# Functional cardiac measurements performed by two-dimensional Doppler echocardiography in normal fetuses: Determination of Z-scores and future prospects

**Luciane Alves Rocha, Nathalie Jeanne Bravo-Valenzuela, Liliam Cristine Rolo, Edward Araujo Júnior**
Department of Obstetrics, Paulista School of Medicine, Federal University of São Paulo (EPM-UNIFESP), São Paulo, Brazil

## ABSTRACT

**Two-dimensional (2D) echocardiogram with the aid of color Doppler and pulsed Doppler allows one to record blood flow waveforms in several structures of the heart. The determination of normal values of these flows in the fetus can help understand cardiac hemodynamics. Given this importance, numerous surveys have been conducted with various existing echocardiographic techniques in order to improve the functional evaluation and consequently, planning of delivery. The aim of this review was to discuss the findings of the reference values of blood flows obtained by 2D echocardiography with Doppler, the current trend of the determination of Z-scores in the functional measurements, and their future prospects.**

**Keywords:** Color Doppler, echocardiography, fetal heart, function, Z-scores

## INTRODUCTION

The anatomical study of the fetal heart is routinely performed by fetal cardiology specialists. However, despite the importance of evaluating fetal cardiac function, there is no consensus to date in relation to the echocardiographic technique that should be used, and often, professionals use their experience to perform a subjective analysis of the heart function.[1,2] There are some difficulties in finding the most appropriate method for a quantitative evaluation and detecting fetal cardiac dysfunction earlier, which is why many researchers are committed to studying various methods currently available.[1-3]

The functional assessment of the fetal heart determines the hemodynamic status and its cardiovascular (CV) adaptation when facing several perinatal complications. These data can be very useful in the clinical management of fetus with growth restriction, monochorionic pregnancies, hydrops fetalis, fetal arrhythmias, and pregnant women with diabetes. Given this importance, numerous studies have been conducted with various existing echocardiographic techniques with the aim of improving the functional evaluation and consequently, planning of childbirth.[2]

Two-dimensional (2D) echocardiogram with the aid of color Doppler and pulsed Doppler enables the recording of blood flow waveforms in several heart structures. In the fetus, these flows can translate the uteroplacental interaction in the maternal–fetal circulation. The waves of the blood flow can be evaluated by measuring the peak velocity and the function of the time in which this wave reaches the peak velocity, with calculation of the velocity–time integral or pulsatility index. Accordingly, an accurate knowledge of the normal values is necessary for an adequate interpretation of the variation of these measures. With this in mind, several studies have recorded blood flow reference values in various

**Access this article online**

Quick Response Code:

Website: www.annalspc.com

DOI: 10.4103/apc.APC_173_18



**How to cite this article:** Rocha LA, Bravo-Valenzuela NJ, Rolo LC, Araujo Junior E. Functional cardiac measurements performed by two-dimensional Doppler echocardiography in normal fetuses: Determination of Z-scores and future prospects. Ann Pediatr Card 2019;12:233-9.

**Address for correspondence:** Prof. Edward Araujo Júnior, Rua Belchior De Azevedo, 156 Apto, 111 Torre Vitoria, São Paulo, CEP 05089-030, Brazil.
E-mail: araujojred@terra.com.br

ways in which these measurements can be performed. The application of Z-score equations, normalizing the reference curves in the functional measures, is a challenge in the current literature, with few studies addressing this topic.

The purpose of this review was to discuss the findings of the reference values of blood flows obtained by 2D echocardiography with Doppler, the current trend of the determination of Z-scores in the functional measurements, and their future prospects.

## METHODS

This review was performed in the following five steps: 1 – the review question; 2 – selection of relevant studies; 3 – quality assessment of the publications; 4 – data synthesis; and 5 – interpretation of the findings.[4] The review question was the following: "What are the normal reference values for fetal cardiac functional echocardiographic parameters?" A search strategy was performed in the PubMed database to identify articles about reference values of fetal cardiac functional parameters published in the English language between 1990 and 2018. The objective was to identify pertinent studies on the functional evaluation of the fetal heart in humans through 2D Doppler echocardiogram. The following mesh terms were used: "fetal heart," "echocardiography," "function," and "reference values." Studies related to tissue three-dimensional (3D) Doppler echocardiography, studies that were not relevant to the subject, and studies where it was not possible to analyze the complete text were excluded. Only studies on normal fetuses with pregnant women without chronic diseases were included.

## RESULTS

### Selected studies

The electronic search demonstrated 119 studies based on titles and abstracts. Of these, 15 were selected and 104 studies were excluded as not meeting the inclusion criteria. Therefore, 15 manuscripts were included in this review.

### Characteristics of the studies included

Among several existing studies on fetal CV hemodynamics, 15 were the most relevant to the theme of our search that addressed the reference values for the measurements of cardiac output of the left and right ventricles and measures of the E and A waves of atrioventricular valves and S and D waves of the pulmonary veins and inferior vena cava performed through fetal echocardiogram with Doppler [Table 1]. From the knowledge of normal values of these measures, we can suggest how the functional cardiac development of the fetus occurs.

## DISCUSSION

### Understanding cardiac hemodynamics of the fetus from the reference values of intracardiac blood flows

CV profile score for the assessment of fetal heart failure has been widely used in the clinical practice, being helpful to identify fetuses at risk of adverse perinatal outcomes.[5,6] This score includes the following parameters: evaluation of hydrops, heart size (ratio between cardiac and thoracic areas), cardiac function (mitral and tricuspid inflow Doppler patterns, right and left ventricle shortening fractions, and presence of mitral and/or tricuspid regurgitation), umbilical vein/arterial and ductus venosus flow Doppler patterns (absent or reversed end-diastolic flow in the umbilical artery, reversed A-wave in ductus venosus, and pulsations in the umbilical vein). The normal value of CV profile score is 10, indicating there are no abnormal signs and values lower than 7 have been related to adverse perinatal outcomes. However, in specific situations, such as fetal growth restriction and early stages of cardiac dysfunction, other parameters should be added to the CV profile score. Draws attention that this score does not include the velocity peaks of ventricular inflow and venous Doppler, but rather the flow pattern of these waves. There is scarcity of studies about reference values for functional parameters which turns difficult its applicability in the clinical practice. Therefore, the knowledge of the normal reference of blood flows obtained by echocardiography with Doppler and the determination of Z-scores in the functional measurements are fundamental.

The 15 included articles focused on reference values of cardiac output measurements, mitral and tricuspid inflow velocities (E and A waves), and Doppler waves of veins (S and D waves) by echocardiography. In general, the authors agree to report an increase in left and right cardiac output with fetal growth, consistently maintaining the right ventricular cardiac output higher than the left, characterizing it as a systemic ventricle throughout the intrauterine period.[7-9]

The classic evaluation of fetal diastolic function has been performed by peak velocity measurements of E (passive ventricular filling) and A (atrial contraction) waves and the E/A ratio with Doppler of mitral and tricuspid blood flow [Figure 1]. After 9 weeks of gestation, it is possible to identify the E and A waves, which maintain E/A ratio always <1.0 until the term because the fetal heart is stiffer due to the higher collagen content preload. The inversion of this ratio indicates diastolic impaired ventricular filling, which can be helpful to detect diastolic dysfunction.[2,10] Using tissue Doppler, the quantification of myocardial peak

**Table 1: Studies related to the reference values of functional measurements of fetal echocardiography**

| Studies | *n* | Country | GA (weeks) | Reference values | Percentile curves | *Z*-score | Applicability of the score |
|---|---|---|---|---|---|---|---|
| Vimpeli *et al*., 2009[8] | 143 | Finland | 11-20 | CCO increased (9-121 mL/min) | Output of RV and LV and combined | No | - |
| Gagnon *et al*., 2016[7] | 104 | Canada | 18-39 | 57 measures, including CO of LV and RV, E and A waves of MV and TV, and S and D waves of IVC | *Z*-score curve | Yes | Difficult interpretation of the equation |
| Mielke *et al*., 2001[9] | 222 | Germany | 13-41 | CCO increased (40-1470 mL/min) | CO and volume of the LV and RV, FO, and DA | No | - |
| Rozmus *et al*., 2010[13] | 198 | Poland | 11-14 | E and A waves increase in the MV and TV | Tei index and E and A waves of the MV and TV | No | - |
| Harada *et al*., 1997[14] | 307 | Portland | 17-39 | E wave increases and A wave is constant in the MV and TV (in the GA groups) | E and A waves of the MV and TV | No | - |
| Hecher *et al*., 1994[15] | 143 | London | 20-40 | S and D waves increase in DV, HV, and IVC; E wave increases; A wave is constant in the MV; E and A waves are constant in the TV | DV, HV, IVC, MV and TV | No | - |
| Gallarreta *et al*., 2010[28] | 46 | Brazil (Ribeirão Preto) | 22-38 | DV and IVC increase velocity with decreasing PI. Increased acceleration time | DV and IVC | No | - |
| Axt-Fliedner *et al*., 2005[29] | 329 | Germany | 20-42 | S and D waves increase in IVC; PI and PIV of these veins decrease | DV, IVC and HV | Yes | Difficult interpretation of the equation |
| Luewan *et al*., 2012[30] | 645 | Thailand | 12-40 | a/S, S-a/D, S-a/$T_{max}$ | IVC | Yes | Clearer interpretation |
| Bahlmann *et al*., 2016[19] | 365 | Germany | 18-41 | S, D, and A waves increase | PV | No | - |
| Brezinka *et al*., 1999[23] | 60 | Netherlands | 20-36 | ET, FT, ICT, and IRT do not change | PV | No | - |
| Better *et al*., 1996[20] | 52 | USA (NY) | 16-38 | S, D, and A waves increase without the influence of HR | PV | No | - |
| Paladini *et al*., 1997[21] | 101 | Italy | | S, D, and A waves increase | PV | No | - |
| Laudy *et al*., 1995[22] | 123 | Netherlands | 20-40 | S, D, and A waves increase and S/D wave decreases | PV | No | - |
| Lenz *et al*., 2002[18] | 98 | Germany | 19-37 | S, D, and A waves increase | PV | No | - |

CCO: Combined cardiac output, LV: Left ventricular, RV: Right ventricular, CO: Cardiac output, MV: Mitral valve, TV: Tricuspid valve, IVC: Inferior vena cava, FO: Foramen ovale, DA: Ductus arteriosus, GA: Gestational age, DV: Ductus venosus, HV: Hepatic vein, PI: Pulsatility index, PIV: Pulsatility index for the vein, PV: Pulmonary vein, ET: Ejection time, FT: Filling time, ICT: Isovolumic contraction time, IRT: Isovolumic relaxation time, HR: Heart rate

velocity and E'/A' ratio enable the evaluation of fetal segmental diastolic function (septal and of the walls of the ventricles).[11,12]

Among all the 15 included studies, three of them evaluated blood flows of the mitral and tricuspid valves, and these present some controversy.[13,14] Rozmus-Warcholinska *et al*.[13] and Hecher *et al*.[15] observed that the E and A waves increased with gestational age. Harada *et al*.[14] found an increasing E wave throughout pregnancy, and the A wave was constant in the mitral and tricuspid valves, suggesting a possible maturation of the ventricles in a later period of pregnancy or after delivery. Thus, we noticed that there are still differences with respect to the flow pattern of the atrioventricular valves, and this evaluation may be important for the interpretation of hemodynamic events in the fetal heart.

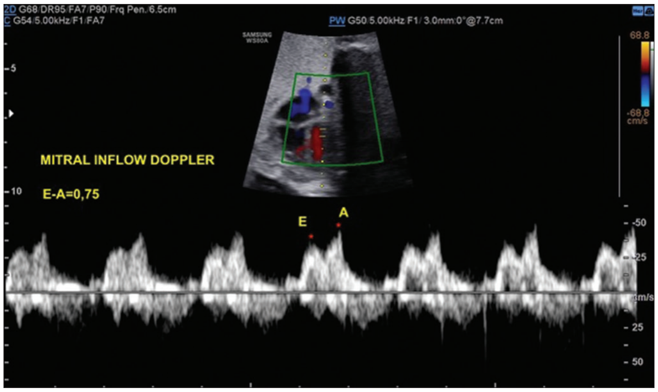


**Figure 1: Doppler tracing of mitral inflow obtained at four-chamber view showing normal pattern of left ventricle diastolic filling with E/A ratio <1.0. The sample volume of the pulsed Doppler (2–3 mm) is positioned in the left ventricle immediately distal to the mitral valve at an insonation angle smaller than 20°. LV: Left ventricle, LA: Left atrium, RV: Right ventricle, RA: Right atrium, M: Mitral valve flow, E: E-wave (passive ventricular filling), A: A-wave (atrial contraction)**

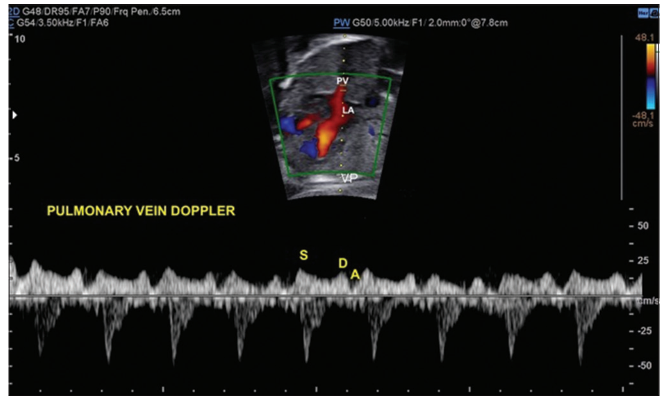


**Figure 2: Pulmonary vein Doppler obtained at four-chamber view at the venoatrial junction, at the right superior pulmonary vein with the left atrium showing normal pattern flow (S, D, and A waves). PV: Pulmonary vein, LA: Left atrium, S: systolic wave, D: Diastolic wave, A: Presystolic velocity (during atrial contraction)**

Similar to ductus venosus, the pattern of pulmonary vein Doppler is triphasic velocity waveform which corresponds to different phases of cardiac cycle: S-wave (peak during ventricular systole), D-wave (peak during ventricular diastole), and A-wave (peak during atrial contraction-late diastole) [Figure 2]. Some studies regarding reference values for ductus venosus Doppler flow in fetuses have been published; however, studies for reference values of pulmonary venous flow Doppler are scarce.[16-18]

In this review, a total of six studies related to the evaluation of the pulmonary veins were identified. Among them, five studies demonstrated an increase in the peak velocity on the S and D waves throughout the gestational period.[18-22] Brezinka *et al.*[23] evaluated the pulmonary vein flow with ejection time, filling time, and isovolumetric contraction and relaxation. With this evaluation parameter, they concluded that there were changes in the pattern of pulmonary vein flow during pregnancy.[23] Here, we identify another issue in which we can ask ourselves when the maturation of the ventricles would really occur: in the postnatal or late gestational period. The analysis of pulmonary vein Doppler is widely used in pediatric and adult clinical practice. In fetuses, it has been proposed as a good echocardiographic Doppler parameter to assess the left heart function because it reflects changes in the left atrial pressure.[24,25] Therefore, potential clinical applications for pulmonary vein Doppler are conditions with possible increase of left atrial pressure, such as fetuses of diabetic pregnant women with myocardial hypertrophy, fetuses with hypoplastic left heart syndrome, and in fetal growth restriction.[26,27] Accordingly, the knowledge of normal reference values of the velocities of the waves of the pulmonary venous waves and its pattern is fundamental.

Under physiological hemodynamics, Doppler vena cava waves are triphasic in shape and are described as follows: S-wave (during ventricular systole), D-wave (during ventricular diastole), and A-wave (reversed flow during atrial contraction) [Figure 3]. An increase of presystolic reverse flow of inferior vena cava (A wave exceeding 15% of the systolic component) is evidence of increase of central venous pressure. It reflects the preload of the right ventricle and right atrial dynamics. In this review, the flows in the inferior vena cava were studied in limited manner in four studies, probably due to the difficulty in appropriately aligning the pulsed Doppler. According to the studies, the S and D waves increase with the progression of pregnancy, being justified by the fall of placental resistance and increased cardiac output, resulting in higher suction force in the inferior vena cava and greater increase in D and S waves with the growth of the fetus.[15,29,30]

### Determining Z-score equations for the reference values of functional measurements by two-dimensional Doppler echocardiography

The elaboration of equations for the calculation of the Z-score is well determined in the structural measurements of the fetal heart, but when we consider functional measures, there are scarce published data.[31,32] Only three articles describe these equations in the functional measurements of the fetal heart using 2D pulsed Doppler [Table 1].

Axt-Fliedner *et al.*,[29] in a study conducted in 2005 in Germany, found some characteristics in blood flows from the inferior vena cava, ductus venosus, and right hepatic vein. A total of 329 fetuses were observed, between 20 and 42 weeks of gestation, and in relation to the inferior vena cava, relevant to our research interest, an increase in the S and D waves was observed along with gestational age. Using the values found in the inferior vena cava, the authors developed equations to estimate the Z-score.[29]

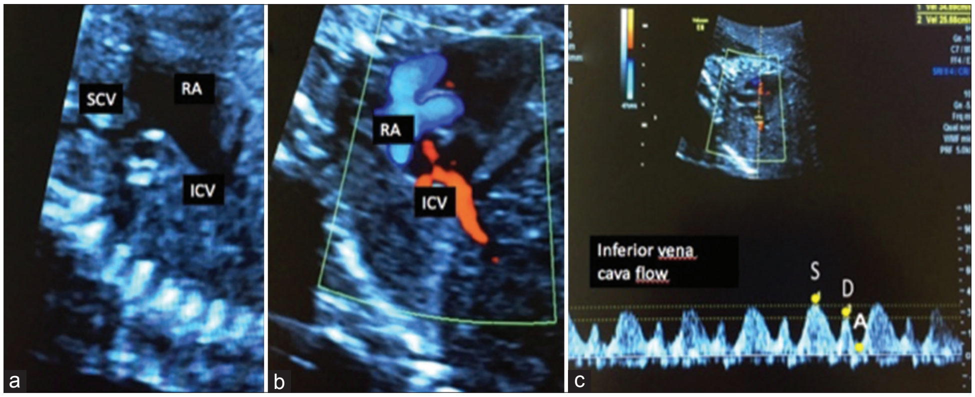


**Figure 3: Normal Doppler waveforms of inferior vena cava Doppler obtained at sagittal view of superior and inferior vena cavas (a). The color Doppler filter was adjusted to lower pulse repetition frequency (b) and the pulsed Doppler sample located in the inferior vena cava with angle of acquisition smaller than 30° (c). RA: Right atrium; SVC: Superior vena cava, IVC: Inferior vena cava, S: Systolic wave, D: diastolic wave, A: Presystolic velocity (during atrial contraction)**

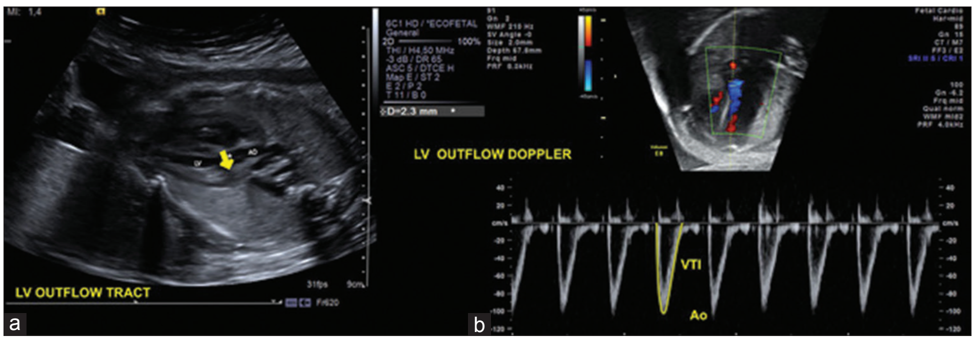


**Figure 4: Calculation of the left ventricle cardiac output in fetuses using the two-dimensional method: cardiac output = heart rate × left ventricle stroke volume (diameter of the left ventricular outflow tract × velocity time integral of the left ventricular outflow tract). (a) Measurement of the left ventricular outflow tract in left-outflow tract view (red arrow); (b) Velocity time integral of the left ventricular outflow tract obtained in the outflow tract view. CO: Cardiac output, SV: Stroke volume, VTI: Mean velocity time integral, LV: Left ventricle, Ao: Aorta**

Coincidentally, also in 2005, the most recent research on the Z-score of structural measures of the fetal heart was published.[32] Schneider *et al.*[32] studied 17 structural cardiac measures in 130 fetuses between 15 and 39 weeks of gestation and, using regression equations, developed Z-score formulas widely used in echocardiographic practice.

Vimpeli *et al.*,[8] in 2009, developed a method to estimate the equation of the curve of the percentiles of the left and right ventricular cardiac output measures [Figure 4]. A total of 143 fetuses were studied, from 11 to 20 weeks of gestation, and Z-scores were not developed through this reference curves.

Luewan *et al.*,[30] in 2012, presented the largest study found in the development of Z-score equations, with the assessment of the inferior vena cava in 645 fetuses between 12 and 40 weeks of gestation. The flow pattern of the inferior vena cava was studied through the pulsatility index, peak velocity index, and preload. The Z-score equations were developed for these measures.

More recently, in 2016, Gagnon *et al.*[7] published a study that presented the largest number of variables measured with the development of the calculations for the Z-scores. A total of 104 fetuses between 18 and 39 weeks of gestation were studied, with 57 measures, including measures of cardiac output of the ventricles [Figure 4] and flow of atrioventricular valves and the inferior vena cava, except for measurements of the pulmonary veins. The equations shown underwent various transformation functions in an attempt to approach a normal distribution, with the result that the formulas were extensive and difficult to interpret.[5]

## Future perspectives

With the technological advances, several tools are emerging for the functional cardiac evaluation. Among them, we can mention the techniques that use the 3D method to estimate cardiac output and volume,[33] as well as the method of evaluation of myocardial fiber deformity by speckle tracking[34-37] and methods which evaluate the contraction velocity of myocardial fibers derived from tissue Doppler.[38] All these tools generate reference values for normal cardiac function in the fetus, from which we can also develop Z-score equations for each technique. Future studies may focus on the validation of such equations of the various existing techniques.

## CONCLUSION

Given the scarce studies addressing the Z-scores in functional measurements in the fetal heart and as these still have sample limitations and equations of limited applicability, the current challenge is to develop more didactic equations to estimate the Z-score of functional measurements of the fetal heart in a more significant sample population and perform its validation in populations of fetuses exposed to the risk of cardiac dysfunction. With the accumulation of information on normal structural and functional measures of the fetal heart, the use of the Z-score will increasingly become part of the routine of the fetal echocardiographic practice as already occurs in the pediatric and adult echocardiographic evaluation.

**Financial support and sponsorship**

Nil.

**Conflicts of interest**

There are no conflicts of interest.

## REFERENCES

1. Donofrio MT, Moon-Grady AJ, Hornberger LK, Copel JA, Sklansky MS, Abuhamad A, *et al.* Diagnosis and treatment of fetal cardiac disease: A scientific statement from the American heart association. Circulation 2014;129:2183-242.
2. Hernandez-Andrade E, Benavides-Serralde JA, Cruz-Martinez R, Welsh A, Mancilla-Ramirez J. Evaluation of conventional Doppler fetal cardiac function parameters: E/A ratios, outflow tracts, and myocardial performance index. Fetal Diagn Ther 2012;32:22-9.
3. Godfrey ME, Messing B, Cohen SM, Valsky DV, Yagel S. Functional assessment of the fetal heart: A review. Ultrasound Obstet Gynecol 2012;39:131-44.
4. Khan KS, Kunz R, Kleijnen J, Antes G. Five steps to conducting a systematic review. J R Soc Med 2003;96:118-21.
5. Hofstaetter C, Hansmann M, Eik-Nes SH, Huhta JC, Luther SL. A cardiovascular profile score in the surveillance of fetal hydrops. J Matern Fetal Neonatal Med 2006;19:407-13.
6. Huhta JC. Fetal congestive heart failure. Semin Fetal Neonatal Med 2005;10:542-52.
7. Gagnon C, Bigras JL, Fouron JC, Dallaire F. Reference values and Z scores for pulsed-wave Doppler and M-mode measurements in fetal echocardiography. J Am Soc Echocardiogr 2016;29:448-60.e9.
8. Vimpeli T, Huhtala H, Wilsgaard T, Acharya G. Fetal cardiac output and its distribution to the placenta at 11-20 weeks of gestation. Ultrasound Obstet Gynecol 2009;33:265-71.
9. Mielke G, Benda N. Cardiac output and central distribution of blood flow in the human fetus. Circulation 2001;103:1662-8.
10. Tulzer G, Khowsathit P, Gudmundsson S, Wood DC, Tian ZY, Schmitt K, *et al.* Diastolic function of the fetal heart during second and third trimester: A prospective longitudinal Doppler-echocardiographic study. Eur J Pediatr 1994;153:151-4.
11. Comas M, Crispi F, Cruz-Martinez R, Martinez JM, Figueras F, Gratacós E. Usefulness of myocardial tissue Doppler vs. conventional echocardiography in the evaluation of cardiac dysfunction in early-onset intrauterine growth restriction. Am J Obstet Gynecol 2010;203:45.e1-7.
12. Naujorks AA, Zielinsky P, Beltrame PA, Castagna RC, Petracco R, Busato A, *et al.* Myocardial tissue Doppler assessment of diastolic function in the growth-restricted fetus. Ultrasound Obstet Gynecol 2009;34:68-73.
13. Rozmus-Warcholinska W, Wloch A, Acharya G, Cnota W, Czuba B, Sodowski K, *et al.* Reference values for variables of fetal cardiocirculatory dynamics at 11-14 weeks of gestation. Ultrasound Obstet Gynecol 2010; 35:540-547.
14. Harada K, Rice MJ, Shiota T, Ishii M, McDonald RW, Reller MD, *et al.* Gestational age- and growth-related alterations in fetal right and left ventricular diastolic filling patterns. Am J Cardiol 1997;79:173-7.
15. Hecher K, Campbell S, Snijders R, Nicolaides K. Reference ranges for fetal venous and atrioventricular blood flow parameters. Ultrasound Obstet Gynecol 1994;4:381-90.
16. Prefumo F, Risso D, Venturini PL, De Biasio P. Reference values for ductus venosus Doppler flow measurements at 10-14 weeks of gestation. Ultrasound Obstet Gynecol 2002;20:42-6.
17. Turan OM, Turan S, Sanapo L, Willruth A, Berg C, Gembruch U, *et al.* Reference ranges for ductus venosus velocity ratios in pregnancies with normal outcomes. J Ultrasound Med 2014;33:329-36.
18. Lenz F, Chaoui R. Reference ranges for Doppler-assessed pulmonary venous blood flow velocities and pulsatility indices in normal human fetuses. Prenat Diagn 2002;22:786-91.
19. Bahlmann F, Gallinat R, Schmidt-Fittschen M, Al Naimi A, Reinhard I, Willruth A. Fetal pulmonary venous blood flow velocities in a normal population and new calculated reference values. Prenat Diagn 2016;36:1033-40.
20. Better DJ, Kaufman S, Allan LD. The normal pattern of pulmonary venous flow on pulsed Doppler examination of the human fetus. J Am Soc Echocardiogr 1996;9:281-5.
21. Paladini D, Palmieri S, Celentano E, Guida F, Salviati M, Morra T, *et al.* Pulmonary venous blood flow in the human fetus. Ultrasound Obstet Gynecol 1997;10:27-31.
22. Laudy JA, Huisman TW, de Ridder MA, Wladimiroff JW. Normal fetal pulmonary venous blood flow velocity. Ultrasound Obstet Gynecol 1995;6:277-81.
23. Brezinka C, Laudy JA, Ursem NT, Hop WC, Wladimiroff JW. Fetal pulmonary venous flow into the left atrium relative to diastolic and systolic cardiac time intervals. Ultrasound Obstet Gynecol 1999;13:191-5.

24. Talbert DG, Johnson P. The pulmonary vein Doppler flow velocity waveform: Feature analysis by comparison of *in vivo* pressures and flows with those in a computerized fetal physiological model. Ultrasound Obstet Gynecol 2000;16:457-67.
25. Keren G, Sherez J, Megidish R, Levitt B, Laniado S. Pulmonary venous flow pattern – Its relationship to cardiac dynamics. A pulsed Doppler echocardiographic study. Circulation 1985;71:1105-12.
26. Crowe DA, Allan LD. Patterns of pulmonary venous flow in the fetus with disease of the left heart. Cardiol Young 2001;11:369-74.
27. Bravo-Valenzuela NJ, Peixoto AB, Nardozza LM, Souza AS, Araujo Júnior E. Applicability and technical aspects of two-dimensional ultrasonography for assessment of fetal heart function. Med Ultrason 2017;19:94-101.
28. Gallarreta FM, Martins WP, Nastri CO, Mauad Filho F, Nicolau LG, Barra DA, *et al.* Evaluation of ductus venosus and inferior vena cava by using multiple Doppler ultrasound parameters in healthy fetuses. Arch Gynecol Obstet 2011;283:959-63.
29. Axt-Fliedner R, Wiegank U, Fetsch C, Friedrich M, Krapp M, Georg T, *et al.* Reference values of fetal ductus venosus, inferior vena cava and hepatic vein blood flow velocities and waveform indices during the second and third trimester of pregnancy. Arch Gynecol Obstet 2004;270:46-55.
30. Luewan S, Srisupundit K, Tongprasert F, Tongsong T. Normal reference ranges of inferior vena cava Doppler indices from 14 to 40 weeks of gestation. J Clin Ultrasound 2012;40:214-8.
31. Pasquini L, Mellander M, Seale A, Matsui H, Roughton M, Ho SY, *et al.* Z-scores of the fetal aortic isthmus and duct: An aid to assessing arch hypoplasia. Ultrasound Obstet Gynecol 2007;29:628-33.
32. Schneider C, McCrindle BW, Carvalho JS, Hornberger LK, McCarthy KP, Daubeney PE. Development of Z-scores for fetal cardiac dimensions from echocardiography. Ultrasound Obstet Gynecol 2005;26:599-605.
33. Simioni C, Araujo Júnior E, Martins WP, Rolo LC, Rocha LA, Nardozza LM, *et al.* Fetal cardiac output and ejection fraction by spatio-temporal image correlation (STIC): Comparison between male and female fetuses. Rev Bras Cir Cardiovasc 2012;27:275-82.
34. DeVore GR, Klas B, Satou G, Sklansky M. Evaluation of fetal left ventricular size and function using speckle-tracking and the Simpson rule. J Ultrasound Med 2019;38:1209-21.
35. DeVore GR, Klas B, Satou G, Sklansky M. Speckle tracking of the basal lateral and septal wall annular plane systolic excursion of the right and left ventricles of the fetal heart. J Ultrasound Med 2019;38:1309-18.
36. DeVore GR, Klas B, Satou G, Sklansky M. Quantitative evaluation of fetal right and left ventricular fractional area change using speckle-tracking technology. Ultrasound Obstet Gynecol 2019;53:219-28.
37. DeVore GR, Klas B, Satou G, Sklansky M. Evaluation of the right and left ventricles: An integrated approach measuring the area, length, and width of the chambers in normal fetuses. Prenat Diagn 2017;37:1203-12.
38. Takano M, Nakata M, Nagasaki S, Ueyama R, Morita M. Assessment of diastolic function of normal fetal heart using dual-gate Doppler. Ultrasound Obstet Gynecol 2018;52:238-42.