The Heart Surgery Forum 2022-4751
26 (1), 2023 [Epub January 2023]
doi: 10.1532/hsf.4751

Online address: http://journal.hsforum.com

Surgery Before Pregnancy in Women with Congenital Heart Disease: A Retrospective Study

Yang Liu,[1] Yanna Li,[2] Jun Zhang,[2] Jiachen Li,[1] Yichen Zhao,[3] Kemin Liu,[3] Xiangming Fan,[1] Jiangang Wang[3]

[1]Department of Pediatric Cardiac Center, Beijing Anzhen Hospital affiliated to Capital Medical University, Chaoyang District, Beijing, China; [2]Department of Obstetrics and Gynecology, Beijing Anzhen Hospital affiliated to Capital Medical University, Chaoyang District, Beijing, China; [3]Department of Adult Cardiac Surgery Center, Beijing Anzhen Hospital affiliated to Capital Medical University, Chaoyang District, Beijing, China

ABSTRACT

Background: This study aimed to investigate if surgery before pregnancy would result in better maternal and fetal outcomes in patients with congenital heart disease.

Methods: A retrospective study was conducted using data collected from the medical records of pregnant patients with congenital heart disease, who were seen at Beijing Anzhen Hospital between 2010 and 2019. The patients were divided into surgical and non-surgical groups, and the differences in outcomes were compared.

Results: A total of 999 patients with congenital heart disease (mean age, 28.7±4.3 years) were enrolled, with 403 (40.0%) and 596 (60.0%) in the surgical and non-surgical groups, respectively. The percentages of almost all adverse events were higher in the non-surgical group than in the surgical group. The adverse events included preterm delivery (9.9 vs. 17.1%), low birth weight (6.5 vs. 11.6%), heart failure (2.7 vs. 6.7%), cesarean section (75.7 vs. 85.9%), pulmonary hypertension (13.6 vs. 36.2%), and death (0.5 vs. 2.3%) (all $P < 0.05$). A total of 16 (1.6%) patients died, including 14 and two in the non-surgical and surgical groups, respectively. Regardless of the type of congenital heart disease, preterm delivery and low birth weight were more common in the non-surgical group compared with the surgical group, and there were no statistical between group differences in the other remaining events.

Conclusions: In the non-surgical group, the results were similar regardless of the type of congenital heart disease, except for preterm delivery and low birth weight. The overall outcome of the surgical group was better than that of the non-surgical group, and surgery before pregnancy reduced maternal and infant risk.

INTRODUCTION

Most women with congenital heart disease (CHD) now survive to adulthood, due to medical improvements in treatment, and many get married and try to start a family. However, concomitant CHD is thought to increase perinatal risk [Regitz-Zagrosek 2018; Schlichting 2019; Roos-Hesselink 2019]. The traditional belief is that cardiac surgery before pregnancy improves maternal and fetal outcomes in patients with CHD. However, relevant studies have been few, and studies with large samples are even more scarce [Wang 2019; Tutarel 2021; Katsuragi 2013].

In 2007, Beijing Anzhen Hospital, affiliated with Capital Medical University, was designated as the only referral and consultation center for pregnant women with heart diseases in Beijing. Almost all pregnant women with CHD visit Beijing Anzhen Hospital for consultation, treatment, and childbirth, and this has laid the foundation for this study.

In a previous study, it was determined that the risk of maternal complications during pregnancy was higher in patients with CHD than in those without CHD. In this study, we aimed to investigate whether it is beneficial to perform surgery before pregnancy in patients with CHD.

MATERIALS AND METHODS

This study retrospectively analyzed the clinical data of 999 pregnant patients with CHD who were admitted to our hospital between January 2010 and December 2019. (Figure 1) The patients were divided into surgical and non-surgical groups, and the differences in obstetric events, cardiovascular

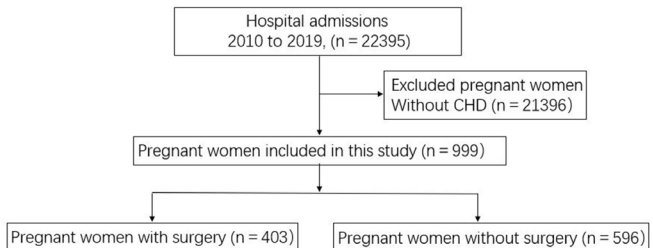

Figure 1. Flowchart of data collection

Received March 26, 2022; accepted April 19, 2022.

Correspondence: Jiangang Wang, Department of Adult Cardiac Surgery Center, Beijing Anzhen Hospital affiliated to Capital Medical University, No. 2 Anzhen Road, Chaoyang District, Beijing, China, Telephone +86-10-64456384 (e-mail: jiangangwang@ccmu.edu.cn)

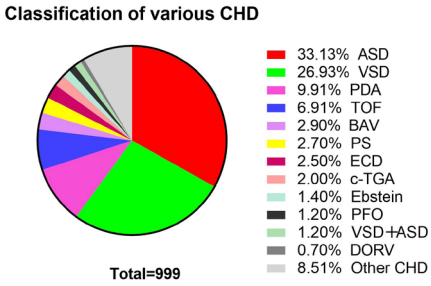

Figure 2. Percentage of each CHD

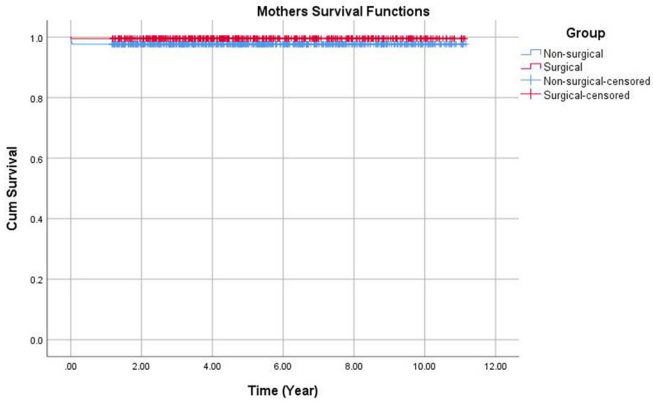

Figure 3. Kaplan–Meier survival plot in the two groups of mothers

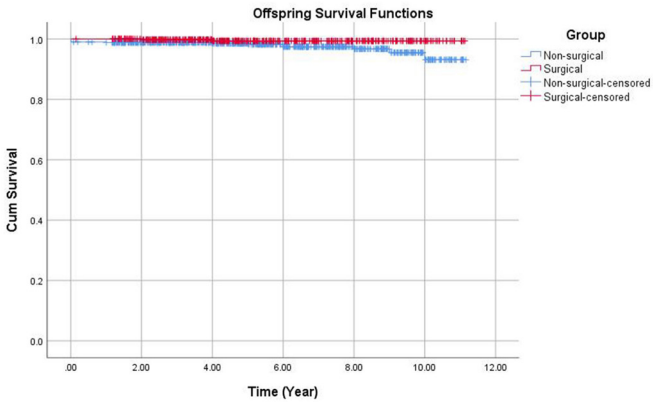

Figure 4. Kaplan–Meier survival plot in the two groups of their offspring

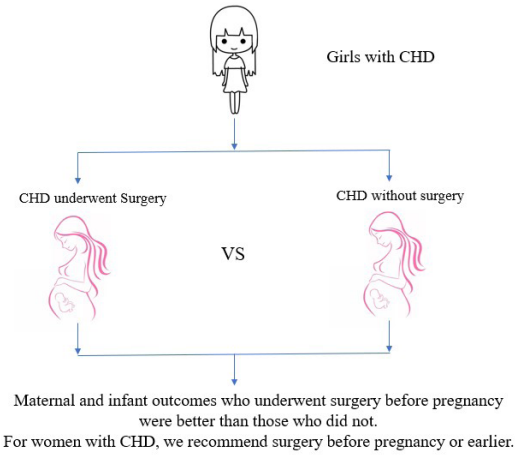

Figure 5.

Table 1. Sociodemographic information for all studied patients

Patient characteristics	Surgical group (*N* = 403)	Non-surgical group (*N* = 596)	*P*-value
Age (years)	20-43	17-44	
Median age (years)	28.9	28.6	0.714
Region, n (%)	-	-	<0.001
City	295 (73.2)	173 (29.0)	
Rural area	108 (26.8)	423 (71.0)	
Education degree, n (%)	-	-	<0.001
With college education	243 (60.3)	125 (21.0)	
Without college education	160 (39.7)	471 (79.0)	
Gravidity, n (%)	-	-	0.028
First	220 (54.6)	245 (41.1)	
Second	81 (20.1)	146 (24.5)	
≥ Three times	102 (25.3)	205 (34.4)	
Pregnant weeks	29-41	28-41	
Mean pregnant weeks	36.5	35.3	0.126
Parity, n (%)	-	-	0.084
Primiparity	342 (84.9)	453 (76.0)	
Multiparity	61 (15.1)	143 (24.0)	

events, delivery procedures, fetal events, and other events were compared. Obstetric events included gestational hypertension, placenta previa, gestational diabetes, placental abruption, hemorrhage, preterm delivery, and preeclampsia. Cardiovascular complications included heart failure (HF), arrhythmias, and thromboembolic events, such as stroke and pulmonary embolism. The delivery procedures included cesarean section (CS), artificial rupture of the membranes, and labor induction. Fetal events included fetal distress, fetal growth restriction, fetal malformation, fetal death or stillbirth, and low birth weight (LBW). Other events included pulmonary hypertension (PH), respiratory disease, systemic hypertension, and death. Analysis of obstetrical outcomes, according to the different CHDs and different classifications of CHD (cyanotic and acyanotic CHD), was performed. Follow up of the women and their offspring was performed through phone call.

Ethical approval: All procedures performed in this study were in accordance with the ethical standards of the research committee of Beijing Anzhen Hospital affiliated with Capital Medical University and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Table 2. Adverse obstetric events, cardiovascular events, delivery procedure, fetal events, and other events experienced by women with CHD admitted for delivery by surgery

	CHD with surgery (*N* = 403)	CHD without surgery (*N* = 596)	OR (95% CI)	*P*-value
Hypertension in pregnancy	8 (2.0)	15 (2.5)	0.82 (0.35-1.96)	0.659
Placenta previa	9 (2.2)	15 (2.5)	0.93 (0.40-2.14)	0.861
Gestational diabetes	50 (12.4)	83 (13.9)	1.05 (0.73-1.52)	0.784
Placental abruption	3 (0.7)	5 (0.8)	0.93 (0.22-3.91)	0.920
Hemorrhage	51 (12.7)	86 (14.4)	0.91 (0.63-1.32)	0.606
Pre-term delivery	40 (9.9)	102 (17.1)	0.57 (0.38-0.83)	0.004
Preeclampsia	21 (5.2)	47 (7.9)	0.68 (0.40-1.15)	0.147
Heart failure	11 (2.7)	40 (6.7)	0.41 (0.21-0.81)	0.010
Arrhythmia	58 (14.4)	72 (12.1)	1.25 (0.86-1.81)	0.236
Thromboembolic event (stroke, PE, and so on)	1 (0.2)	3 (0.5)	0.52 (0.05-4.97)	0.566
Cesarean section	305 (75.7)	512 (85.9)	0.70 (0.52-0.94)	0.019
Artificial rupture of the membranes	10 (2.5)	16 (2.7)	1.14 (0.52-2.51)	0.745
Induction	9 (2.2)	17 (2.9)	0.82 (0.36-1.85)	0.626
Fetal distress	24 (6.0)	39 (6.5)	1.59 (0.94-2.70)	0.086
Fetal growth restriction	1 (0.2)	11 (1.8)	0.14 (0.02-1.08)	0.059
Fetal malformation	0 (0.0)	2 (0.3)	NC	NC
Fetal death or stillbirth	1 (0.2)	3 (0.5)	0.52 (0.05-4.97)	0.566
Infant of low birth weight	26 (6.5)	69 (11.6)	0.54 (0.38-0.89)	0.018
PH	55 (13.6)	216 (36.2)	0.30 (0.22-0.42)	<0.001
Death	2 (0.5)	14 (2.3)	0.51 (0.32-0.79)	0.009
Respiratory diseases	4 (1.0)	10 (1.7)	0.62 (0.19-1.98)	0.415
Systemic hypertension	6 (1.5)	15 (2.5)	0.61 (0.24-1.60)	0.317

CHD, congenital heart disease; CI, confidence interval; NC, Not calculated; OR, odds ratio; PH, pulmonary hypertension. Values are n (%) unless otherwise indicated.

This study was approved by the research committee of Beijing Anzhen Hospital affiliated with Capital Medical University (authorization number: 2021152X), which permitted the collection of data for audit and research purposes.

Statistical analyses: For the variables that were normally distributed, descriptive statistics, such as mean, standard deviation, and range values, were calculated and analyzed using the Kolmogorov-Smirnov test and Shapiro-Wilk test. For non-normal data, the median values were compared. A student-independent test was used to compare the means of the two groups. Categorical variables were expressed in terms of frequencies and percentages. Logistic regression was used to calculate crude odds ratios (ORs), adjusted ORs, and 95% confidence intervals (CIs) for each comorbidity and the different cardiovascular, obstetric, fetal-related, delivery-related, and other relevant events. We initially performed a univariate analysis, and a multivariable logistic regression analysis was performed for variables with $P < 0.1$. For all analyses, a P-value of < 0.05 was considered statistically significant. All statistical analyses were conducted using SPSS (IBM SPSS Statistics v22.0, Inc. Chicago, IL, USA) and R version 4.0.4 (R Foundation for Statistical Computing, Vienna, Austria, 2021).

RESULTS

A total of 999 pregnant patients (mean age, 28.7±4.3 years) with CHD, comprising 403 (40.0%) and 596 (60.0%) in the surgical and non-surgical groups, respectively, were enrolled. The most common CHDs were the following: atrial septal defect (ASD, 33.1%), ventricular septal defect (VSD, 26.9%), patent ductus arteriosus (PDA, 9.9%), and tetralogy of Fallot (TOF, 6.9%). (Figure 2) The various types of CHD are shown in Supplementary Table 1. (Supplementary Table 1)

Sociodemographic information of the patients (region, highest educational attainment, gravidity, and parity) are summarized in Table 1. (Table 1) There were no significant differences in age, mean number of pregnancies, or parity between the two groups. Compared with the non-surgical group, the surgical group had a higher proportion of women

Table 3. Adverse obstetric events, cardiovascular events, delivery procedure, fetal events, and other events experienced by women with ASD admitted for delivery by surgery

	ASD with surgery (*N* = 102)	ASD without surgery (*N* = 229)	OR (95% CI)	*P*-value
Hypertension in pregnancy	2 (0.02)	5 (0.02)	1.12 (0.21-5.85)	0.897
Placenta previa	2 (0.02)	7 (0.03)	1.58 (0.32-7.72)	0.574
Gestational diabetes	20 (0.20)	25 (0.11)	0.50 (0.27-0.96)	0.035
Hemorrhage	11 (0.11)	25 (0.11)	1.01 (0.48-2.15)	0.971
Pre-term delivery	7 (0.07)	36 (0.16)	0.40 (0.17-0.92)	0.031
Preeclampsia	6 (0.06)	10 (0.04)	0.73 (0.26-2.07)	0.554
Heart failure	0 (0.00)	13 (0.06)	NC	NC
Arrhythmia	16 (0.16)	27 (0.12)	0.72 (0.37-1.40)	0.332
Thromboembolic event (stroke, PE, and so on)	1 (0.01)	1 (0.004)	0.44 (0.03-7.15)	0.566
Cesarean section	69 (67.65)	179 (78.17)	1.71 (1.02-2.88)	0.043
Artificial rupture of the membranes	2 (0.02)	4 (0.02)	0.89 (0.16-4.93)	0.893
Induction	1 (0.01)	3 (0.01)	1.34 (0.14-13.05)	0.801
Fetal distress	7 (0.07)	10 (0.04)	0.62 (0.23-1.68)	0.346
Fetal growth restriction	1 (0.01)	0 (0.0)	NC	NC
Infant low birth weight	6 (0.06)	34 (0.15)	0.36 (0.15-0.88)	0.026
PH	9 (0.09)	129 (0.56)	12.64 (6.08-26.29)	<0.001
Death	0 (0.00)	2 (0.01)	NC	NC
Respiratory diseases	0 (0.00)	2 (0.01)	NC	NC
Systemic hypertension	1 (0.01)	8 (0.03)	3.66 (0.45-29.62)	0.225

ASD, atrial septal defect; CI, confidence interval; NC, not calculated; OR, odds ratio; PH, pulmonary hypertension. Values are n (%) unless otherwise indicated.

who lived in the city and had a college education ($P < 0.05$). However, the non-surgical group had more pregnancies than that had by the surgical group ($P < 0.05$).

The incidence of almost all events, including preterm delivery, LBW, HF, CS, PH, and death ($P < 0.05$), was significantly higher in the non-surgical group than in the surgical group. Additional details are provided in Table 2. (Table 2)

In both groups with ASD, there were significant differences in preterm delivery, LBW, CS, and PH, while the other events were similar. (Table 3) Both groups with VSD, PDA, and TOF also had had similar events except for preterm delivery and LBW (Supplementary Tables 2–4). (Supplementary Table 2)(Supplementary Table 3)(Supplementary Table 4)

Analysis according to CHD classification was performed. In both cyanotic and acyanotic CHD (Supplementary Table 5), there were significant differences in the incidence of gestational diabetes, preterm delivery, preeclampsia, HF, CS, LBW, and respiratory diseases, and the incidence of these events were higher in cyanotic CHD than in acyanotic CHD. (Supplementary Table 5)

In addition, patients with pulmonary arterial hypertension associated with CHD vs. those with no association with CHD also were analyzed. (Supplementary Table 6) Preterm delivery, HF, CS, artificial rupture of the membranes, labor induction, LBW, and respiratory diseases were significantly different between the two groups, and the incidence of these events were higher in CHD with PH than in CHD without PH.

A total of 16 patients (1.6%) died, including 14 and two in the non-surgical and surgical groups, respectively. The details are shown in Table 4. (Table 4) Furthermore, eight newborns (0.8%) died in the hospital, all of whom were born to mothers in the non-surgical group.

Follow up: The mean follow-up duration was 5.9±2.8 years. In the surgical group, none of the patients died after discharge, while one (0.2%) offspring died after discharge. In the non-surgical group, six (1.5%) patients died after discharge and four (0.7%) offspring died after discharge, the maternal and infant survival rate in the surgical group was higher than that in the non-surgical group. (Figure 3)(Figure 4). PH was observed in both groups, with 21 (5.2%) and 119 (20.0%) of patients in the surgical and non-surgical groups, respectively. Most required targeted drug therapy. In addition, there were five (1.2%) and 21 (3.5%) patients with cardiac insufficiency (lighter than heart failure) in the surgical and non-surgical groups, respectively.

DISCUSSION

The sociodemographic information demonstrated that there was a higher rate of CHD surgeries in cities than in

Table 4. Death cases of mothers

Number	Age	Diagnosis	Surgery	Diagnosis before pregnancy	Estimated sPAP	NYHA	Pregnant weeks	Delivery	Fetal birth weight	Offspring outcome	Death causes
1	27	VSD, PH	Yes	Yes	121	IV	35	CS	2140	Alive	PHC, HF, Metabolic acidosis
2	27	VSD, PDA, PH	Yes	Yes	122	IV	34	CS	2110	Alive	PHC, MOF
3	30	PDA, ES, PH	No	Yes	89	IV	30	VD	1040	Death	Pseudoaneurysm of pulmonary artery ruptured
4	25	VSD, ES, PH	No	Yes	100	IV	31	CS	1570	Death	PH, MOF, HF
5	20	VSD, ASD, PDA, ES, PH	No	No	107	III	36	CS	1830	Death	PHC, HF, hypoxemia
6	28	VSD, ES, PH	No	Yes	116	IV	30	CS	1270	Death	PHC, HF
7	23	VSD, PH	No	Yes	131	IV	33	CS	1450	Death	PHC, HF
8	21	DORV, VSD, PH, ITP	No	Yes	106	IV	31	CS	1380	Death	PHC, HF, pulmonary infection
9	29	VSD, PH	No	Yes	83	II	32	CS	1560	Alive	PHC, ES, sudden death, HF, RF
10	24	PDA, ES, PH	No	Yes	102	IV	30	CS	930	Alive	PHC
11	32	TECD, PDA, PH	No	Yes	53	III	36	CS	2950	Alive	HF
12	28	ASD, PH	No	Yes	110	IV	33	CS	1950	Alive	HF
13	20	PDA, ES, PH	No	Yes	116	III	32	CS	1160	Alive	PHC, HF, MOF
14	28	VSD, ES, PH	No	Yes	120	IV	35	CS	1330	Alive	PHC, HF, MOF, DIC
15	24	SV, CAT, TAPVC, ASD, PH	No	Yes	133	III	34	CS	1190	Alive	HF
16	30	ASD, ES, PH	No	Yes	74	IV	33	CS	1790	Alive	PHC, HF, MOF

ASD, atrial septal defect; CAT, common arterial trunk; CPHD, chronic pulmonary heart disease; CS, cesarean section; DIC, diffuse intravascular coagulation; DORV, double outlet of right ventricle; ES, Eisenmenger syndrome; HF, heart failure; IPAH, idiopathic pulmonary arterial hypertension; ITP, idiopathic thrombocytopenic purpura; MOF, multiple organ failure; PDA, patent ductus arteriosus; PH, pulmonary hypertension; PHC, pulmonary hypertension crisis; RF, respiratory failure; SV, single ventricle; TAPVC, total anomalous pulmonary venous connection; TECD, total endocardial cushion defect; VD, vaginal delivery; VSD, ventricular septal defect

the rural areas, which may be due to economic reasons. Some families in the rural areas might have been unable to pay for hospitalization during the patient's early life, resulting in a delay in surgical interventions. A higher proportion of patients in the surgical group had college education, and this may be related to the improved cardiorespiratory fitness after surgery, which enabled the patients to stay in school. In the non-surgical group, patients tended to have multiple pregnancies that resulted to spontaneous or induced abortion.

The incidence of simple CHDs, such as ASD and VSD, was higher than that of complex CHDs. This may be because some patients with complex CHD die before they reach reproductive age or may choose not to have children. It should be noted that in this study, some patients had combined malformations. In these cases, they were classified according to the most complex malformation. For example, if one patient had a double outlet right ventricle (DORV) combined with VSD, that patients would be classified under DORV.

In this study, the proportion of non-surgical patients (60.0%) was higher than that of surgical patients. This may be because there were more patients with simple CHDs. The defects were small enough to cause no symptoms in the early stages, making the pregnancy generally well-tolerated. The CHD may not have been detected until during pregnancy. Some types of CHD, such as patent foramen ovale (PFO), do not require surgical treatment because of the small defect and minimal pathophysiological impact. None of the 20 patients with PFO underwent surgery in this study. This finding is consistent with that of Bredy et al. [Bredy 2018]. However, some patients with complicated CHDs, such as TOF, should be operated on at an early stage. However, there were still seven women (10.1%) in this study who had not undergone surgery, mostly due to financial reasons. A few patients with complex CHD did not undergo surgery because they did not believe that the condition was serious, and this delayed treatment. Some patients were advised to undergo surgery but refused treatment.

Supplementary Table 1. Classification of various congenital heart disease

	Total 999	Surgery 403 (40.0%)	Without surgery 596 (60.0%)
ASD	331 (33.1%)	102 (30.8%)	229 (69.2%)
VSD	269 (26.9%)	131 (48.7%)	138 (51.3%)
PDA	99 (9.9%)	44 (44.4%)	55 (55.6%)
TOF	69 (6.9%)	62 (89.9%)	7 (10.1%)
Bicuspid aortic valve	29 (2.9%)	1 (3.4%)	28 (96.6%)
PS or right ventricular outflow tract stenosis	27 (2.7%)	2 (7.4%)	25 (92.6%)
ECD	25 (2.5%)	15 (60.0%)	10 (40.0%)
c-TGA	20 (2.0%)	1 (5.0%)	19 (95.0%)
Ebstein's anomaly	14 (1.4%)	1 (7.1%)	13 (92.9%)
PFO	12 (1.2%)	0 (0.0%)	12 (100.0%)
VSD + ASD	12 (1.2%)	9 (75.0%)	3 (25.0%)
DORV	7 (0.7%)	4 (57.1%)	3 (42.9%)
AS + BAV	6 (0.6%)	0 (0.0%)	6 (100.0%)
DCRV	5 (0.5%)	1 (20.0%)	4 (80.0%)
Three atrial	5 (0.5%)	1 (20.0%)	4 (80.0%)
ASD + PS	4 (0.4%)	2 (50.0%)	2 (50.0%)
VSD + PS	4 (0.4%)	2 (50.0%)	2 (50.0%)
MI	4 (0.4%)	2 (50.0%)	2 (50.0%)
ASD + PDA	3 (0.3%)	0 (0.0%)	3 (100.0%)
PAPVC + ASD	3 (0.3%)	2 (66.7%)	1 (33.3%)
CoA	3 (0.3%)	1 (33.3%)	2 (66.7%)
AS + AI + BAV	3 (0.3%)	2 (66.7%)	1 (33.3%)
Other diseases with the aortic valve	3 (0.3%)	0 (0.0%)	3 (100.0%)
TGA	2 (0.2%)	0 (0.0%)	2 (100.0%)
TAPVC	2 (0.2%)	1 (50.0%)	1 (50.0%)
PAPVC	2 (0.2%)	1 (50.0%)	1 (50.0%)
AS + MI + BAV	2 (0.2%)	1 (50.0%)	1 (50.0%)
CoA + BAV	2 (0.2%)	0 (0.0%)	2 (100.0%)
VSD + MI	1 (0.1%)	1 (100.0%)	0 (0.0%)
VSD + PDA	1 (0.1%)	0 (0.0%)	1 (100.0%)
VSD + CoA	1 (0.1%)	0 (0.0%)	1 (100.0%)
PDA + PS	1 (0.1%)	0 (0.0%)	1 (100.0%)
PDA + aortic arch diseases	1 (0.1%)	1 (100.0%)	0 (0.0%)
TOF + double arch of aorta	1 (0.1%)	0 (0.0%)	1 (100.0%)
Three atrial + ASD	1 (0.1%)	0 (0.0%)	1 (100.0%)
Three atrial + VSD	1 (0.1%)	0 (0.0%)	1 (100.0%)
Three atrial + ASD + PS	1 (0.1%)	0 (0.0%)	1 (100.0%)
Coronary artery right ventricular fistula	1 (0.1%)	1 (100.0%)	0 (0.0%)
Coronary arterio-pulmonary artery fistula	1 (0.1%)	0 (0.0%)	1 (100.0%)
ECD + ruptured aneurysm of the sinus of Valsalva	1 (0.1%)	1 (100.0%)	0 (0.0%)
Ruptured aneurysm of the sinus of Valsalva	1 (0.1%)	1 (100.0%)	0 (0.0%)
MS	1 (0.1%)	1 (100.0%)	0 (0.0%)

AI + BAV	1 (0.1%)	0 (0.0%)	1 (100.0%)
Discrete subaortic membrane	1 (0.1%)	0 (0.0%)	1 (100.0%)
Other CHD	16 (1.6%)	9 (56.25%)	7 (43.75%)

AI, aortic insufficiency; AS, aortic (valve) stenosis; ASD, atrial septal defect; BAV, bicuspid aortic valve; CHD, congenital heart disease; CoA, coarctation of aorta; c-TGA, corrected transposition of great arteries; DCRV, double chamber of right ventricle; DORV, double outlet of right ventricle; ECD, endocardial cushion defect; MI, mitral insufficiency; MS, mitral stenosis; PAPVC, partial anomalous pulmonary venous connection; PDA, patent ductus arteriosus; PFO, patent foramen ovale; PS, pulmonary stenosis; TAPVC, total anomalous pulmonary venous connection; TOF, Tetralogy of Fallot; VSD, ventricular septal defect

Supplementary Table 2. Adverse obstetric events, cardiovascular events, delivery procedure, fetal events, and other events experienced by women with VSD admitted for delivery by surgery

	VSD with surgery (*N* = 131)	VSD without surgery (*N* = 138)	*P*-value	OR (95% CI)
Hypertension in pregnancy	5 (0.04)	0 (0.0)	0.996	NC
Placenta previa	2 (0.02)	2 (0.01)	0.958	0.95 (0.13-6.83)
Gestational diabetes	15 (0.11)	13 (0.09)	0.586	0.80 (0.37-1.76)
Placental abruption	1 (0.01)	3 (0.02)	0.361	2.89 (0.30-28.13)
Hemorrhage	16 (0.12)	22 (0.16)	0.381	1.36 (0.68-2.73)
Pre-term delivery	23 (0.18)	35 (0.25)	0.121	1.60 (0.88-2.88)
Preeclampsia	3 (0.02)	13 (0.09)	0.022	4.44 (1.24-15.95)
Heart failure	5 (0.04)	13 (0.09)	0.075	2.62 (0.91-7.57)
Arrhythmia	23 (0.18)	12 (0.09)	0.034	0.45 (0.21-0.94)
Thromboembolic event (stroke, PE, and so on)	1 (0.01)	0 (0.00)	0.996	NC
Cesarean section	98 (0.75)	109 (0.79)	0.417	1.27 (0.72-2.24)
Artificial rupture of the membranes	4 (0.03)	3 (0.02)	0.652	0.71 (0.16-3.21)
Induction	4 (0.03)	7 (0.05)	0.408	1.70 (0.49-5.94)
Fetal distress	7 (0.05)	10 (0.07)	0.523	1.38 (0.51-3.75)
Fetal growth restriction	0 (0.00)	3 (0.02)	0.996	NC
Fetal malformation	0 (0.00)	1 (0.01)	0.996	NC
Fetal death or stillbirth	0 (0.00)	2 (0.01)	0.996	NC
Infant of low birth weight	21 (0.16)	32 (0.23)	0.142	1.58 (0.86-2.92)
PH	27 (0.21)	43 (0.31)	0.050	1.74 (1.00-3.04)
Death	2 (0.02)	6 (0.04)	0.193	2.93 (0.58-14.79)
Respiratory diseases	1 (0.01)	3 (0.02)	0.361	2.89 (0.30-28.13)
Systemic hypertension	2 (0.02)	1 (0.01)	0.541	0.47 (0.04-5.26)

CI, confidence interval; NC, not calculated; OR, odds ratio; PH, pulmonary hypertension; VSD, ventricular septal defect. Values are n (%) unless otherwise indicated.

Compared with the surgical group, the incidences of almost all adverse events, such as preterm delivery, LBW, HF, CS, PH, and death were significantly more frequent ($P < 0.05$) in the non-surgical group than in the surgical group. We believe that surgery can reduce maternal and fetal risk, which contradicts the findings of Yadav et al. [Yadav 2018].

A total of 16 maternal deaths occurred in this study, which were related to PH, HF, and multiple organ failure. Two patients in the surgical group died during childbirth, due to late CHD surgery and irreversible PH. Therefore, in CHDs such as VSD, ASD, and PDA, which can result in PH and develop into Eisenmenger syndrome (ES) in the late-stage, surgical treatment should be conducted as early as possible to avoid irreversible results. There were 59 patients with ES in this study, and 58 (98.3%) were from in non-surgical group, which further illustrates the necessity of early surgery.

In this study, there were patients who wanted to undergo surgery but did not have the opportunity. Others were prepared to undergo surgery, which was deferred due to severe PH. These findings were consistent with those of Sliwa et al.

Supplementary Table 3. Adverse obstetric events, cardiovascular events, delivery procedure, fetal events, and other events experienced by women with PDA admitted for delivery by surgery

	PDA with surgery (*N* = 44)	PDA without surgery (*N* = 55)	*P*-value	OR (95% CI)
Hypertension in pregnancy	0 (0.00)	2 (0.04)	0.998	NC
Placenta previa	0 (0.00)	2 (0.04)	0.998	NC
Gestational diabetes	8 (0.18)	7 (0.13)	0.454	NC
Placental abruption	0 (0.00)	1 (0.02)	0.998	0.93 (0.22-3.91)
Hemorrhage	3 (0.07)	11 (0.20)	0.074	3.42 (0.89-13.12)
Pre-term delivery	2 (0.05)	14 (0.25)	0.012	7.17 (1.53-33.54)
Preeclampsia	5 (0.11)	5 (0.09)	0.710	0.78 (0.21-2.89)
Heart failure	0 (0.00)	8 (0.15)	0.997	NC
Arrhythmia	2 (0.05)	6 (0.11)	0.263	2.57 (0.49-13.42)
Cesarean section	36 (0.82)	44 (0.80)	0.819	0.89 (0.32-2.45)
Artificial rupture of the membranes	1 (0.02)	3 (0.05)	0.439	2.48 (0.25-24.72)
Induction	0 (0.00)	4 (0.07)	0.998	NC
Fetal distress	4 (0.09)	3 (0.05)	0.487	0.58 (0.12-2.73)
Infant of low birth weight	0 (0.00)	9 (0.16)	0.997	NC
PH	1 (0.02)	16 (0.29)	0.006	17.64 (2.23-139.28)
Death	0 (0.00)	3 (0.05)	0.998	NC
Respiratory diseases	0 (0.00)	3 (0.05)	0.998	NC
Systemic hypertension	1 (0.02)	1 (0.02)	0.873	0.80 (0.05-13.10)

CI, confidence interval; NC, not calculated; OR, odds ratio; PDA, patent ductus arteriosus; PH, pulmonary hypertension. Values are n (%) unless otherwise indicated.

[Sliwa 2016; Ladouceur 2017]. There also were patients with complicated CHD who had insisted on getting pregnant, despite the doctors' recommendation. Approximately 50% of the women who insisted on getting pregnant regardless of doctors' recommendation had poor outcomes.

Eight newborns (0.8%) died in the hospital, due to premature birth and LBW, and all eight were born to mothers in the non-surgical group. In addition, maternal PH, HF, death, and neonatal death were higher in the non-surgical group than in the surgical group during follow up.

There were a few women in our study with cyanosis. We randomly selected women with cyanotic and acyanotic CHD, and poor maternal outcomes were noted in those with cyanotic CHD.

Some CHDs can go untreated for life. However, it should be emphasized that in CHDs that warrant treatment, it is preferable to do so before pregnancy. As the surgery is risky, a "pregnancy cardiac team" is needed, and it is important to choose an experienced and qualified cardiac center for treatment [Baumgartner 2020; Greutmann 2015; Cauldwell 2018]. The rate of arrhythmia was higher in the surgical group than in the non-surgical group (14.4 vs. 12.1%), which suggested that more arrhythmias may occur after surgery. This is consistent with the reports by Greenberg et al. [Greenberg 2017; Al-Khatib 2018].

In the surgical group, there was one woman with complicated CHD who underwent Glenn surgery and a total cavopulmonary connection for correction of transposition of the great arteries, PA, ASD, VSD, and PDA. She became pregnant a few years later and gave birth to a child, and she and her child were found to be well at the follow up. This finding is consistent with that of a report by Naguib et al. [Naguib 2010]. Overall, in the surgery group, the women with simple CHDs underwent surgery before severe PH occurred, and the outcomes of pregnancy and childbirth were good. Some women with complicated CHDs, such as TOF, generally tolerated pregnancy after surgical correction. However, in women who have undergone a systemic-pulmonary shunt or palliative procedures, the functional status of their shunt should be evaluated.

For those with severe PH and complicated CHD without surgery, the risk to mothers and children during the perinatal period is significantly increased. Based on our research, we believe that early surgery was helpful in reducing the risk to both mothers and children during the perinatal period.

Study limitations: This was a retrospective single-center study, and data were collected from medical records. We focused on the delivery period as most patients were referred in the later stages of pregnancy, and we often were unable to obtain information on events occurring during early pregnancy. The subsequent analysis may therefore contain bias.

Supplementary Table 4. Adverse obstetric events, cardiovascular events, delivery procedure, fetal events, and other events experienced by women with TOF admitted for delivery by surgery

	TOF with surgery (*N* = 62)	TOF without surgery (*N* = 7)	*P*-value	OR (95% CI)
Hypertension in pregnancy	0 (0.00)	0 (0.00)	NC	NC
Placenta previa	0 (0.00)	1 (0.14)	0.999	NC
Gestational diabetes	0 (0.00)	3 (0.43)	0.999	NC
Placental abruption	0 (0.00)	1 (0.14)	0.999	NC
Hemorrhage	9 (0.15)	2 (0.29)	0.347	2.36 (0.40-14.05)
Pre-term delivery	7 (0.11)	3 (0.43)	0.040	5.89 (1.09-31.97)
Preeclampsia	1 (0.02)	1 (0.0)	0.117	10.17 (0.56-184.01)
Heart failure	0 (0.00)	1 (0.14)	0.997	NC
Arrhythmia	13 (0.21)	0 (0.00)	0.999	NC
Thromboembolic event (stroke, PE, and so on)	0 (0.00)	0 (0.00)	NC	NC
Cesarean section	50 (0.81)	7 (1.00)	0.999	NC
Artificial rupture of the membranes	0 (0.00)	1 (0.0)	0.999	NC
Induction	0 (0.00)	2 (0.0)	0.999	NC
Fetal distress	0 (0.00)	2 (0.0)	0.999	NC
Fetal growth restriction	1 (0.02)	0 (0.00)	0.999	NC
Fetal malformation	0 (0.00)	0 (0.00)	NC	NC
Fetal death or stillbirth	0 (0.00)	0 (0.00)	NC	NC
Infant of low birth weight	6 (0.10)	3 (0.43)	0.026	7.00 (1.26-39.00)
PH	5 (0.08)	0 (0.00)	0.999	NC
Death	0 (0.00)	0 (0.00)	NC	NC
Respiratory diseases	2 (0.03)	0 (0.00)	0.999	NC
Systemic hypertension	15 (0.24)	6 (0.86)	0.317	0.61 (0.24-1.60)

CI, confidence interval; NC, not calculated; OR, odds ratio; PH, pulmonary hypertension; TOF, Tetralogy of Fallot. Values are n (%) unless otherwise indicated.

There were a few data that were incomplete, incorrectly entered, or unavailable. In addition, there was a lack of data on scheduled or unscheduled CSs. The inclusion of women with simple CHDs, such as PFO and ASD, with small defects may have caused bias as simple CHDs tend to have very little impact on the body. Additional potential sources of bias included the differences in the number of patients in each group, differences in the age of patients in the two groups, several demographic characteristics (e.g., rural area), and differences due to the lesion requiring surgery rather than the procedure itself in the two groups.

CONCLUSIONS

Most of the events were similar except for preterm delivery and LBW, regardless of the type of CHD. However, perinatal outcomes were better in women with CHD who had undergone surgery before pregnancy than in those who had not undergone surgery before pregnancy, which suggests that surgery before pregnancy can reduce maternal and infant risk.

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Supplementary Table 5. Adverse obstetric events, cardiovascular events, delivery procedure, fetal events, and other events experienced by women with cyanotc vs not cyanotc CHD admitted for delivery by surgery.

	Cyanotc CHD (*N* = 59)	Not cyanotc CHD (*N* = 196)	*P*-value	OR (95% CI)
Hypertension in pregnancy	1 (1.69)	4 (2.04)	0.867	1.21 (0.13-11.03)
Placenta previa	0 (0.00)	6 (3.06)	0.997	NC
Gestational diabetes	2 (3.39)	31 (15.82)	0.024	5.36 (1.24-23.09)
Placental abruption	0 (0.00)	1 (0.51)	0.998	NC
Hemorrhage	12 (20.34)	23 (11.73)	0.096	0.52 (0.24-1.12)
Pre-term delivery	44 (74.58)	11 (5.61)	<0.001	0.02 (0.01-0.05)
Preeclampsia	10 (16.95)	11 (5.61)	0.008	0.29 (0.12-0.73)
Heart failure	11 (18.64)	40 (20.41)	<0.001	0.02 (0.01-0.07)
Arrhythmia	7 (11.86)	23 (11.73)	0.978	0.99 (0.40-2.43)
Thromboembolic event (stroke, PE, and so on)	0 (0.00)	2 (1.02)	0.997	NC
Cesarean section	56 (94.92)	133 (67.86)	<0.001	0.11 (0.03-0.38)
Artificial rupture of the membranes	0 (0.00)	5 (2.55)	0.997	NC
Induction	0 (0.00)	3 (1.53)	0.997	NC
Fetal distress	3 (5.08)	14 (7.14)	0.580	1.44 (0.40-5.18)
Fetal growth restriction	3 (5.08)	1 (0.51)	0.044	0.096 (0.01-0.94)
Fetal malformation	1 (1.69)	0 (0.00)	0.995	NC
Fetal death or stillbirth	1 (1.69)	0 (0.00)	0.995	NC
Infant of low birth weight	46 (77.97)	8 (4.08)	<0.001	0.01 (0.01-0.03)
Death	11 (18.64)	0 (0.00)	0.995	NC
Respiratory diseases	3 (5.08)	1 (0.51)	0.044	0.10 (0.01-0.94)
Systemic hypertension	2 (3.39)	6 (3.06)	0.899	0.90 (0.18-4.58)

CHD, congenital heart disease; CI, confidence interval; NC, not calculated; OR, odds ratio. Values are n (%) unless otherwise indicated.

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Supplementary Table 6. Adverse cardiovascular, obstetric, and fetal events experienced by women with CHD admitted for delivery by presence of PH

	CHD with PH (*N* = 260)	CHD without PH (*N* = 739)	*P*-value	OR (95% CI)
Hypertension in pregnancy	7 (2.69)	15 (2.01)	0.627	1.24 (0.52-3.06)
Placenta previa	4 (1.54)	19 (2.57)	0.293	0.55 (0.18-1.65)
Gestational diabetes	26 (10.00)	108 (14.61)	0.058	0.66 (0.43-1.01)
Placental abruption	2 (0.77)	6 (0.81)	0.944	0.94 (0.18-4.72)
Hemorrhage	34 (13.08)	98 (13.26)	0.885	0.98 (0.65-1.46)
Pre-term delivery	91 (35.00)	74 (10.01)	<0.001	2.83 (1.96-4.09)
Preeclampsia	20 (7.69)	45 (6.09)	0.349	1.28 (0.75-2.21)
Heart failure	33 (12.69)	16 (2.17)	<0.001	6.34 (3.49-11.58)
Arrhythmia	34 (13.08)	93 (12.58)	0.895	1.04 (0.69-1.56)
Thromboembolic event (stroke, PE, and so on)	1 (0.38)	3 (0.41)	0.960	0.94 (0.11-9.13
Cesarean section	230 (88.46)	554 (74.97)	<0.001	2.52 (1.68-3.77)
Artificial rupture of the membranes	2 (0.77)	24 (3.25)	0.046	0.24 (0.06-0.98)
Induction	2 (0.77)	24 (3.25)	0.046	0.24 (0.06-0.98)
Fetal distress	10 (3.85)	47 (6.36)	0.121	0.59 (0.28-1.15)
Fetal growth restriction	4 (1.54)	8 (1.08)	0.565	1.44 (0.45-4.77)
Fetal malformation	1 (0.38)	1 (0.14)	0.460	2.84 (0.18-45.63)
Infant of low birth weight	87 (33.46)	46 (6.22)	<0.001	2.67 (1.71-4.17)
Respiratory/pulmonary diseases	7 (2.69)	7 (0.95)	0.048	2.88 (1.01-8.31)
Systemic hypertension	4 (1.54)	16 (2.17)	0.464	0.65 (0.22-1.99)

CHD, congenital heart disease; OR, odds ratio; PH, pulmonary hypertension. Values are n (%) unless otherwise indicated.