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Prenatal Diagnosis of Congenital Heart Disease and Birth Outcomes

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Abstract

This study was undertaken to examine the impact that prenatal diagnosis of congenital heart disease (CHD) has on birth and early neonatal outcomes. The prevalence of prenatally diagnosed CHD has risen over the past decade, but the effect that prenatal diagnosis of CHD has on peripartum decisions remains unclear. No consensus exists on the effect of prenatal diagnosis on neonatal outcomes. Between January 2004 and July 2009, a retrospective chart review of all neonates with CHD admitted to our institution's neonatal intensive care unit was conducted. Obstetric and postnatal variables were collected. Among the 993 subjects, 678 (68.3 %) had a prenatal diagnosis. A prenatal diagnosis increased the odds of a scheduled delivery [odds ratio (OR) 4.1, 95 % confidence interval (CI) 3.0–5.6] and induction of labor (OR 11.5, 95 % CI 6.6–20.1). Prenatal diagnosis was not significantly associated with cesarean delivery when control was used for maternal age, multiple gestation, and presence of extracardiac anomaly. Mean gestational

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age had no impact on prenatal diagnosis, but prenatal diagnosis was associated with increased odds of delivery before a gestational age of 39 weeks (OR 1.5, 95 % CI 1.1–1.9) and decreased odds of preoperative intubation (OR 0.5, 95 % CI 0.3–0.6). Prenatal diagnosis did not have an impact on preoperative or predischarge mortality. Prenatal diagnosis was associated with increased odds of a scheduled delivery, birth before a gestational age of 39 weeks, and a decreased need for invasive respiratory support. Prenatal diagnosis of CHD was not associated with preoperative or predischarge mortality.

Keywords

Birth; Congenital heart disease; Neonatal; Obstetrical; Outcomes; Prenatal diagnosis

Over the past decade, the prevalence of prenatally diagnosed congenital heart disease (CHD) has risen, mostly due to improved obstetric screening. Prenatal detection rates for severe forms of CHD such as hypoplastic left heart syndrome (HLHS), reported to be 37 % in the late 1990s, reached 75–77 % by 2005–2008 [2, 29, 31].

Prenatal diagnosis of CHD is considered beneficial for the neonate, allowing for the immediate delivery of medical care and thereby decreasing morbidity such as metabolic acidosis, hypoxemia, and end-organ injury [4, 11, 19, 29, 32, 33]. Consensus is lacking on the impact of prenatal diagnosis on neonatal mortality.

Several case series reports have previously described improved survival for specific critical CHD lesions including HLHS [31], dextro-transposition of the great arteries (D-TGA) [3], and coarctation of the aorta [12]. These findings, however, have not been replicated in other similar series [2, 9, 17, 25, 29]. Prenatal diagnosis of CHD has been associated with improved parental understanding of the neonatal medical condition [34], yet the impact that prenatal diagnosis of CHD has on obstetric outcomes is less well described.

This study sought to explore the association between prenatal diagnosis of CHD and obstetric and peripartum outcomes. We hypothesized that antenatal knowledge of CHD would lead to increased scheduled deliveries that would occur earlier in gestation than spontaneous labor. Furthermore, we sought to investigate the impact of these delivery decisions on neonatal outcomes including gestational age, need for respiratory support, and preoperative and overall predischarge mortality.

Methods

Between 1 January 2004 and 1 July 2009, we conducted a retrospective chart review of all infants with hemodynamically significant CHD admitted to the Morgan Stanley Children's Hospital of New York–Presbyterian, a tertiary care center with a level 4 neonatal intensive care unit (NICU) and a specialized fetal diagnosis and management center, the Center for Prenatal Pediatrics. Institutional review board approval for this study was obtained.

Subjects were identified via review of the NICU admission database and cross-queried with the pediatric cardiothoracic surgical database and the Center for Prenatal Pediatrics database. No infants with minor lesions including small ventricular septal defects, atrial septal defects, and patent ductus arteriosus associated with prematurity were included in the study.

Obstetric data consisting of delivery mode, delivery location, and date of delivery, as well as maternal gravidity and parity status were collected. Neonatal characteristics such as timing

of cardiac diagnosis, type of heart defect, birth weight, and gestational age also were recorded.

For the purposes of this analysis, we defined a scheduled delivery as one in which either cesarean delivery or induction of labor was planned ahead of time. A delivery initiated due to late-term discovery of maternal or fetal findings that required urgent attention (e.g., maternal preeclampsia or oligohydramnios) was not considered a scheduled delivery. Induction of labor was defined as either administration of medication (e.g., oxytocin or intravaginal misoprostol) or artificial rupture of membranes before the natural onset of labor. Conversion to cesarean was defined as a cesarean delivery after the onset of labor when cesarean delivery was not previously planned. For analyses of neonatal outcomes, nonelective intubation was defined as intubation for hemodynamic instability or apnea.

Statistical Analysis

Univariate descriptive statistics are summarized as means ± standard deviations. Differences in outcomes between infants with a prenatal diagnosis and those with a postnatal diagnosis were tested using Student's t test for continuous variables, and 2×2 tables as well as Pearson's χ^2 statistic for categorical variables. Univariate relationships were explored using binary logistic regression for dichotomous outcomes. Multivariate linear and logistic regression was used to evaluate associations with control used for potential confounding variables. Alpha values were set at 0.05.

Results

Baseline Subject Characteristics

During the period of the study, 993 neonates with CHD were identified, 678 (68.3 %) of which had a prenatal diagnosis. The most common cardiac abnormalities in the cohort were single-ventricle lesions (25.4 %), D-TGA (13 %), and tetralogy of Fallot (TOF, 11.3 %) (Table 1). A total of 668 infants (67.2 %) underwent cardiothoracic surgery before NICU discharge, and 63 infants (6.3 %) had catheter-based intervention without cardiothoracic surgery. Demographic and noncardiac characteristics are shown in Table 2.

Infants born with a prenatal diagnosis of CHD were more likely to have older mothers, extracardiac anomalies, and certain types of cardiac defects such as single-ventricle morphology [odds ratio (OR) 3.4, 95 % confidence interval (CI) 2.3–4.9), HLHS (OR 2.5, 95 % CI 1.5–4.1), and double-outlet right ventricle (OR 15, 95 % CI 2–110) (Table 1). Infants born with total anomalous pulmonary venous return (TAPVR) (OR 0.01, 95 % CI 0.0–0.07), D-TGA (OR 0.5, 95 % CI 0.3–0.7), pulmonary valve stenosis (OR 0.3, 95 % CI 0.2–0.7), or isolated arch anomalies (OR 0.6, 95 % CI 0.4–0.97) were less likely to have a prenatal diagnosis. The prenatal diagnosis rate for CHD was 66 % when infants with extracardiac anomalies were excluded.

Delivery Outcomes

Multiple associations were found between prenatal diagnosis and obstetric outcomes (Table 3). Infants with prenatally diagnosed CHD had greater odds of delivery at our institution (OR 116.2, 95 % CI 64.3–209.7), scheduled delivery (OR 4.1, 95 % CI 3.0–5.6), and delivery on a weekday (OR 1.8, 95 % CI 1.3–2.6) than those with a postnatal diagnosis.

Cesarean delivery occurred for 45 % of the study cohort. The prenatal diagnosis group had a higher rate of cesarean delivery (47.4 %) than the postnatal diagnosis group (40.4 %) ($p = 0.04$). However, the rate of conversion from induced vaginal or spontaneous labor to cesarean delivery was similar in the two groups (16.5 vs. 15.0 %; $p = 0.6$). As shown in Fig.

1, the indications for cesarean delivery generally were similar between the pre- and postnatal diagnosis groups. Prior cesarean was the most common indication for cesarean in both groups. Elective cesarean deliveries were more common in the prenatal diagnosis group (11.9 vs. 2.5 %).

In a multivariate regression model with control used for maternal age, multiple gestation, and the presence of an extracardiac anomaly (all associated with cesarean in the univariate analysis), prenatal diagnosis of CHD was not significantly associated with cesarean delivery.

Gestational Age

Of the 958 infants with documented gestational age, 559 (58.4 %) were born before a gestational age of 39 weeks, 341 (35.6 %) were born before 38 weeks, and 207 (21.6 %) were born before 37 weeks. Although the mean gestational age at birth did not differ between the pre- and postnatal diagnosis groups (37.8 ± 2.2 vs. 38.0 ± 2.5 weeks; $p = 0.2$), infants with a prenatal diagnosis had higher odds of a gestational age less than 39 weeks (OR 1.5, 95 % CI 1.1–1.9) (Table 3). Over the 5½-year study period, the proportion of deliveries before 39 weeks did not change within the prenatal diagnosis group.

In addition to prenatal diagnosis, the other factors associated with delivery before 39 weeks included multiple gestation pregnancy (OR 25.7, 95 % CI 6.2–105.5), extracardiac anomaly (OR 2.4, 95 % CI 1.7–3.3), cesarean delivery (OR 2.2, 95 % CI 1.7–2.9), older maternal age (31.0 ± 6.4 vs. 29.8 ± 6.4; $p = 0.004$), and higher maternal gravidity (2.9 ± 2.1 vs. 2.6 ± 1.9; $p = 0.02$) (Table 4). Scheduled (i.e., non-urgent) cesarean delivery was associated with increased odds of delivery before 39 weeks (OR 1.7, 95 % CI 1.3–2.4), whereas scheduled induction of labor had decreased odds of delivery before 39 weeks (OR 0.3, 95 % CI 0.2–0.4).

In the multivariate analysis, the independent predictors of gestational age less than 39 weeks included prenatal diagnosis (OR 1.4, $p = 0.03$), multiple gestation pregnancy (OR 21.0, $p<0.001$), presence of extracardiac anomaly (OR 2.1, $p<0.001$), greater maternal gravidity (OR 1.1, $p = 0.02$), and cesarean delivery (OR 1.8, $p<0.001$).

Neonatal Outcomes

Analyses of neonatal and mortality outcomes were conducted on 884 subjects. We excluded subjects with undocumented gestational age ($n = 35$), premature delivery (gestational age<32 weeks; $n = 25$), transfer to our institution outside the neonatal period (>28 days of life; $n = 19$), CHD suspected prenatally but excluded on the postnatal echocardiogram ($n = 27$), and comfort care planned and provided exclusively from the time of birth ($n = 8$).

Respiratory Status

The univariate analysis showed prenatal diagnosis associated with lower levels of respiratory support before surgery or catheter-based intervention compared with postnatal diagnosis (Table 5). This included lower odds of intubation overall (OR 0.5, 95 % CI 0.3–0.6), nonelective intubation (OR 0.6, 95 % CI 0.5–0.8), high-frequency oscillatory ventilation (OR 0.2, 95 % CI 0.1–0.5), and inhaled nitric oxide therapy (OR 0.4, 95 % CI 0.2–0.8). Univariate associations with nonelective intubation specifically are shown in Table 6.

Earlier gestational age conferred increased risk of nonelective intubation (OR 0.89, 95 % CI 0.83–0.97), whereas the impact of cesarean delivery was not significant (OR 1.1, 95 % CI 0.8–1.4). Multivariate analyses showed nonelective intubation associated with a body weight less than 2,500 g (OR 1.9, $p = 0.008$), prostaglandin administration (OR 4.6, $p<0.001$),

single-ventricle morphology (OR 3.4, $p<0.001$), D-TGA (OR 4.4, $p<0.001$), and TAPVR (OR 7.0, $p<0.001$). Notably, subjects with a prenatal diagnosis were less likely to require nonelective intubation in this multivariate model (OR 0.6, $p = 0.002$). Gestational age was not significant in the model (OR 0.9, $p = 0.056$). The R^2 of this model was 24.5 % (data not shown).

Preoperative and Overall Mortality

Death before cardiac surgery occurred for 39 subjects (4.4 %), and death after cardiac surgery occurred for 43 subjects (4.9 %). Neither prenatal diagnosis nor cesarean delivery was associated with mortality. In univariate comparisons, gestational age was associated with both preoperative mortality (OR 0.78, 95 % CI 0.64–0.90; $p<0.001$) and predischarge mortality (OR 0.74, 95 % CI 0.67–0.83; $p<0.001$) (Table 7).

In the multivariate analysis, preoperative mortality was independently associated with single-ventricle morphology (OR 4.2, $p<0.001$) and the presence of an extracardiac anomaly (OR 5.1, $p<0.001$) but not with gestational age ($p = 0.09$). In a multivariate analysis of mortality before hospital discharge, gestational age was significantly associated with mortality (OR 0.74, $p<0.001$) together with single-ventricle morphology (OR 4.6, $p<0.001$) and the presence of an extracardiac anomaly (OR 2.4, $p = 0.001$).

Discussion

A prenatal diagnosis of CHD provides the opportunity to conduct a scheduled delivery in a stable environment with prepared management of mother and neonate. This study found that a prenatal diagnosis has a significant impact on delivery practices, specifically by increasing the odds of a delivery in-house at our institution via a scheduled delivery.

In studies of routine pregnancy, it has become evident that elective cesarean delivery is detrimental to the health of the mother, neonate, and future offspring compared with vaginal delivery [1, 10, 18, 28]. Although certain congenital malformations, such as sacrococcygeal tumor or myelomeningocele, may be indications for a cesarean delivery [16], no evidence shows that the fetus with CHD has a higher risk of intrapartum fetal distress favoring the routine practice of cesarean delivery [14, 21, 26]. Whenever possible, our fetal care center encourages vaginal delivery, as reflected in the findings of our study. When the delivery of a neonate with a prenatal diagnosis of CHD was scheduled, induced labor for vaginal delivery was significantly more common than cesarean delivery. Furthermore, we have observed that a prenatal diagnosis of CHD did not increase the likelihood of conversion to cesarean delivery, suggesting that the obstetrician's threshold for conversion to cesarean delivery during labor was not lowered by the existence of a prenatal CHD diagnosis.

Despite these practices, the overall rate of cesarean delivery was 45 % in our series from January 2004 to July 2009, which is greater than the overall rate of 31.8 % for cesarean delivery in the United States in 2007 [20]. A large population-based study in Sweden from 1992 to 2001 found the odds for cesarean delivery to be approximately two times greater with CHD than in the general population despite a low prenatal detection rate [5]. In our study, risk factors such as older maternal age, presence of extracardiac anomalies, and multiple gestation pregnancy predicted cesarean delivery rather than a prenatal diagnosis of CHD. This finding suggests that the high rate of cesarean delivery seen in our cohort relates to the referral bias inherent to our center and not specifically to a prenatal diagnosis of CHD.

The current study showed no difference in mean birth gestational age between infants with and those without a prenatal diagnosis of CHD. This contrasts with previous studies that reported an earlier mean birth gestational age for neonates with a prenatal diagnosis [2, 33].

However, we found that a prenatal diagnosis did slightly increase the odds of delivery before 39 weeks gestation. This finding merits attention because delivery before 39 weeks gestation is associated with worse neonatal outcomes for healthy newborns [23, 24, 30, 35]. Indeed, Costello et al. [8] recently reported increased mortality, morbidity, and resource utilization for neonates with critical CHD delivered at term but before 39 weeks. We observed in our data that scheduled cesarean deliveries are significantly associated with delivery before 39 weeks. This was observed despite our current clinical guideline to deliver infants whenever possible after the 39-week gestational age cutoff and thus may reflect older practice patterns.

Delaying scheduled cesarean deliveries to dates as late in gestation as possible may be an obstetric outcome that could substantially benefit postnatal outcomes. We hypothesize that long-term neurodevelopmental outcomes may benefit equally from birth later in gestation.

Respiratory disease is an important source of morbidity in the neonatal period that may extend into childhood. Our finding of reduced need for mechanical ventilation among neonates with a prenatal diagnosis is consistent with the previous findings of Friedberg et al. [13], who published data collected from three referral centers in Northern California from 2004 to 2005. Their report acknowledges that some patients are intubated electively for the purpose of transport to a tertiary care center.

Accordingly, in our study, we carefully categorized the indications for intubation for each subject to discriminate intubation for elective indications such as patient transport, cardiac magnetic resonance imaging, or noncardiac surgery, from intubation for nonelective indications. We have observed that a prenatal diagnosis reduces the odds of nonelective intubation even when control is used for severity or type of cardiac lesion, birth weight, and prostaglandin administration. We consider this to be a clinically relevant outcome and an indication that prenatal diagnosis improves preoperative clinical stability. Furthermore, we have shown that a prenatal diagnosis reduces the likelihood of higher levels of respiratory support such as high-frequency oscillatory ventilation and nitric oxide administration.

Prenatal diagnosis itself was not associated with preoperative or predischarge mortality in this large neonatal cohort encompassing a broad spectrum of CHD admitted to a tertiary care referral center. There are challenges associated with studying associations between a prenatal diagnosis of CHD and postnatal outcomes such as mortality. Fetuses with severe CHD (e.g., single-ventricle lesions) or major extracardiac anomalies, who are likely to be less stable postnatally, also are more likely to be detected by prenatal screening [7, 22, 27]. Postnatal outcomes are inextricably dependent on the rates of elective pregnancy termination, which are influenced by disease severity among other factors [15, 25].

Studies can be further confounded by incomplete ascertainment, wherein cases of CHD are not included when death has occurred at home or before transfer to a tertiary care center. Using death registry data, Chang et al. [6] estimated that as many as 30 annual deaths due to missed or late diagnosis of critical CHD occurred in the state of California over a 15-year period. Unfortunately, a compulsory system is not currently established in the United States for identifying all postmortem cases of CHD.

Although prenatal diagnosis did not have an impact on preoperative mortality, we observed that single-ventricle lesions and the presence of extracardiac anomalies were associated with preoperative mortality. Fortunately, in the current era, there are very few neonates who cannot be resuscitated and stabilized. This may limit the impact of prenatal diagnosis on early mortality as a primary outcome. We postulate that influences which are less clearly defined, such as prognosis of a single-ventricle lesion or severe extracardiac malformations, affected the decision to with-draw care after resuscitation and stabilization.

In addition to the presence of a single-ventricle lesion or extracardiac anomalies, earlier gestational age (with gestational age less than 32 weeks excluded) was independently associated with death before hospital discharge. This observation gives further impetus to avoidance of premature delivery in the setting of CHD and advocates for scheduling elective deliveries at a later gestational age.

Study Limitations

The limitations of this study include the retrospective nature of the data collection. In addition, only records from our institution were reviewed. Records from transfer hospitals were not directly available. This study examined the obstetric and neonatal practice patterns at one institution, so the results may not directly translate to all other institutions. Furthermore, the impact of a prenatal CHD diagnosis on pregnancy termination rates in our area could not be evaluated due to the ascertainment bias particular to our high-volume tristate referral base. Many patients with a diagnosis of severe fetal CHD in the outside community terminate locally and thus are never evaluated at our center. It should be recognized that our study population captured only neonates in the population who survived until admission to our NICU. The total mortality rate due to unknown or late diagnosis of CHD in our catchment area is not known.

In conclusion, although prenatal diagnosis was associated with increased odds of a scheduled delivery and birth before a gestational age of 39 weeks, prenatal diagnosis was associated with a decreased need for invasive respiratory support. Prenatal diagnosis of CHD was not associated with preoperative or predischarge mortality among infants managed in a tertiary care center.

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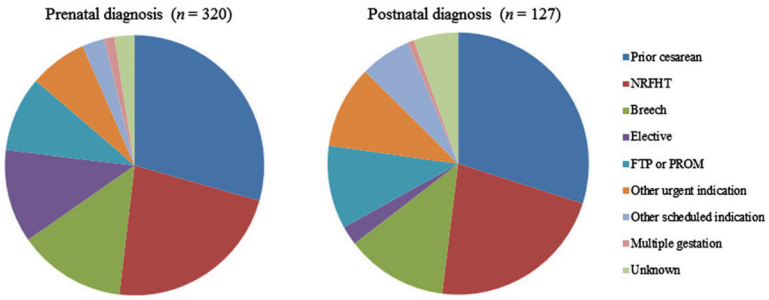

Fig. 1.

Indications for cesarean delivery between the pre- and postnatal diagnosis groups. Among the 447 cesarean deliveries, the most common indication for cesarean delivery was prior cesarean delivery in both the pre- and postnatal diagnosis groups. More elective cesarean deliveries were performed in the prenatal diagnosis group. Other urgent indications included maternal indications such as preeclampsia or placental abruption and fetal indications such as poor biophysical profile or fetal hydrops. Other scheduled indications included maternal disease such as fibroids or heart disease and fetal conditions such as macrosomia. *NRFHT* nonreassuring fetal heart tones, *FTP* failure to progress, *PROM* prolonged rupture of membranes

Table 1

Odds of prenatal diagnoses by specific congenital heart disease (CHD) type

CHD type	Prenatal diagnosis (*n* = 678) *n* (%) total	Postnatal diagnosis (*n* = 315) *n* (%)	OR (95 % CI)	*p* value
Single ventricle (all)	214 (31.6)	38 (12.1)	3.4 (2.3–4.9)	< 0.001
HLHS	93 (13.7)	19 (6.0)	2.5 (1.5–4.1)	< 0.001
Complex single ventricle	79 (11.7)	12 (3.8)	3.3 (1.8–6.2)	< 0.001
D-TGA (all)	70 (10.3)	59 (18.7)	0.5 (0.3–0.7)	< 0.001
D-TGA (intact ventricular septum)	37 (5.5)	41 (13.0)	0.4 (0.2–0.6)	< 0.001
D-TGA (ventricular septal defect)	23 (3.4)	13 (4.1)	0.8 (0.4–1.6)	0.6
TOF	84 (12.4)	28 (8.9)	1.4 (0.9–2.3)	0.1
Isolated arch anomaly	52 (7.7)	37 (11.7)	0.6 (0.4–0.97)	0.04
Arch anomaly with additional anomaly	63 (9.6)	21 (6.7)	1.4 (0.9–2.4)	0.2
TAPVR	1 (0.1)	44 (14.0)	0.01 (0.00–0.07)	< 0.001
Pulmonary valve stenosis	17 (2.5)	22 (7.0)	0.3 (0.2–0.7)	0.001
Double-outlet right ventricle	31 (4.6)	1 (0.3)	15.0 (2.0–110.7)	< 0.001
Double-outlet right ventricle with malposed great vessels	25 (3.7)	5 (1.6)	2.4 (0.9–6.3)	0.07
Balanced atrioventricular canal	23 (3.4)	6 (1.9)	1.8 (0.7–4.5)	0.2
Interrupted aortic arch	14 (2.1)	9 (2.9)	0.7 (0.3–1.7)	0.4

Excludes CHD types present in less than 2 % of subjects

OR odds ratio, *CI* confidence interval, *HLHS* hypoplastic left heart syndrome, *D-TGA* dextro-transposition of the great arteries, *TOF* tetralogy of Fallot, *TAPVR* total anomalous pulmonary venous return

Table 2

Association of prenatal diagnosis and other noncardiac subject characteristics

Subject characteristic	Prenatal diagnosis (*n* = 678) *n* (%)	Postnatal diagnosis (*n* = 315) *n* (%)	OR (95 % CI)	*p* value
Manhattan resident	80 (11.8)	33 (10.5)	1.1 (0.7–1.8)	0.5
Female sex	293 (43.2)	131 (41.6)	1.1 (0.8–1.4)	0.6
Multiple gestation pregnancy	52 (7.7)	14 (4.4)	1.8 (1.0–3.3)	0.06
Presence of extracardiac anomaly	174 (25.7)	55 (17.5)	1.6 (1.2–2.3)	0.004
Genetic anomaly	68 (10.0)	21 (6.7)	1.6 (0.9–2.6)	0.08
Mean maternal age (years)	30.9 ± 6.6	29.7 ± 6.1		0.006
Mean maternal gravidity	2.8 ± 2.0	2.8 ± 1.9		0.9
Mean maternal parity	1.1 ± 1.6	1.2 ± 1.6		0.4

OR odds ratio, *CI* confidence interval

Table 3

Associations of prenatal diagnosis and delivery outcomes

Delivery outcome	Prenatal diagnosis (*n* = 678) *n* (%)	Postnatal diagnosis (*n* = 315) *n* (%)	OR (95 % CI)	*p* value
Birth at our institution	565 (83.3)	13 (4.1)	116.2 (64.3–209.7)	< 0.001
Scheduled delivery	374 (55.7)	73 (23.6)	4.1 (3.0–5.6)	< 0.001
Weekday birth (Monday–Friday)	590 (87.0)	247 (78.4)	1.8 (1.3–2.6)	0.001
Cesarean delivery	320 (47.4)	127 (40.4)	1.3 (1.0–1.7)	0.04
Conversion to cesarean	70 (10.4)	33 (10.5)	1.0 (0.6–1.5)	1.0
Induction of labor	236 (35.0)	14 (4.4)	11.5 (6.6–20.1)	< 0.001
GA < 39 weeks	410 (61.2)	149 (51.7)	1.5 (1.1–1.9)	0.006
GA < 38 weeks	245 (36.6)	96 (33.3)	1.2 (0.9–1.5)	0.4
GA < 37 weeks	144 (21.5)	63 (21.9)	1.0 (0.7–1.4)	0.9
BW < 2,500 g	157 (23.7)	59 (19.5)	1.3 (0.9–1.8)	0.2
Mean GA (weeks)	37.8 ± 2.2	38.0 ± 2.5		0.2
Mean BW (g)	2,924 ± 669	3,068 ± 688		0.002

OR odds ratio, *CI* confidence interval, *GA* gestational age, *BW* body weight

Table 4

Subject characteristics associated with delivery before 39 weeks

Subject characteristic	GA < 39 weeks (*n* = 559) *n* (%)	OR (95 % CI)	*p* value
Prenatal diagnosis	410 (73.3)	1.5 (1.1–1.9)	0.006
Single ventricle	147 (26.2)	1.1 (0.8–1.5)	0.4
Multiple gestation pregnancy	64 (11.4)	25.7 (6.2–105.5)	< 0.001
Extracardiac anomaly	167 (29.9)	2.4 (1.7–3.3)	< 0.001
Maternal age (years)	31.0 ± 6.4		0.004
Maternal gravidity	2.9 ± 2.1		0.02
Cesarean	300 (53.9)	2.2 (1.7–2.9)	< 0.001
Scheduled cesarean	150 (26.9)	1.7 (1.3–2.4)	0.001
Induction of labor	105 (18.9)	0.4 (0.3–0.6)	< 0.001
Scheduled induction of labor	81 (14.5)	0.3 (0.2–0.4)	< 0.001

GA gestational age, *OR* odds ratio, *CI* confidence interval

Table 5

Associations of prenatal diagnosis and preoperative neonatal outcomes

Mode of support	Prenatal diagnosis (*n* = 611) *n* (%)	Postnatal diagnosis (*n* = 273) *n* (%)	OR (95 % CI)	*p* value
Intubation	286 (47.7)	179 (66.3)	0.5 (0.3–0.6)	<0.001
Intubation, nonelective	183 (30.7)	112 (41.8)	0.6 (0.5–0.8)	0.001
High-frequency oscillatory ventilation	9 (1.5)	17 (6.3)	0.2 (0.1–0.5)	< 0.001
Nitric oxide	19 (3.1)	19 (7.0)	0.4 (0.2–0.8)	0.009
Pressors	174 (28.6)	93 (34.2)	0.8 (0.6–1.0)	0.09
Prostaglandin	441 (72.7)	189 (69.7)	1.2 (0.8–1.6)	0.4
Antibiotics	225 (36.9)	193 (71.5)	0.23 (0.17–0.32)	< 0.001

OR odds ratio, *CI* confidence interval

Table 6

Subject characteristics associated with nonelective intubation

Subject characteristic	Nonelective intubation (n = 295) n (%)	OR (95 % CI)	p value
Prenatal diagnosis	183 (62.0)	0.6 (0.5–0.8)	0.001
Single ventricle	110 (37.2)	2.5 (1.8–3.4)	< 0.001
D-TGA	59 (20)	2.3 (1.5–3.4)	< 0.001
TOF	29 (9.8)	0.8 (0.5–1.2)	0.2
TAPVR	21 (7.1)	2.2 (1.2–4.2)	0.01
BW < 2,500 g	75 (26.2)	1.6 (1.2–2.3)	0.005
Mean GA (weeks)	37.8 ± 2.2	0.89 (0.83–0.97)	0.004
Birth at our institution	147 (49.8)	0.5 (0.4–0.7)	< 0.001
Scheduled delivery	133 (45.9)	0.9 (0.7–1.2)	0.5
Cesarean delivery	134 (45.7)	1.1 (0.8–1.4)	0.6
Prostaglandins administered	256 (87.1)	3.9 (2.7–5.8)	< 0.001

OR odds ratio, *CI* confidence interval, *D-TGA* dextrotransposition of the great arteries, *TOF* tetralogy of Fallot, *TAPVR* total anomalous pulmonary venous return, *BW*

body weight, *GA* gestational age

Table 7

Subject characteristics associated with preoperative and predischarge mortality

Subject characteristic	Preoperative mortality (39 subjects)			Predischarge mortality (82 subjects)		
	n (%)	OR (95% CI)	*p* value	*n* (%)	OR (95% CI)	*p* value
Prenatal diagnosis	26 (66.7)	0.9 (0.4–1.8)	0.7	60 (73.2)	1.2 (0.7–2.1)	0.4
Single ventricle	18 (46.2)	2.6 (1.4–5.0)	0.003	40 (48.8)	3.1 (2.0–5.0)	< 0.001
Extracardiac anomaly	24 (61.5)	6.1 (3.1–11.8)	< 0.001	35 (42.7)	2.9 (1.8–4.6)	< 0.001
BW < 2,500 g	15 (42.9)	3.1 (1.6–6.2)	0.001	29 (37.7)	2.6 (1.6–4.3)	< 0.001
GA	NA	0.78 (0.64–0.90)	< 0.001	N/A	0.74 (0.67–0.83)	< 0.001
Scheduled delivery	14 (35.9)	0.6 (0.3–1.2)	0.1	35 (43.8)	0.8 (0.5–1.4)	0.5
Cesarean delivery	23 (59.0)	1.8 (0.96–3.5)	0.06	43 (52.4)	1.4 (0.9–2.2)	0.1

OR odds ratio, *CI* confidence interval, *BW* body weight, *GA* gestational age