

Preventing Complications in Pregnant Women With Cardiac Disease



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ABSTRACT

BACKGROUND Pregnancy can lead to complications in women with heart disease, and these complications can be life threatening. Understanding serious complications and how they can be prevented is important.

OBJECTIVES The primary objectives were to determine the incidence of serious cardiac events (SCEs) in pregnant women with heart disease, whether they were preventable, and their impact on fetal and neonatal outcomes. Serious obstetric events were also examined.

METHODS A prospectively assembled cohort of 1,315 pregnancies in women with heart disease was studied. SCEs included cardiac death or arrest, ventricular arrhythmias, congestive heart failure or arrhythmias requiring admission to an intensive care unit, myocardial infarction, stroke, aortic dissection, valve thrombosis, endocarditis, and urgent cardiac intervention. The Harvard Medical Study criteria were used to adjudicate preventability.

RESULTS Overall, 3.6% of pregnancies (47 of 1,315) were complicated by SCEs. The most frequent SCEs were cardiac death or arrest, heart failure, arrhythmias, and urgent interventions. Most SCEs (66%) occurred in the antepartum period. Almost one-half of SCEs (49%) were preventable; the majority of preventable SCEs (74%) were secondary to provider management factors. Adverse fetal and neonatal events were more common in pregnancies with SCEs compared with those without cardiac events (62% vs. 29%; $p < 0.001$). Serious obstetric events were less common (1.7%) and were primarily due to pre-eclampsia with severe features.

CONCLUSIONS Pregnant women with heart disease are at risk for serious cardiac complications, and approximately one-half of all SCEs are preventable. Strategies to prevent serious cardiac complications in this high-risk cohort of women need to be developed. (J Am Coll Cardiol 2020;75:1443-52) © 2020 by the American College of Cardiology Foundation.

For women with heart disease, the hemodynamic stress of pregnancy can lead to cardiac and obstetric complications. In particular, cardiac complications are common and occur in 5% to 15% of pregnancies in women with heart disease (1-3). Most often, cardiac complications are not severe; however, serious or life-threatening complications can occur, and these types of complications have important long-term effects on the health of the mother and her child. Furthermore, some of these complications may be preventable. The Confidential Enquiries Into Maternal Mortality in the United

Kingdom found that in 36% of maternal cardiac-related deaths, improvements in care could potentially have changed the outcome (4), and the Maternal Mortality Review Committee in the United States found that cardiovascular and coronary death was preventable in 68% of cases (5). Although maternal deaths are important, they are very rare in developed countries, and nonfatal cardiac complications are much more common. However, few studies have focused on nonfatal serious cardiac events (SCEs), and none have specifically examined these events in women with heart disease, a particularly



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Manuscript received December 16, 2019; accepted January 13, 2020.

**ABBREVIATIONS
AND ACRONYMS****CHF** = congestive heart failure**SCE** = serious cardiac event**SOE** = serious obstetric events

high-risk group of women. By understanding serious complications in pregnant women with heart disease and their contributing factors, preventive strategies can be developed to improve the long-term outcomes in this group of women. Therefore, the aims of this

study were to determine the incidence of serious and life-threatening cardiac and obstetric complications in pregnant women with heart disease, to determine if cardiac complications were preventable, and to examine the impact of SCEs on the fetus and neonate.

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METHODS

This was an analysis of a prospectively assembled cohort of pregnant women with heart disease. Pregnant women with heart disease were recruited as part of a larger multicenter study, CARPREG (Canadian Cardiac Disease in Pregnancy) (3,6). Women seen at 2 large tertiary centers (in Toronto and Vancouver) between 2004 and 2014 who agreed to participate were included. Although many women received antenatal care at the study hospitals, some women were referred to the study center for antenatal care only after their index serious events. The study was approved by the local research ethics boards, and participants gave written informed consent.

BASELINE CHARACTERISTICS. Baseline variables collected have been described previously (6). We collected the following information for each pregnancy: maternal age, gestational age at the first antenatal visit, gravity and parity, maternal weight, cardiac diagnosis, presence of cyanosis, New York Heart Association functional class, smoking history, concurrent medical conditions (hypertension, gestation hypertension, or diabetes mellitus), prior cardiac complication, and cardiac medications.

OUTCOMES. All adverse cardiac and obstetric events during pregnancy and up to 6 months postpartum were reviewed. The definition of an adverse cardiac event has been described elsewhere (3). The focus of the study was to examine only those events that were deemed serious or life-threatening. SCEs and serious obstetric events (SOEs) were identified and reviewed by 2 cardiologists to ensure that the events met the criteria for a serious event. When necessary, additional information from the treating physicians was requested.

SCEs were defined as cardiac death or cardiac arrest, serious arrhythmias including sustained ventricular arrhythmias or other sustained arrhythmias

requiring admission to an intensive care unit, congestive heart failure (CHF) requiring admission to an intensive care unit, aortic dissection, myocardial infarction, cerebrovascular events, mechanical valve thrombosis, pulmonary embolism, endocarditis, or the need for urgent cardiac intervention (during pregnancy and up to 4 weeks postpartum). If a woman had an SCE such as heart failure or an arrhythmia followed by maternal death or cardiac arrest, the event was classified as a death or cardiac arrest. For calculation of the event rate, each pregnancy was assigned 1 primary SCE.

SOEs were based on published obstetric research (7,8), with the definition of endpoints in accordance with the American College of Obstetricians and Gynecologists (9,10). SOEs included noncardiac death, HELLP syndrome (hemolysis, elevated liver enzymes, and low platelet count), and pre-eclampsia with severe features (systolic blood pressure ≥ 160 mm Hg or diastolic blood pressure ≥ 110 mm Hg on 2 occasions at least 4 h apart and any of the following: thrombocytopenia [platelet count $< 100,000/\mu\text{L}$], impaired liver function, severe persistent right upper quadrant or epigastric pain unresponsive to medication and not accounted for by alternative diagnoses, progressive renal insufficiency [serum creatinine concentration > 1.1 mg/dl or a doubling of serum creatinine in the absence of other renal disease], pulmonary edema, and new-onset cerebral or visual disturbance) (9), severe postpartum hemorrhage, amniotic fluid embolism, and acute fatty liver. To calculate the incidence of pre-eclampsia, only pregnancies that went beyond 20 weeks were included in the analysis.

Adverse fetal and neonatal outcomes included fetal death (> 20 weeks of gestation), neonatal deaths (death within the first 28 days of life), pre-term delivery (birth at < 37 weeks of gestation), small for gestational age (birth weight < 10 th percentile), respiratory distress syndrome, and intraventricular hemorrhage. For comparison purposes, we examined the rates of adverse fetal and neonatal events in pregnancies with SCEs, with nonserious cardiac complications, and with no cardiac complications. Nonserious cardiac events included CHF and sustained or symptomatic arrhythmias not requiring admission to an intensive care unit.

PREVENTABLE EVENTS. If an event met the criteria for an SCE, it was adjudicated as to whether it was preventable and if specific preventable factors could be identified. Preventable events were defined as deviations in standard care that could have led to adverse events (11-13). To adjudicate if SCEs were

preventable, we used a previously established tool first used in the Harvard Medical Practice Study and modified in subsequent studies (14,15). This tool classifies preventability into 6 categories (totally preventable, preventable, probably preventable, possibly preventable, unpreventable, and definitely not preventable) and is less 1-dimensional than a yes-or-no classification. For the purpose of this study, SCE were then categorized into 2 categories: preventable (including those classified as probably or possibly preventable) and not preventable. In all cases, a consensus on preventability was reached by the reviewing cardiologists. At least 2 cardiologists reviewed each case. If an SCE was deemed preventable, the case was adjudicated as to the contributing factors that led to the event. Possible contributing factors included: 1) health care provider management factors; 2) patient-related factors; 3) system-related factors; and 4) iatrogenic factors. Provider management factors included all diagnostic and treatment errors. System-related factors occurred if established policies had not been followed or patients had been lost to follow-up. The national and international guidelines for prevention of pre-eclampsia with aspirin had not been published at the start of the study period, and therefore, we did not adjudicate this SOE for preventability.

DATA ANALYSIS. SPSS version 22.0 for Windows (IBM, Armonk, New York) was used for data analysis. Baseline characteristics are presented as mean ± SD. Comparisons between pregnancies with and those without SCEs were performed using the chi-square test, Student's *t*-test, or the Fisher exact test as appropriate. Rates of SCEs were stratified according to CARPREG II risk scores (3) and then further grouped in risk categories on the basis of similar rates of SCE (risk categories 0 or 1, 2 or 3, and ≥4). A chi-square test was used to determine differences in event rates among the 3 risk categories. We also examined adverse fetal and neonatal outcomes in pregnancies complicated by SCE, pregnancies with nonserious cardiac events, and pregnancies with no cardiac adverse events using a chi-square test. A 2-sided *p* value of <0.05 was considered to indicate statistical significance.

RESULTS

Baseline characteristics of the 1,315 pregnancies are shown in Table 1. Women diagnosed with acquired heart disease (*p* < 0.001), high-risk native valve lesions (*p* = 0.01), and mechanical valves (*p* = 0.03) were more likely to have SCEs. SCEs were also more likely to occur in women with at least mild systemic

TABLE 1 Baseline Characteristics of Women With Heart Disease With and Without Serious Cardiac Events During Pregnancy

	Serious Cardiac Events (n = 47)	No Serious Cardiac Events (n = 1,268)	p Value
Clinical variables			
Maternal age, yrs	32 ± 7	31 ± 5	0.46
Nulliparity	24 (51)	638 (50)	0.92
Twins or triplets	1 (2)	33 (3)	1.00
Body mass index, kg/m ² (n = 1,081)	28 ± 8	25 ± 6	0.04
Smoking	6 (13)	81 (6)	0.08
Late pregnancy assessment (first antenatal visit >20 weeks)	18 (38)	452 (36)	0.71
Prior hypertension, gestational hypertension, or diabetes mellitus	4 (9)	84 (7)	0.61
Prior cardiac events*	18 (38)	381 (30)	0.23
At least mild systemic ventricular dysfunction	19 (40)	150 (12)	<0.001
NYHA functional class III/IV or cyanosis	5 (11)	29 (2)	<0.001
Cardiac medications at first antenatal visit (except anticoagulation or ASA)	20 (43)	260 (21)	<0.001
No prior cardiac intervention	27 (57)	590 (47)	0.14
Cardiac diagnosis			
Congenital heart disease	23 (49)	791 (62)	0.06
Acquired heart disease	21 (45)	263 (21)	<0.001
Isolated arrhythmias	3 (6)	213 (17)	0.06
High-risk cardiac lesions			
High-risk valve lesion	11 (23)	142 (11)	0.01
Pulmonary hypertension	3 (6)	30 (2)	0.11
Mechanical heart valve	4 (9)	28 (2)	0.03
High-risk aortopathy	5 (11)	29 (2)	<0.001
Coronary artery disease	4 (9)	23 (2)	0.01
CARPREG II risk score			
0 or 1	2 (4)	498 (39)	<0.001
2 or 3	17 (36)	405 (32)	0.54
>4	28 (60)	365 (29)	<0.001

Values are mean ± SD or n (%). High-risk valve lesions included any significant left ventricular outflow tract obstruction (aortic valve area <1.5 cm², subaortic gradient >30 mm Hg, mitral valve area <2 cm). Pulmonary hypertension was defined as right ventricular systolic pressure >50 mm Hg in the absence of right ventricular outflow obstruction. High-risk aortopathy included Marfan syndrome, bicuspid valve disease with aortic dimension >45 mm, Loeys-Dietz syndrome, vascular Ehlers-Danlos syndrome, and prior aortic dissection. *Including congestive heart failure, stroke, and arrhythmia. ASA = acetylsalicylic acid; CARPREG = Canadian Cardiac Disease in Pregnancy; NYHA = New York Heart Association.

ventricular dysfunction (*p* < 0.001) and with New York Heart Association functional class III or IV or cyanosis (*p* < 0.001).

SERIOUS CARDIAC EVENTS. Overall, 17% of pregnancies (226 of 1,315) were complicated by adverse maternal cardiac events, of which 3.6% (47 of 1,315) were considered serious (Table 2, Figure 1). Four pregnancies were complicated by >1 SCE and 1 pregnancy by 3 SCEs. There were 5 maternal deaths (0.4%) in women with the following diagnosis: congenitally corrected transposition of the great arteries, complete transposition of the great arteries with a Rastelli operation, mechanical aortic valve, and non-obstructive hypertrophic cardiomyopathy. One woman with a repaired atrioventricular defect and

TABLE 2 Serious Cardiac Events in Pregnant Women With Heart Disease and Timing of Events (N = 1,315)

	Antepartum	Intrapartum	Postpartum	
Any serious cardiac event	47 (3.6)	31 (2.4)	4 (0.3)	12 (0.9)
Cardiac death	5 (0.4)	3	0	2
Cardiac arrest	4 (0.3)	2	0	2
Heart failure requiring admission to an intensive care unit	8 (0.6)	4	2	2
Serious arrhythmias*	6 (0.5)	5	1	0
Myocardial infarction	5 (0.4)	2	0	3
Aortic dissection	4 (0.3)	3	1	0
Endocarditis	3 (0.2)	3	0	0
Mechanical valve thrombosis	2 (0.2)	2	0	0
Stroke	1 (0.07)	1	0	0
Urgent cardiac intervention	9 (0.7)	6	0	3

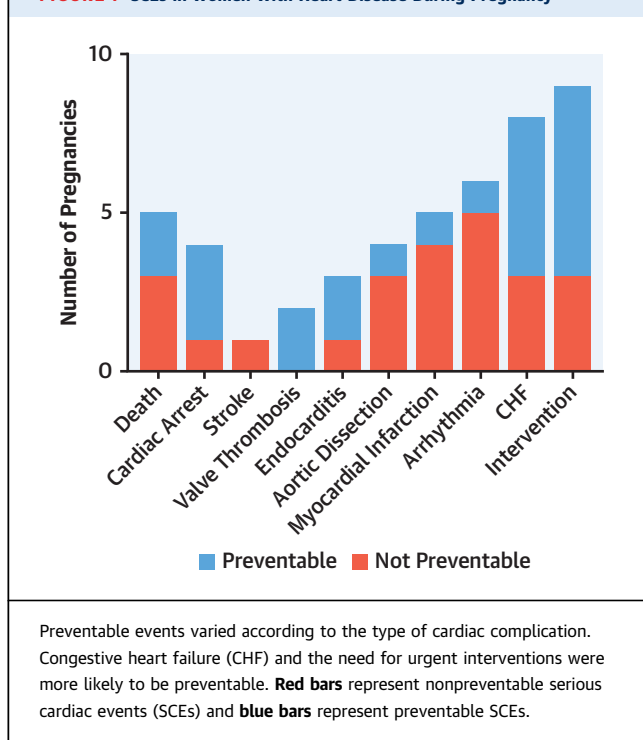
Values are n (%) or n. *Serious arrhythmias included 4 cases of sustained ventricular tachycardia and 2 cases of atrial arrhythmias requiring admission to an intensive care unit.

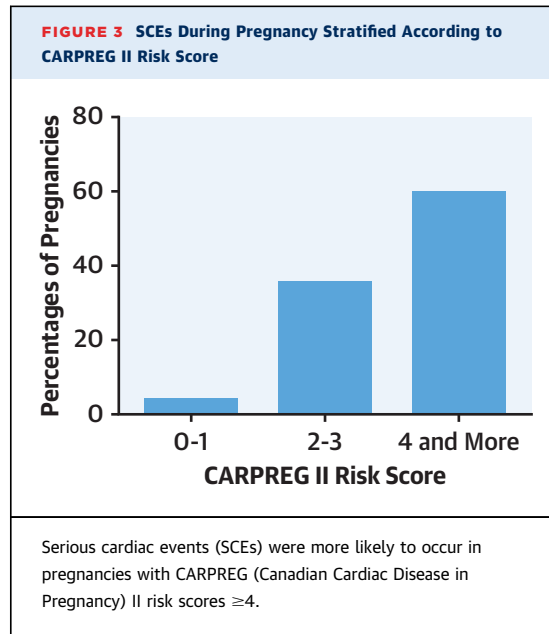
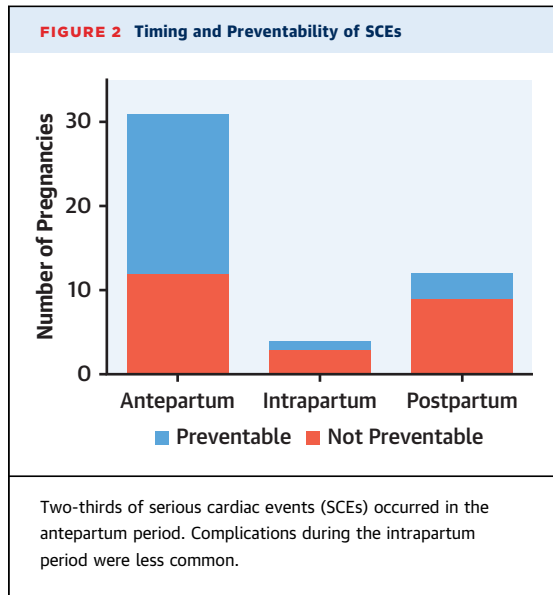
residual severe regurgitation underwent urgent postpartum surgery for recurrent CHF and died in the post-operative period. Of the 5 deaths, 4 were secondary to cardiac arrests. Four women (0.3%) survived cardiac arrest. All postpartum cardiac arrests and deaths (n = 4) occurred within the first week after delivery. CHF requiring admission to an intensive

care unit, serious arrhythmias, and urgent intervention were the most common SCEs, occurring in 1.7% of pregnancies (23 of 1,315). Urgent cardiac interventions were required in 0.7% of cases (9 of 1,315) and included cardiac valve surgery (n = 2), valvuloplasty (n = 3), surgical resection of an intracardiac tumor (n = 2), closure of a large secundum atrial septal defect in a symptomatic woman with decreased right ventricular systolic function and elevated pulmonary artery pressures (n = 1), and aortic root replacement for aortic dilation in a woman with Marfan syndrome (n = 1). CHF requiring intensive care unit admission most commonly occurred in women with acquired heart disease or newly diagnosed cardiomyopathies. Although all women were seen in consultation at the tertiary care study centers, some women were transferred to the study centers after developing cardiac complications.

SCEs occurred predominantly in the antepartum period (n = 31 [66%]) (Table 2, Figure 2). Most arrhythmias, cerebrovascular events, endocarditis, and aortic dissections occurred in the antepartum period, whereas CHF was more common in the third trimester and early postpartum. Women with SCEs were more likely to have undiagnosed heart disease prior to pregnancy compared with those without SCEs (32% vs. 4%; p < 0.001). SCEs were more common in pregnancies with higher CARPREG II risk scores (Figure 3). Sixty percent of SCE (n = 28) occurred in women who had risk scores of ≥ 4 . Six of the women with SCEs (13%) also had pre-eclampsia, and 2 of these women had myocardial infarctions. Length of stay in women with SCEs (n = 47) was 14 days longer compared with women who have did not have SCEs (median length of stay in pregnancies with SCEs 17 days [range: 4 to 100 days] vs. pregnancies without SCEs 3 days; p < 0.001).

PREVENTABLE SCEs. Forty-nine percent of the SCE (23 of 47) were considered preventable, including 2 maternal deaths (Figure 1). Urgent cardiac interventions and CHF were the most common (48% [11 of 23]) preventable SCEs. All preventable urgent cardiac interventions and CHF admissions were related to health care provider management factors: failure to identify the high-risk patient or underlying condition prior to pregnancy, late recognition of cardiac deterioration, or treatment not matching best practice. In comparison, arrhythmias and myocardial infarction were deemed to be preventable in only 1 of 6 and 1 of 5 cases, respectively. One woman with diabetes and a 6-week history of new-onset angina did not seek medical care until she presented with myocardial infarction at 29 weeks of gestation. Three

FIGURE 1 SCEs in Women With Heart Disease During Pregnancy



women with Marfan syndrome had aortic dissections: 1 case was deemed possibly preventable because the underlying condition was not recognized or treated with beta-blockers until the patient presented with a type B aortic dissection at 38 weeks of gestation. Two women did not seek care because they did not have health care coverage in Canada. Preventable provider management factors related to medications were identified: 2 preventable events were related to sub-optimal anticoagulation management. Preventable SCEs were more likely to occur in the antepartum compared with the postpartum period (Figure 2).

Table 3 shows the specific factors contributing to the preventable SCEs. Overall, 74% of the preventable events (17 of 23) were related to provider management factors. The most common contributing factors were failure to identify the underlying cardiac condition prior to pregnancy, failure to recognize a high-risk patient, delay in treatment or intervention, and late recognition of cardiac deterioration. Preventable SCEs were more likely to occur at smaller, non-study center hospitals (15 of the 23 preventable SCEs), and provider management factors were the most common contributing factors (87% of the cases) at these sites. Furthermore, a significant portion (38%) of those with provider management-related errors occurred in women with previously undiagnosed heart disease. In contrast to small non-study center hospitals, at the tertiary care study centers, patient-related factors, such as failure to seek care and noncompliance with treatment, were more likely to contribute to preventable SCEs.

RELATIONSHIP BETWEEN SCEs AND PERINATAL OUTCOMES. Table 4 shows the fetal and neonatal adverse events in the 47 women with SCEs. There were 42 live births, 2 neonatal deaths, 1 stillbirth, and 2 miscarriages. Two miscarriages and 1 fetal death occurred after valve replacement surgery during pregnancy. There were 2 neonatal deaths following delivery at 26 and 28 weeks of gestation. One neonatal death occurred in a woman with mechanical valve thrombosis after cardiac arrest, and another death occurred in an infant born with multiple fetal abnormalities after exposure to teratogenic medications (warfarin and an angiotensin II receptor blocker). Adverse fetal and neonatal events were more common in pregnancies with SCEs compared with pregnancies with nonserious cardiac events or pregnancies without any adverse cardiac events (62% vs. 32% vs. 29%; $p < 0.001$) (Table 4). Furthermore, the preventable antepartum SCEs were frequently (68% of cases) associated with adverse fetal or neonatal events.

SERIOUS OBSTETRIC EVENTS. Twenty-two pregnancies (1.7%) were complicated by SOEs. There were no maternal obstetric deaths. The most common SOE was pre-eclampsia with severe features (18 of 22 SOEs), including 1 woman with HELLP syndrome and 1 with eclampsia. Two-thirds of these women delivered pre-term and/or had babies that were small for gestational age. All women except 1 had at least 1 risk factor for pre-eclampsia, including history of pre-eclampsia ($n = 6$), diabetes mellitus ($n = 2$),

TABLE 3 Factors Contributing to Preventable Serious Cardiac Events (n = 23)

Provider management-related factors*	17 (74)
Failure to identify condition prior pregnancy	8
Failure to identify condition as high risk	6
Delay in treatment/intervention	5
Late recognition of cardiac deterioration	5
Inappropriate treatment	4
No preconception counseling provided	1
Patient-related factors*	4 (17)
Failure to seek care	5
Noncompliant with treatment	4
Noncompliant with visits	2
No health care access	2
Iatrogenic factors (infection after instrumentation)	1 (4)
System-related factors (lost for follow-up)	1 (4)

Values are n (%) or n. *Errors are not mutually exclusive.

hypertension (n = 2), assisted reproductive technologies (n = 3), chronic kidney disease (n = 2), systemic lupus erythematosus (n = 1), multifetal pregnancy (n = 5), and nulliparity (n = 8) (16,17). Pre-eclampsia with or without severe features occurred in 5.1% (65 of 1,280 deliveries after 20 weeks of gestation) of pregnancies. Five pregnancies (0.4%) were complicated by severe postpartum hemorrhage. One woman with a mechanical mitral valve had postpartum bleeding and required an emergency hysterectomy. There was no clear association between SCEs and SOEs: only 2 of the 47 pregnancies with SCEs had concomitant SOEs.

DISCUSSION

Although cardiac complications in pregnant women with heart disease have been previously reported, we examined only those complications that were serious or life threatening. Serious cardiac complications in

pregnancy are important because they have potential long-term consequences for mothers and their children. In this cohort of women with heart disease seen in tertiary care pregnancy and heart disease programs, 3.6% of pregnancies were complicated by SCEs. The most common SCEs were cardiac death or arrest, CHF requiring admission to an intensive care unit, serious arrhythmias, and urgent cardiac interventions. SCEs were associated with high rates (62%) of adverse fetal and neonatal events. Approximately one-half of all the SCEs were preventable, and they were most commonly due to failures in the provision of care by health care teams or patient-related factors. These findings highlight the urgent need for interventions to educate providers and patients about the risk for pregnancy in this high-risk group of women.

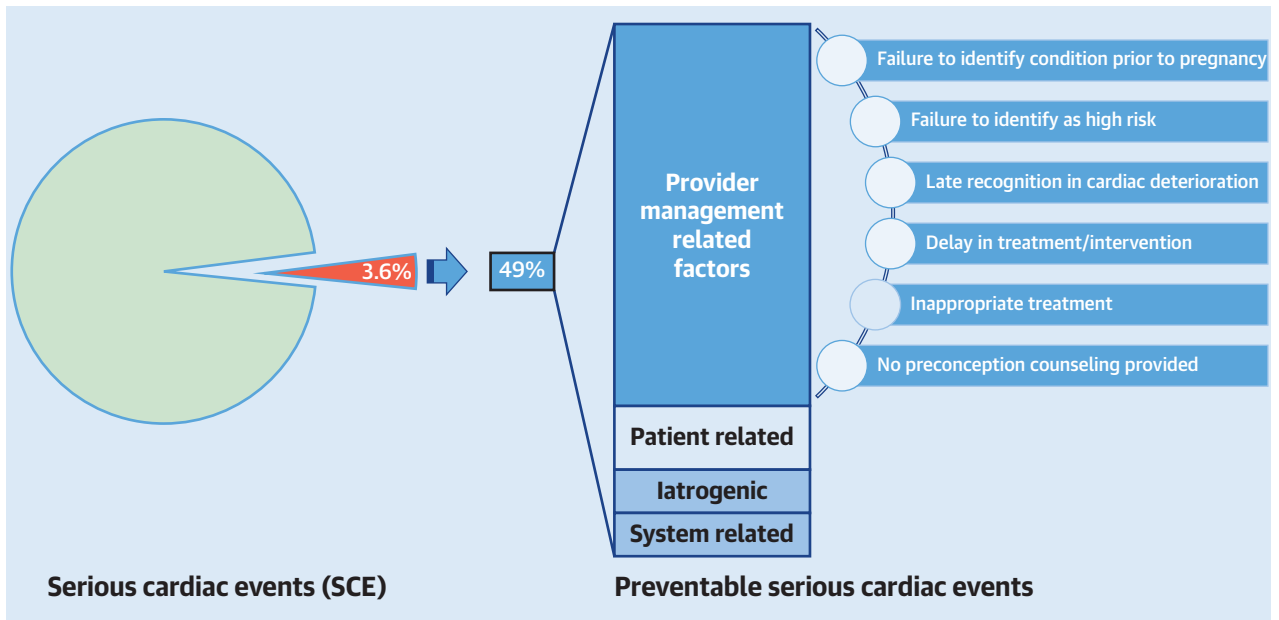
Pregnancies in women with heart disease are associated with significant risks. In our study, SCEs occurred in 3.6% of pregnancies and maternal mortality in 0.4% of pregnancies. These rates of serious complications are much higher than the general population, although precise comparisons among studies are difficult because the definition of serious complications varies between studies. In the United States (Illinois), cardiovascular mortality in pregnancy has been reported at 8.2 per 100,000 live births (18), much lower compared with the cardiovascular mortality of 4 per 1,000 deliveries in our cohort of women with heart disease. Severe maternal morbidity due to cardiovascular disease in the general population has been reported at 2.3 per 10,000 deliveries in the Netherlands (19), much lower than the rate of SCEs in our study. In view of these risks, women with heart disease must have appropriate pre-conception counseling by an experienced pregnancy heart team so that they can make

TABLE 4 Adverse Fetal and Neonatal Outcomes in Pregnant Women With Heart Disease

	Entire Cardiac Population (N = 1,315)	Pregnancies With SCEs (n = 47)	Pregnancies With No Cardiac Events		Pregnancies With Nonserious Cardiac Events	
			(n = 1,089)	p Value*	(n = 179)	p Value†
Any adverse fetal event‡	396 (30)	29 (62)	310 (29)	<0.001	57 (32)	0.001
Fetal and neonatal death	26 (2)	3 (6)§	17 (2)	0.05	6 (3)	0.40
Pre-term delivery	195 (15)	21 (45)	139 (13)	<0.001	35 (20)	0.01
Respiratory distress syndrome	44 (3)	7 (15)	26 (2)	<0.001	11 (6)	0.07
Intraventricular hemorrhage	7 (0.5)	2 (4)	3 (0.3)	0.015	2 (1)	0.19
Small for gestational age	219 (17)	10 (21)	183 (17)	0.43	26 (14)	0.27
Live births	1,268 (96)	42 (89)	1,053 (97)	0.24	173 (97)	0.54

Values are n (%). Terminations and spontaneous abortions are not included in the table. Events are not mutually exclusive. *SCEs compared with no cardiac events. †SCEs compared with nonserious cardiac events. ‡Any of the following: pre-term birth, small for gestational age, intraventricular hemorrhage, respiratory distress syndrome, fetal death, and neonatal death. §Fetal death at 22 weeks after aortic valve replacement surgery, neonatal death following delivery at 28 weeks with multiple fetal abnormalities after exposure to teratogens, and neonatal death following delivery at 26 weeks (emergency cesarean delivery because of maternal cardiac arrest).
SCE = serious cardiac event.

CENTRAL ILLUSTRATION Preventable Serious Cardiac Events in Women With Heart Disease and Their Contributing Factors



Pfaller, B. et al. *J Am Coll Cardiol.* 2020;75(12):1443-52.

Serious cardiac events (SCEs) occurred in 3.6% of pregnancies in women with heart disease, and 49% of the events were preventable. The majority of preventable SCEs (74%) were secondary to provider management errors.

an informed decision as to whether they wish to pursue pregnancy (20).

Most SCEs occurred in the antepartum (66%) or postpartum (26%) period, and SCEs at the time of labor and delivery were less common (8%). This finding is important to emphasize because many physicians focus on the risks at the time of labor and delivery, but this is not when women are at the highest risk. Although it is important to carefully plan for labor and delivery, antepartum and postpartum surveillance of are equally as important. Furthermore, although most women had cardiac diagnoses established prior to pregnancy, women with SCEs were more likely to have undiagnosed cardiac disease at the time of their presentation. Physicians caring for pregnant women need to be attentive to the signs and symptoms of cardiac disease, and when present, patients should undergo a complete cardiac assessment, including electrocardiography and transthoracic echocardiography (20).

Many groups, including ours, have identified baseline maternal risk factors that predict which women are at highest risk for cardiac complications

during pregnancy (1,2,6,21,22). Similar to these prior studies, we found that women with specific high-risk cardiac lesions (high-risk aortopathy, significant left-sided outflow tract obstruction, coronary artery disease), cyanosis, or ventricular dysfunction were at highest risk for SCEs (3,6,23,24). The CARPREG II risk score, which includes these risk factors along with others, has been used to identify women at risk for any adverse cardiac events (both SCEs and nonserious cardiac events) in pregnancy. Although this study was not designed to validate a risk score, we found that higher CARPREG II risk scores were associated with increased risk for SCEs. Approximately 60% of all the SCEs occurred in women who had CARPREG II risk scores of ≥ 4 .

In this study, almost 50% of SCEs (including maternal deaths) were potentially preventable, and most of the preventable SCEs were due to provider management failures (Central Illustration). This is similar to other studies on maternal mortality and morbidity in the noncardiac population (5). In the United States, one-quarter to two-thirds of maternal mortality is reported to be preventable (18,25).

In another report, 26% of maternal cardiovascular deaths were believed to be preventable, and most were attributable to delay and failure in diagnosis or delay in treatment (25). A study of severe acute complications in pregnant women admitted to the intensive care unit found that 39% of the admitted cases were potentially preventable with improvements in care by providers (26).

We also found differences in factors contributing to preventable SCEs on the basis of the health care center. At smaller, nonstudy centers, provider factors, such as failure to identify or transfer high-risk patients and delays in or suboptimal treatment, were common factors contributing to preventable SCEs. For example, in 2 women with dilated cardiomyopathy, dyspnea was incorrectly diagnosed as anxiety, and both developed CHF during pregnancy. A woman with a mechanical valve did not receive appropriate twice daily weight-based low-molecular weight heparin and did not have her anti-Xa levels followed closely during pregnancy. At larger tertiary care study centers, patient-related factors such as failure to seek care notwithstanding cardiac symptoms or noncompliance with treatment were more common causes of preventable SCEs. For example, 1 woman with newly detected ventricular tachycardia was advised not to get pregnant until her ventricular tachycardia was adequately diagnosed and treated; despite this advice, she became pregnant and had recurrent ventricular tachycardia during pregnancy. Two women delayed treatment because they did not have Canadian health insurance.

There are likely a number of reasons that the types of errors differ at smaller medical centers compared with tertiary care centers. For instance, smaller centers are more likely to encounter pregnant women with previously undiagnosed heart disease, and this may contribute to a higher proportion of physician-related factors affecting outcomes. Variability in the types of preventable errors between centers also means that different interventions may be more effective at different sites. For instance, at larger centers, more efforts could be focused on programs to educate women with heart disease about the risks of pregnancy and the need for regular antenatal surveillance. Although patient education is often a part of the cardiologist's clinic visit, the role of the clinic nurse or physician assistant could be expanded to provide additional patient education. Joint cardio-obstetric clinics may better help coordinate patient care and improve patient compliance. In comparison, at smaller centers, educational initiatives for physicians and emergency department protocols for the assessment of pregnant women with cardiac symptoms may be

helpful. Cardiac disease is now the number one cause of maternal mortality in many countries, yet physician awareness and recognition of the problem lags behind. Awareness of regional cardio-obstetric clinics must be increased, and pathways for easy transfer to these clinics need to be streamlined. Independent of the center, optimal care of this complex population requires excellent communication between multidisciplinary team members. Joint cardio-obstetric clinics, timely distribution of care plans to all health care providers, and shared health records are some examples of methods that can help improve communication among care providers.

In general, women with heart disease have higher rates of adverse neonatal and fetal complications compared with healthy obstetric populations (27,28). For women with heart disease who develop SCEs during pregnancy, the risk to their offspring is even higher, with >60% of those pregnancies having perinatal complications. This is likely due to a number of maternal cardiac, maternal obstetric, and environmental factors. For example, SCEs have an impact on maternal hemodynamic status, and poor maternal hemodynamic status and impaired uteroplacental perfusion have been shown to be related to poor perinatal outcomes (29). However, many of the factors that contribute to poor perinatal outcomes are not well understood, and more studies on maternal-fetal interactions in this population are needed. Nonetheless, the relationship between maternal and perinatal health emphasizes the need for coordinated care by a multidisciplinary cardio-obstetric team (30).

Pre-eclampsia with severe features was the most common obstetric complication in our cohort. The risk for developing pre-eclampsia (with or without serious features) and serious postpartum hemorrhage in pregnant women with heart disease is similar to that in the general population (31,32). However, pre-eclampsia in women with pre-existing heart disease may have more serious consequences for maternal and neonatal health. In our study, pre-eclampsia with severe features occurred in 18 pregnancies, and 60% of women with heart disease and pre-eclampsia with severe features delivered infants pre-term and/or small for gestational age. This high rate of complications suggests that pre-eclampsia with severe features in women with heart disease may be a particularly bad combination.

STUDY LIMITATIONS. In this study, we evaluated only serious and life-threatening complications in pregnant women, who were seen at tertiary care referral centers, and thus the incidence of serious complications may be inflated because of referral

bias. Alternatively, complications rates may be lower than elsewhere, as the study cohort consisted only of women seen at large, well-established high-risk obstetric care centers, both of which deliver state-of-the-art pregnancy care. This study was part of a larger study examining pregnancy outcomes in pregnant women with heart disease, and adjudication of events for preventability was done retrospectively, so some information pertaining to the contributing factors leading to the SCEs may not have been recorded.

CONCLUSIONS

Pregnant women with heart disease are at risk for serious and life-threatening cardiac and obstetric complications. Approximately one-half of these cardiac events are preventable. Strategies to prevent serious maternal cardiac complications in this high-risk cohort of women need to be developed.

ACKNOWLEDGMENT The authors gratefully acknowledge the generous donation provided by Mrs.

Josephine Rogers (Toronto) and support from the Allan Tiffin Trust (Toronto) and the St. Paul's Hospital Foundation (Vancouver).

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PERSPECTIVES

COMPETENCY IN PATIENT CARE AND PROCEDURAL

SKILLS: Women with heart disease are at risk for complications during pregnancy, and many maternal cardiac complications are preventable.

TRANSLATIONAL OUTLOOK: Future research should seek strategies to prevent maternal, neonatal and fetal complications in pregnant women with heart disease.

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KEY WORDS arrhythmias, complications, heart disease, heart failure, maternal mortality, pregnancy