Predicting the Future: Delivery Room Planning of Congenital Heart Disease Diagnosed by Fetal Echocardiography

Mary T. Donofrio, MD[1]

[1] Division of Cardiology, Fetal Heart Program, Children's National Health System, Washington, District of Columbia

Am J Perinatol 2018;35:549–552.

Address for correspondence Mary T. Donofrio, MD, Division of Cardiology, Fetal Heart Program, Children's National Health System, 111 Michigan Avenue, Northwest, Washington, DC 20010 (e-mail: MDonofri@childrensnational.org).

Abstract

Advances in prenatal imaging have improved the examination of the fetal cardiovascular system. Fetal echocardiography facilitates the prenatal diagnosis of congenital heart disease (CHD) and through sequential examination, allows assessment of fetal cardiac hemodynamics, predicting the evolution of anatomical and functional cardiovascular abnormalities in utero and during the transition to a postnatal circulation at delivery. This approach allows detailed diagnosis with prenatal counseling and enables planning to define perinatal management, selecting the fetuses at a risk of postnatal hemodynamic instability who are likely to require a specialized delivery plan. The prenatal diagnosis and management of critical neonatal CHD has been shown to play an important role in improving the outcome of newborns with these conditions, allowing timely stabilization of the circulation prior to cardiac intervention or surgery, thus reducing the risk of perioperative morbidity and mortality. Diagnostic protocols aimed at risk-stratifying severity and potential postnatal compromise in fetuses with CHD have been developed to identify those who may require special intervention at birth or within the first days of life. In addition, new methodologies are being studied to improve the accuracy of prediction of disease severity. Perinatal management of neonates with a prenatal diagnosis of CHD requires a close collaboration between obstetric, neonatal, and cardiology services. In this article, the management of fetuses with CHD will be discussed, along with summarizing the in utero and fetal echocardiographic findings used for risk stratification of newborns with CHD and reviewing the basic principles used for planning for neonatal resuscitation and initial transitional care of these complex newborns.

Keywords

- fetal echocardiography
- prenatal diagnosis
- delivery management
- congenital heart disease

Advances in fetal echocardiography (FE) have provided a detailed characterization of cardiac anatomy and physiology, and through sequential examination, assessment of changes that occur during gestation. When a cardiac anomaly is identified, a perinatal management plan for those at a risk of postnatal hemodynamic instability can be created. In recent years, protocols for risk stratification of congenital heart disease (CHD) based on FE parameters, taking into account the severity of the cardiac defect and the expected degree of postnatal hemodynamic compromise, have been developed.[1–4] Management of newborns with a prenatal diagnosis of CHD requires a multidisciplinary team composed of fetal and pediatric cardiologists, obstetricians, maternal–fetal specialists, neonatologists, and surgical specialists.[5]

Fetal/Transitional Circulation

The risk of hemodynamic instability at birth in CHD depends on the type of cardiac defect, how the circulation is affected by changes in pulmonary and systemic resistance that occur with transition, and whether patency of the fetal shunt pathways including the foramen ovale (FO) and ductus

DOI https://doi.org/10.1055/s-0038-1637764.
ISSN 0735-1631.

arteriosus (DA) are necessary to deliver blood to the systemic or pulmonary circulations. While the factors that influence the evolution of CHD need further investigation, the potential progression of CHD in utero supports sequential evaluation. Serial FE creates possibilities for fetal intervention to alter the natural history of CHD as well as assists clinicians in delivery planning for specific CHDs that evolve in utero.[6]

Delivery Planning for Congenital Heart Disease

The majority of neonates with CHD do not require specialized care in the perinatal period. The delivery plan can be determined by maternal care needs with routine neonatal care and pediatric outpatient cardiology care. In contrast, for newborns at a risk of compromise, delivery at the cardiac center or in close proximity may improve outcome. Previous studies have shown that infants with a prenatal diagnosis of high-risk CHD and appropriate postnatal management have a better outcome compared with those diagnosed postnatally.[7] Delivery planning requires multidisciplinary collaboration. Care is determined by the risk of hemodynamic instability anticipated, the medical resources available, the availability and distance of transportation to the cardiac center, and any obstetric or maternal complications. When highly specialized care is needed, strategies to avoid delays in treatment are essential. The advantages of in utero versus postnatal transportation of the fetus (vs. newborn) with CHD vary according to the local obstetric and pediatric resources available. In addition, if an induction or planned cesarean section is considered, it should be noted that infants with CHD delivered near term have a lower mortality compared with those delivered before 39 weeks.[8] Studies have found that infants with CHD diagnosed prenatally tend to be born earlier and with lower birthweights compared with newborns diagnosed postnatally.[9] While this is, in part, related to necessary planned delivery coordination, in the absence of fetal or maternal complications, the advantages of term delivery should be considered.

Models for Risk-Stratified Delivery Room and Postnatal Care

Several authors[1–4] have proposed prenatal classification protocols for postnatal risk in newborns with CHD. Recently, the American Heart Association Statement on Fetal Cardiology described a comprehensive protocol for delivery room (DR) risk stratification of CHD using FE criteria.[10] Levels of postnatal care (LOC) are based on expected cardiovascular compromise and then linked to specific management strategies.

Low-risk CHD (LOC 1): CHDs that are expected to be stable at birth include left-to-right shunt lesions, mild valve abnormalities, and benign arrhythmias. In the absence of maternal or obstetric risk, newborns with low-risk CHD usually can be delivered at or near term through a normal mode of delivery and require confirmation of the diagnosis and outpatient cardiology follow-up.[10]

Minimal-risk CHD (LOC 2): CHDs with severe pulmonary or systemic outflow tract obstruction are usually stable in the DR, though they become compromised as the DA closes. The delivery plan for these babies includes assuring that a neonatologist is present in the DR, administration of prostaglandin E1 (PGE1), open communication with pediatric cardiology, and transport to the cardiac center for intervention/surgery.[10] DR recommendations vary based on the presence of additional fetal or maternal or obstetrical factors that may impact mode of delivery, pediatric resources available at the delivery hospital, and the distance to the cardiac center.

Historically, ductal-dependent cardiac lesions were considered to be critical CHDs since newborns with these defects often presented in extremis with DA closure. Newborns identified prenatally with ductal-dependent CHD can now be stabilized with PGE1 and therefore, as long as neonatal resources are available, can be considered to be at minimal risk of DR compromise. Findings on FE that predict a ductal-dependent pulmonary circulation at delivery include the following:[10] (1) reversed flow in the DA, (2) reversed orientation of the DA with an angle $<$90 degrees between the DA and aorta, and (3) pulmonary valve z-score of less than –3 after 16 weeks' gestation in tetralogy of Fallot (TOF) (►**Table 1**). The following features identified during fetal assessment of CHD can be used to predict a ductal-dependent systemic circulation at delivery:[10] (1) reversed blood flow across the FO and (2) reversed systolic flow in the transverse aorta (►**Table 1**).

High-risk CHD (LOC 3 and 4): CHDs at the highest risk of cardiovascular compromise in the DR include defects that require immediate stabilization with cardiac intervention such as balloon atrial septostomy (BAS) for D-transposition of the great arteries (D-TGAs), atrial septoplasty for hypoplastic left heart syndrome (HLHS) with restrictive/intact atrial septum (RAS/IAS), cardioversion of unstable arrhythmias, or urgent pediatric cardiothoracic surgery or extracorporeal membrane oxygenation for obstructed total anomalous pulmonary venous return (TAPVR) or severe CHD with cardiac failure. For infants with prenatal diagnosis of these high-risk CHDs, delivery should be planned at a cardiac center with availability of the neonatologist and cardiologist in the DR or with coordinated initial stabilization in the DR with urgent transportation to the nearby cardiac center. Mode and timing of delivery are determined by the multidisciplinary care team, and a planned induction or cesarean section is often proposed to ensure institution of the postnatal care plan.

FE parameters that predict need for urgent cardiac intervention at birth because of rapid deterioration from severe hypoxia and low cardiac output in HLHS with a RAS/IAS and obstructed pulmonary venous flow include the following:[10] (1) pulmonary vein Doppler velocity–time interval with the ratio of forward/reversed flow $<$ 3 and (2) lack of pulmonary vasoreactivity during maternal hyperoxia (MH) testing[11] (►**Table 1**). Given that FO restriction can become more severe in the third trimester, serial assessment during pregnancy is recommended. In a prospective study, pulmonary vein Doppler predicted the need for atrial septoplasty with a sensitivity of 100% and a specificity of 97%.[1] An additional advantage of fetal diagnosis is the potential for in utero intervention to open the atrial septum prior to delivery.[12]

Table 1 Risk-stratified classification of delivery room care of newborns with CHD

Predicted risk of DR instability	LOC	Obstetric recommendations	Neonatal recommendations	CHD diagnoses
Low/not expected	LOC 1	Mode and time of delivery based on level of maternal care	No specialized care in the DR Cardiology consult with outpatient follow-up	Shunt lesions (VSD, ASD, AVSD) Mild valve disease Benign arrhythmias
Minimal	LOC 2	Mode and time of delivery based on level of maternal care Planned delivery $\geq$ 39 weeks can be considered to coordinate services	Neonatologist in the DR, PGE1 if indicated Transport to the cardiac center for intervention/ surgery	Ductal-dependent lesions including HLHS, PA/IVS, severe TOF Nonsustained or controlled tachyarrhythmias or bradyarrhythmias with adequate ventricular rate
High	LOC 3	Mode and time of delivery usually planned with delivery at 38–39 weeks to coordinate services	Neonatologist and cardiologist in the DR Plan for urgent intervention/ catheterization or urgent transport if indicated	HLHS at a risk of RAS D-TGAs at a risk of RAS CHD or arrhythmia with decreased heart function
High	LOC 4	Mode and time of delivery usually planned with delivery (possible c/s) at 38–39 weeks (or earlier if fetal cardiac dysfunction, or hydrops and GA appropriate) at the cardiac center	Neonatologist, cardiologist and surgery team (if indicated) in the DR Plan for intervention/ catheterization, surgery or ECMO	HLHS with RAS or IAS TGA with RAS or IAS, abnormal DA Obstructed TAPVR Tachyarrhythmia or bradyarrhythmia with hydrops Severe Ebstein's anomaly or TOF/APV with hydrops

Abbreviations: APV, absent pulmonary valve; ASD, atrial septal defect; AVSD, atrioventricular septal defect; CHD, congenital heart disease; c/s, cesarean section; DR, delivery room; D-TGAs, transposition of the great arteries; ECMO, extracorporeal membrane oxygenation; GA, gestational age; HLHS, hypoplastic left heart syndrome; IAS, intact atrial septum; LOC, level of postnatal care; PA/IVS, pulmonary atresia with intact ventricular septum; PGE1, prostaglandin E1; RAS, restrictive atrial septum; TAPVR, total pulmonary venous return; TOF, tetralogy of Fallot; VSD, ventricular septal defect.

Postnatal compromise in D-TGAs depends on whether the FO and/or DA are restrictive or closed at birth. At delivery, a RAS/IAS prevents oxygenated blood from reaching the systemic circulation. In addition, in those with a restrictive/closed DA, pulmonary hypertension may occur. The following parameters have been associated with a higher risk of DR compromise:[10] (1) presence of a hypermobile or tethered septum primum or bowing or IAS and (2) presence of an abnormal DA that is either small or has abnormal flow (►**Table 1**). Changes in the FO may occur late in pregnancy, and therefore sequential FE up until the time of delivery has been recommended. In a prospective study using FE parameters,[2] evaluation of the atrial septum in fetuses with D-TGAs predicted the need for urgent BAS in 15 (88%) of 17 who were assigned as high risk. However, 10 fetuses were considered to be at a low risk according to published criteria. Among these, 3 (30%) did not require BAS; however, FE failed to predict the need for BAS in 7 (70%). In one, severe hypoxia and acidosis occurred, resulting in a change to the protocol with all babies with D-TGAs assigned as high risk (LOC 3 or 4). Overall, the prenatal prediction of need for BAS had a sensitivity of 68% and a specificity of 60%. Given the current limitations of FE to predict postnatal need for BAS, it is recommended that all babies with D-TGAs be considered high risk.[10]

TAPVR is a rare CHD with a high mortality. An important risk factor for poor outcome is the coexistence of pulmonary vein obstruction, which leads to severe hypoxia soon after birth. Obstructed TAPVR can be predicted[13] by pulmonary vein flow pattern with nonpulsatile, low-velocity, monophasic flow. The prenatal detection of TAPVR is overall low, though, when diagnosed prenatally, survival is improved. If the Doppler pattern suggests that obstruction or the venous pathway is infradiaphragmatic, a planned delivery at or near the cardiac center with urgent cardiac surgery is recommended.

CHDs at risk for heart failure, hydrops, and fetal/neonatal death include severe Ebstein's anomaly, TOF with absent pulmonary valve (APV), cardiomyopathies, uncontrolled tachyarrhythmia, and complete atrioventricular block. Even if born at term, there is an increased risk of poor outcome because of complications from low cardiac output, pulmonary hypoplasia, and heart failure. Prenatal assessment and close follow-up are indicated, and premature or early delivery may be required in the presence of fetal distress[10] (►**Table 1**).

Accuracy of Fetal Echocardiography for the Diagnosis/Prediction of Postnatal Care

FE has a high diagnostic accuracy, though accuracy varies depending on the type of defect, being higher (86%) in single ventricle defects such as HLHS and lower in D-TGAs (28%) and TAPVR (13%).[4] Accuracy for prediction of postnatal care is less

consistent, ranging from 20 to 96%, depending on the specific CHD.[2–4] In a prospective study, a sensitivity of 90 to 97% was reported for the prediction of low/minimal-risk CHD (LOC 1 or 2), whereas sensitivity for high-risk CHD (LOC 3 or 4) was 83%.[2] In the same study, the accuracy to predict those newborns requiring standard DR care (LOC 1) versus those requiring special intervention at birth (LOC 2–4) was high with a sensitivity of 99% and a specificity of 90%. These classifications are of particular importance for the perinatal management in areas with limited pediatric resources, where the delivery plan may change according to the distance to the cardiac center.

Novel Methods of In Utero Assessment

The administration of oxygen to the expectant mother during the third trimester as a diagnostic tool that simulates postnatal physiology by decreasing fetal pulmonary resistance and increasing pulmonary flow has been described.[11,14,15] In HLHS with RAS/IAS, lack of pulmonary vasoreactivity during MH was associated with need for urgent cardiac intervention,[11] and in fetuses with a borderline left heart, MH was useful in determining left ventricular adequacy.[14] In a recent report, MH predicted transitional changes in HLHS with RAS, TAPVR, D-TGAs, and Ebstein's anomaly.[15] Further studies are needed to define its predictive accuracy for postnatal outcome.

Fetal magnetic resonance imaging (MRI) has been used to assess the lung parenchyma in fetuses with HLHS, TAPVR, and TOF/APV. In HLHS, fetuses with lung parenchyma described as "nutmeg lung" had higher mortality compared with the group of HLHS without these findings.[16] In TOF/APV, fetal MRI identified fluid trapping in the lungs and pulmonary hypoplasia.[17]

Conclusion

In summary, FE can accurately diagnose and predict postnatal severity of CHDs. Identification of fetuses requiring in utero intervention or specialized DR care allows the creation of detailed fetal, perinatal, and delivery recommendations tailored for the specific lesions. Despite advances, prediction of postnatal compromise remains challenging for some defects. For these, diagnostic models integrating FE and other tools such as MH and MRI may be beneficial. Only by expanding efforts to design strategies for improving detection, identifying risk factors, investigating fetal intervention, and creating coordinated multidisciplinary DR care plans, will the field move forward to improve outcome beyond current practice.

Conflict of Interest
None.

References

1 Donofrio MT, Levy RJ, Schuette JJ, et al. Specialized delivery room planning for fetuses with critical congenital heart disease. Am J Cardiol 2013;111(05):737–747
2 Donofrio MT, Skurow-Todd K, Berger JT, et al. Risk-stratified postnatal care of newborns with congenital heart disease determined by fetal echocardiography. J Am Soc Echocardiogr 2015;28 (11):1339–1349
3 Berkley EM, Goens MB, Karr S, Rappaport V. Utility of fetal echocardiography in postnatal management of infants with prenatally diagnosed congenital heart disease. Prenat Diagn 2009;29 (07):654–658
4 Pruetz JD, Carroll C, Trento LU, et al. Outcomes of critical congenital heart disease requiring emergent neonatal cardiac intervention. Prenat Diagn 2014;34(12):1127–1132
5 Brown KL, Sullivan ID. Prenatal detection for major congenital heart disease: a key process measure for congenital heart networks. Heart 2014;100(05):359–360
6 Trines J, Hornberger LK. Evolution of heart disease in utero. Pediatr Cardiol 2004;25(03):287–298
7 Holland BJ, Myers JA, Woods CR Jr. Prenatal diagnosis of critical congenital heart disease reduces risk of death from cardiovascular compromise prior to planned neonatal cardiac surgery: a meta-analysis. Ultrasound Obstet Gynecol 2015;45(06):631–638
8 Costello JM, Polito A, Brown DW, et al. Birth before 39 weeks' gestation is associated with worse outcomes in neonates with heart disease. Pediatrics 2010;126(02):277–284
9 Peyvandi S, Nguyen TA, Almeida-Jones M, et al; University of California Fetal Consortium (UCfC). Timing and mode of delivery in prenatally diagnosed congenital heart disease - an analysis of practices within the University of California Fetal Consortium (UCfC). Pediatr Cardiol 2017;38(03):588–595
10 Donofrio MT, Moon-Grady AJ, Hornberger LK, et al; American Heart Association Adults With Congenital Heart Disease Joint Committee of the Council on Cardiovascular Disease in the Young and Council on Clinical Cardiology, Council on Cardiovascular Surgery and Anesthesia, and Council on Cardiovascular and Stroke Nursing. Diagnosis and treatment of fetal cardiac disease: a scientific statement from the American Heart Association. Circulation 2014;129(21):2183–2242
11 Szwast A, Tian Z, McCann M, Donaghue D, Rychik J. Vasoreactive response to maternal hyperoxygenation in the fetus with hypoplastic left heart syndrome. Circ Cardiovasc Imaging 2010;3(02): 172–178
12 Moon-Grady AJ, Morris SA, Belfort M, et al; International Fetal Cardiac Intervention Registry. International Fetal Cardiac Intervention Registry: a worldwide collaborative description and preliminary outcomes. J Am Coll Cardiol 2015;66(04): 388–399
13 Ganesan S, Brook MM, Silverman NH, Moon-Grady AJ. Prenatal findings in total anomalous pulmonary venous return: a diagnostic road map starts with obstetric screening views. J Ultrasound Med 2014;33(07):1193–1207
14 Channing A, Szwast A, Natarajan S, Degenhardt K, Tian Z, Rychik J. Maternal hyperoxygenation improves left heart filling in fetuses with atrial septal aneurysm causing impediment to left ventricular inflow. Ultrasound Obstet Gynecol 2015;45(06):664–669
15 Schidlow DN, Donofrio MT. Prenatal maternal hyperoxygenation testing and implications for critical care delivery planning among fetuses with congenital heart disease: early experience. Am J Perinatol 2018;35(01):16–23
16 Saul D, Degenhardt K, Iyoob SD, et al. Hypoplastic left heart syndrome and the nutmeg lung pattern in utero: a cause and effect relationship or prognostic indicator? Pediatr Radiol 2016; 46(04):483–489
17 Chelliah A, Berger JT, Blask A, Donofrio MT. Clinical utility of fetal magnetic resonance imaging in tetralogy of Fallot with absent pulmonary valve. Circulation 2013;127(06):757–759