmonary artery, PD, ductus arteriosus, Ao, aortic arch, LA, left atrium.

CAVAL LONG-AXIS VIEW

The caval long-axis view is obtained with the imaging plane parallel to the caval connections to the right atrium. The superior vena cava and the inferior vena cava drain from a posterior position to a medial connection to the right atrium (Clip 14, Fig. **7**).

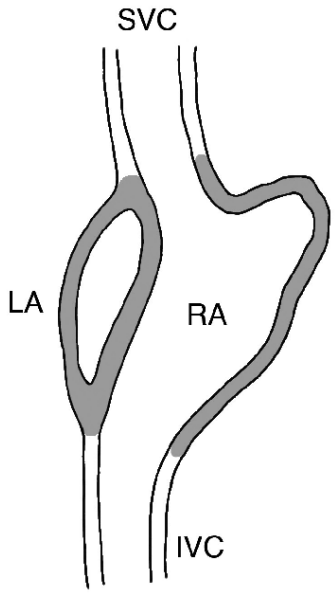

Figure 7: Caval long-axis view. LA, left atrium, SVC, superior vena cava, IVC, inferior vena cava, RA, right atrium.

MYOCARDIAL FUNCTION

An assessment of fetal cardiac function can be made using traditional M mode to provide information on wall thickness and ventricular shortening fraction. An m-mode set of measurements can be made with the beam set perpendicular to the lower half of the interventricular septum [37,38]. The function can be measured as a shortening fraction > 30% (diastole-systole/diastole). Diastolic functions is impaired when a fetal and a fully developed myocardium are compared, indicating that fetal myocardium is less compliant. Observations on the diastolic function of the human fetal myocardium are made by Doppler echocardiographic blood flow velocity profiles. In the human fetus, peak blood flow velocity is greater during active filling (atrial contraction) than during the rapid filling phase, because of the atriosystolic function. This finding indicates diminished ventricular compliance in the fetal heart [39]. The fetus has a limited range of heart rates over which cardiac outputs can be maintained. Prolonged extreme bradycardia (heart rate less than 50 beats/min) or tachycardia (heart rate higher than 200) is known to cause congestive heart failure and hydrops. Some investigators have stated that alterations in heart rate are the major determinants of cardiac output. The relationship between cardiac cycle length and stroke volume indicates that the major regulator of cardiac output in the human fetus is the Frank-Starling mechanism.

HEART RATE

Cardiac rate and regular rhythm should be confirmed. Fetal cardiac activity is detectable from 6 weeks on by suprapubic ultrasound and about one week earlier by transvaginal ultrasound. The normal fetal heart rate varies with gestational age. It is around 100 beats per minute (bpm) at 8 weeks, reaches 175 bpm by 10 weeks, 150 at 15 weeks and slows further to about 140 +- 20 bpm at 20 weeks and 130 + - 20 bpm at term. Mild bradycardia is transiently observed in normal second-trimester fetuses. Fixed bradycardia, especially heart rates that remain below 110 beats per minute, requires timely evaluation for possible heart block. Mild tachycardia (>160 beats per minute) can occur as a normal variant during fetal movement. Persistent tachycardia, however, should be further evaluated for possible fetal distress or more serious tachydysrhythmias [40,41].

REFERENCES

[1] Van Praagh R. The segmental approch to diagnosis in congenital heart disease. The cardiovascular system. Birth Defect : Original article Series 1972; 8: 4-23.

[2] Van Praagh R, Weinberg PM, Matsuoka R, Van Praagh S: Malposition of the heart. In : Adams FH, Emmanouilides GC (eds) : Moss'Heart Disease in Infants, Children and Adolescents, 3rd ed. Baltimore, Williams e Wilkins. 1983; pp. 422-458.

[3] Brown Na, Wolpert J: The developmentof handedness in left/right asymmetry. Development 1990; 109: 1.

[4] Casey B, Devoto M, Jones KL, Ballabio A. Mapping a gene for familial situs abnormalities to human chromosome Xq2 q27.1. Nat Genet 1993; 5: 403–7.

[5] Ferrero GB, Gebbia M, Pilia G *et al.* A submicroscopic deletion in Xq26 associated with familial situs ambiguus. Am J Hum Genet 1997; 61: 395–401

[6] Ware SM, Peng J, Zhu L et al. Identification and functional analysis of ZIC3 mutations in heterotaxy and related congenital heart defects. Am J Hum Genet 2004; 74: 93–105.

[7] Casey B, Devoto M, Jones KL, Ballabio A: Mapping a gene for familiar situs abnormalities to human chromosome Xq24-q27.1 Nature 1993; 5: 403.

[8] Van Praagh R, Van Praagh S, Vlad P, Keith JD: Anatomic types of congenital Dextrocardia. Diagnostic and Embryologic implications. Am J Cardiol 1964; 13: 510-31.

[9] Comstock CH: "Normal fetal heart axis and position." Obstet Gynecol 1987; 70:255-9.

[10] Shipp TD, Bromley BB, Hornberger LK, Nadel A, Benacerraf BR. Levorotation of the fetal cardiac axis: a clue for the presefice of congenital heart disease. Obstet Gynecol 1995, 85: 97-102.

[11] Smith RS, Comstock CH, Kirk JS, Lee W. Ultrasonographic left cardiac axis deviation: a marker for fetal anomalies. Obstet Gynecol 1995; 85: 187-91.

[12] Lev M, Liberthson RR, Golden JG, Eckner FA, Arcilla RA. The pathologic anarthomy of mesocardia. Am J Cardiol 1971; 28 : 428-35.

[13] Macartney FJ, Zuberbuhler JR, Anderson RH. Morphological considerations pertaining to recognition of atrial isomerism. Consequences for sequential chamber localisation. Br Heart J 1980; 44: 657.

[14] Lin JH, Chang CI, Wang JK *et al*. Intrauterine diagnosis of heterotaxy syndrome. Am Heart J 2002; 143: 1002–8.

[15] De Araujo LML, Silverman NH, Filly RA, Golbu MS, Finkbeiner WE, Schmidt KG. Prenatal detection of left atrial isomerism by ultrasound. J Ultrasound Med 1987; 6: 667-70.

[16] Pasquini L, Sanders SP, Parness I, *et al.* Echocardiographic and anatomic findings in atrioventricular discordance with ventriculoarterial concordance. Am J Cardiol 1988 1;62(17):1256-62.

[17] Pasquini L, Sanders SP, Parness IA, Colan SD, Van Praagh S, Mayer JE Jr *et al.* Conal anatomy in 119 patients with d-loop transposition of the great arteries and ventricular septal defect: an echocardiographic and pathologic study. J Am Coll Cardiol 1993; 21(7): 1712-21.

[18] Rychik J, Ayres N, Cuneo B, *et al*. American Society of Echocardiography guidelines and standards for performance of the fetal echocardiogram. J Am Soc Echocardiogr 2004; 17: 803–10.

[19] Wood D, Respondek-Liberska M, Puerto B, Weiner S Perinatal echocardiography: protocols for evaluating the fetal and neonatal heart. World Association of Perinatal Medicine Ultrasonography Working Group. J Perinat Med. 2009; 37(1): 5-11.

[20] Cardiac screening examination of the fetus: guidelines for performing the 'basic' and 'extended basic' cardiac scan. Ultrasound Obstet Gynecol. 2006; 27(1): 107-13.

[21] 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: 648–55.

[22] Berning RA, Silverman NH, Villegas M, Sahn DJ, Martin GR, Rice MJ. Reversed shunting across the ductus arteriosus or atrial septum in utero heralds severe congenital heart disease. J Am Coll Cardiol 1996; 27: 481-6.

[23] Sharland GK, Chan KY, Allan LD. Coarctation of the aorta: difficulties in prenatal diagnosis. Br Heart J 1994; 71: 70–5.

[24] Kirk JS, Comstock CH, Lee W, Smith RS, Riggs TW, Weinhouse E. Fetal cardiac asymmetry: a marker for congenital heart disease. Obstet Gynecol 1999; 93: 189–92

[25] Sharland GK, Allan LD. Normal fetal cardiac measurements derived by cross-sectional echocardiography.Ultrasound Obstet Gynecol 1992; 2: 175-81.

[26] Tan J, Silverman NH, Hoffman JIE, Villegas M, Schmidt KG. Cardiac dimensions determined by cross-sectional echocardiographyechocardiography in the normal human fetus from 18 weeks to term. Am J Cardiol 1992; 70: 1459-67.

[27] Wigton TR, Sabbagha RE, Tamura RK, Cohen L, Minogue JP, Strasburger JF. Sonographic diagnosis of congenital heart disease: comparison between the four-chamber view and multiple cardiac views. Obstet Gynecol 1993; 82: 219– 24.

[28] Kirk JS, Riggs TW, Comstock CH, Lee W, Yang SS, Weinhouse E. Prenatal screening for cardiac anomalies: the value of routine addition of the aortic root to the four-chamber view. Obstet Gynecol 1994; 84: 427–31.

[29] Yoo S-J, Lee Y-H, Cho KS. Abnormal three-vessel view on sonography: a clue to the diagnosis of congenital heart disease in the fetus. AJR Am J Roentgenol 1999; 172: 825– 30.

[30] Kirk JS, Riggs TW, Comstock CH, Lee W, Yang SS, Weinhouse E. Prenatal screening for cardiac anomalies: the value of routine addition of the aortic root to the four-chamber view. Obstet Gynecol 1994; 84: 427–31.

[31] DeVore G. The aortic and pulmonary outflow tract screening examination in the human fetus. J Ultrasound Med 1992; 11: 345–8.

[32] Vinals F, Heredia F, Giuliano A. The role of the three vessels and trachea view (3VT) in the diagnosis of congenital heart defects. Ultrasound Obstet Gynecol 2003; 22: 358–67.

[33] Yagel S, Arbel R, Anteby EY, Raveh D, Achiron R. The three vessels and trachea view (3VT) in fetal cardiac scanning. Ultrasound Obstet Gynecol 2002; 20: 340–5.

[34] Allan LD, Tynan MJ, Campbell S, Wilkinson JL, Anderson RH. Echocardiographic and anatomical correlates in the fetus. Br Heart J 1980; 44: 444–51.

[35] Nomiyama M, Ueda Y, Toyota Y, Kawano H. Fetal aortic isthmus growth and morphology in late gestation. Ultrasound Obstet Gynecol. 2002; 19(2): 153-7.

[36] Pasquini L, Mellander M, Seale A, et al. Z-scores of the fetal aortic isthmus and duct: an aid to assessing arch hypoplasia. Ultrasound Obstet Gynecol. 2007; 29: 628–33.

[37] DeVore GR, Siassi B, Platt LD. Fetal Echocardiography. IV.Mmode assessment of ventricular size and contractility during the second and third trimesters of pregnancy in the normal fetus. Am J Obstet Gynecol 1984; 150: 981–8.

[38] Simpson J. Echocardiographic evaluation of cardiac function in the fetus. Prenatal Diagn 2004; 24: 1081-91.

[39] Reed KL, Sahn DJ, Scagnelli S, Anderson CF, Shenker L. Doppler echocardiographic studies of diastolic function in the human fetal heart: changes during gestation. J Am Coll Cardiol 1986b; 8: 391–5.

[40] Kleinman C, Donnerstein R, Jaffe C, et al. Fetal echocardiography. A tool for evaluation of in utero cardiac arrhythmias and monitoring of in utero therapy. Am J Cardiol 1983; 51:237-43.

[41] Copel JA, Liang RI, Demasio K, Ozeren S, Kleinman CS The clinical significance of the irregular fetal heart rhythm. Am J Obstet Gynecol 2000; 182: 813–17.