SECTION 1: CARDIOVASCULAR AND RESPIRATORY DISORDERS

1 STRUCTURAL HEART DISEASE IN PREGNANT WOMEN

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Introduction

This chapter will outline the physiological changes, hemodynamic goals, management, and anesthetic options with regards to patients with acquired or congenital structural heart disease during pregnancy, labor, and delivery. There is no consensus as to the optimal anesthetic technique for the conditions being discussed. General and regional anesthesia can have significant cardiovascular effects on a parturient with cardiac disease. In addition, many pharmacological agents commonly used in anesthetic and obstetric practice can have adverse hemodynamic effects (Table 1.1).

Due to the nature and the rarity of the cardiac diseases discussed, there is a lack of randomized controlled studies to guide our practice. As a result, case reports and expert opinion will form the basis of discussing the anesthetic techniques. However, management options and anesthetic techniques must be individualized and based on the prevailing hemodynamic condition and obstetric needs.

Scope of the problem

An estimated 0.2–3.0% of pregnant patients have cardiac disease,[1] an increasing cause of maternal mortality.[2,3] The 2000–2 *Confidential Enquiries into Maternal Deaths in the United Kingdom* reported that cardiac disease was the second most common nonobstetric cause of maternal death after psychiatric disease.[4] Cardiac disease is also more common than the leading direct causes of maternal death.[4,5] The maternal mortality rate ranges from 0.4% in New York Heart Association (NYHA) class I–II women to 6.8% in class III–IV (Tables 1.2 and 1.3). Despite a dramatic decline over the last few decades in the incidence of rheumatic heart disease among women of childbearing age in the developed world, more women with partially or fully corrected congenital heart disease (CHD) are surviving to reproductive age because of improved surgical techniques and advances in medical management.[6,7]

The principal danger for a pregnant woman with a heart lesion is cardiac decompensation because of the inability to meet the additional demands imposed by the physiological changes of pregnancy and parturition. In addition, infection, hemorrhage, and thromboembolism can compound the risk. Maternal and neonatal outcomes can both be improved by meticulous peripartum care. However, some women with serious cardiac disease may still suffer significant morbidity and mortality despite optimal medical care.[4,8]

Physiology of pregnancy

A comparison between normal cardiopulmonary parameters in the pregnant and nonpregnant states is shown in Table 1.4. Pregnancy exerts a progressive cardiovascular stress that peaks at approximately 28–32 weeks of gestation.[9] Cardiac output (CO) starts to increase by the tenth week of gestation and continues to rise to a peak of 30–50% above baseline by 32 weeks' gestation. The increase in CO is due to increased stroke volume (SV) – up to 30% above baseline – in the first half of pregnancy. This is in contrast to the latter half of pregnancy when CO is maintained by an increase in heart rate (HR) – up to 15% above baseline – in addition to the increased SV. Plasma volume increases by 40–50% from prepregnant levels. This raised plasma volume exceeds the increase in red blood cells resulting in a relative anemia that may compromise oxygen delivery. Blood pressure (BP) usually falls during pregnancy due to progesterone-induced vasodilatation and the low resistance placental bed. Pulse pressure widens due to a greater reduction in diastolic BP compared to systolic BP.

Hyperventilation associated with pregnancy results from the respiratory stimulating effects of progesterone and leads to hypocarbia ($PaCO_2$ 27–34 mmHg) and a mild respiratory alkalosis (pH of 7.40–7.45).

Labor pain, periodic changes in venous return due to uterine contractions, and maternal expulsive efforts increase CO approximately 45% above prelabor levels. These physiological stresses can be minimized by good analgesia and anesthesia, careful fluid and hemodynamic management, as well as careful positioning to avoid aortocaval compression.[10]

Further increases in preload occur after delivery due to autotransfusion from the contracting uterus and relief of aortocaval compression.[11] These fluid shifts cause further stress on an already potentially compromised cardiac lesion. Postpartum normalization of systemic vascular resistance (SVR) and loss of the low resistance placental bed increases afterload. Careful fluid and hemodynamic monitoring for days to weeks postpartum are essential to minimize potential problems in this crucial period.

Symptoms and signs of normal pregnancy and heart disease

Easy fatigability, dyspnea, and orthopnea of normal pregnancy may simulate heart disease. Orthopnea is more common in obese women and may be due to limitation of diaphragmatic motion. Chest pain during pregnancy is most often due to hiatal hernia, esophageal reflux, or distension of the ribcage. Tachycardia is normal in pregnancy, as are premature atrial and ventricular depolarizations. Orthostatic syncope may occur with sudden assumption of the upright position. Syncope occurring in later pregnancy is usually due to supine hypotension secondary to inferior vena caval compression.

Obstetric Anesthesia and Uncommon Disorders, eds. David R. Gambling, M. Joanne Douglas and Robert S. F. McKay. Published by Cambridge University Press.

Table 1.1 Cardiovascular effects of commonly used anesthetic and obstetric drugs

	Heart rate	Blood pressure	SVR	Cardiac output	Myocardial contractility	Venodilation
Etomidate	↔	↔ or ↓	↔ or ↓	↔	↔	↔
Ketamine	↑↑	↑	↑ or ↔	↑	↑[a]	↔
Thiopental	↑	↓↓	↔ to ↑[b]	↓	↓	↑
Propofol	↑ or ↔	↓	↓↓	↔ to ↓	↓	↑
Succinylcholine	↔ to ↓ with repeat doses	↔ to ↑	↔ to ↑	↔	↔	↔ to ↓
Atracurium	↔ or ↑	↔ to ↓	↔	↔	↔	↔ to ↑
Pancuronium	↑	↑	↔ to ↑	↑	↑	↔
Rocuronium	↔ or ↑	↔	↔	↔	↔	↔
Vecuronium	↔	↔	↔	↔	↔	↔
Fentanyl	↓	↔ to ↓	↔	↔	↔	↔
Meperidine	↔ or ↑	↓	↓	↓	↓	↑
Morphine	↔ or ↓	↓	↓	↓	↓	↑
Halothane	↔ or ↑	↓	↓	↔ or ↓	↓↓	↓
Isoflurane	↑↑	↓	↓↓	↔ or ↑	↓	↓
Sevoflurane	↑	↓	↓	↔ or ↓ ?	↓	↔
Nitrous oxide	↔ or ↑	↔ or ↑	↔ or ↑	↓ or ↑	↔	↔ or ↓
Lidocaine	↔	↔	↔	↑	↑	↑ if used for regional anesthesia
Lidocaine toxicity	↓	↓	↑	↓	↓	↑
Midazolam	↔ or ↑	↓	↔ or ↓	↔	↔ or ↓	↔
Ergometrine	↑	↑↑	↑	↑	↑	↓
Oxytocin	↔ or ↑	↔ to ↑ (<10 U) ↓ (>10 U bolus dose)	↔ to ↓	↔	↔	↔ to ↑
Magnesium sulfate	↔ or ↓	↓	↓	↔	↔	↑
Nitroglycerin	↔	↓↓	↔ to ↓	↓	↔	↑↑
Terbutaline	↑	↔ to ↓	↔ to ↓	↑	↔ to ↑	↑

The response is represented by a five-point scale from a marked increase (↑↑) to marked decrease (↓↓), ↔ is no effect, ↑ is a slight increase, ↓ is a slight decrease.

[a] Secondary effect from endogenous catecholamine release

[b] May decrease due to histamine release

There are various caveats in the interpretation of these data. Some values are derived from animal studies, some from human volunteers, and some from patients. Values may vary depending on whether a patient is mechanically ventilated or breathing spontaneously. In addition, the hemodynamic effects of these agents may change in the presence of other anesthetic agents. Finally, the hemodynamic response may be different in patients who are hypovolemic, have sympathetic overactivity, or a sympathectomy. The values and ranges indicated in this table are the authors' opinion of the most likely clinical response for most patients and have been taken in part from the following texts:

Bowdle, T. A., Horita, A. & Kharasch, E. D. (eds). *The Pharmacologic Basis of Anesthesiology: Basic Science and Practical Applications*. New York: Churchill Livingstone, 1994 and Norris, M. C. (ed). *Obstetric Anesthesia*. Philadelphia: J. B. Lippincott, 1993.

Some cardiovascular findings on physical examination may be confusing. Peripheral edema occurs in 60–80% of pregnant individuals, and is attributed to hemodilution, a fall in plasma oncotic pressure, and an increase in capillary pressure secondary to raised venous pressure in the legs. However, this is not associated with hepatomegaly. Rales are likely the result of upward displacement of the diaphragm. Prominent peripheral and neck veins are related to the hypervolemia of pregnancy and the vasodilatory effects of progesterone. However, mean right atrial pressure is not elevated and the hepatojugular reflex is not positive. Pseudo-cardiomegaly is related to displacement of the apex by the gravid uterus. There is often a third heart sound due to volume loading and right ventricular outflow tract murmurs are common.

Certain symptoms and signs suggest the presence of heart disease. A careful history and physical examination will allow these to be differentiated beyond the symptoms and signs of normal pregnancy. Symptoms suggestive of heart disease

Table 1.2 New York Heart Association (NYHA) functional capacity and objective assessment[a]

Functional capacity	Objective assessment
Class I. Patients with cardiac disease but without limitation of physical activity. Ordinary physical activity does not cause fatigue, palpitations, dyspnea, or angina.	*No* objective evidence of cardiovascular disease.
Class II. Patients with cardiac disease resulting in slight limitation of physical activity. They are comfortable at rest. Ordinary physical activity results in fatigue, palpitation, dyspnea, or angina.	Objective evidence of *minimal* cardiovascular disease.
Class III. Patients with cardiac disease resulting in marked limitation of physical activity. They are comfortable at rest. Less than ordinary activity causes fatigue, palpitation, dyspnea, or angina.	Objective evidence of *moderately severe* cardiovascular disease.
Class IV. Patients with cardiac disease resulting in inability to carry on any physical activity without discomfort. Symptoms of heart failure or angina may be present even at rest. If any physical activity is undertaken, discomfort is increased.	Objective evidence of *severe* cardiovascular disease.

[a] AHA medical/scientific statement: 1994 revisions to classifications of functional capacity and objective assessment of patients with diseases of the heart. *Circulation* 1994; **90**: 644.

Table 1.3 Maternal mortality associated with heart disease in pregnancy

Group 1: Mortality <1%	
	Atrial septal defect
	Ventricular septal defect
	Patent ductus arteriosus
	Pulmonary/tricuspid disease
	Tetralogy of Fallot, corrected
	Bioprosthetic valve
	Mitral stenosis, NYHA class I and II
Group 2: Mortality 5–15%	
2A	Mitral stenosis NYHA class III–IV
	Aortic stenosis
	Coarctation of aorta, without valvular involvement
	Uncorrected Tetralogy of Fallot
	Previous myocardial infarction
	Marfan syndrome with normal aorta
2B	Mitral stenosis with atrial fibrillation
	Artificial valve
Group 3: Mortality 25–50%	
	Primary pulmonary hypertension or Eisenmenger syndrome
	Coarctation of aorta, with valvular involvement
	Marfan syndrome with aortic involvement

Adapted from: Foley, M. R.: Cardiac disease. In Dildy, G. A., Belfort, M. A., Saade, G. R., Phelan, J. P., Hankins, G. D. & Clark, S. L. (eds.), *Critical Care Obstetrics*, 4th edn. Malden: Blackwell Science, 2004, pp. 252–74.

Table 1.4 Normal hemodynamic and ventilatory parameters in the nonpregnant and pregnant patient

	Nonpregnant	Pregnant	Percentage change
Cardiac output (l/min)	4.3 ± 0.9	6.2 ± 1.0	+ 45%
Heart rate (beats/min)	71 ± 10	83 ± 10	+ 17%
Systemic vascular resistance (dyne.sec.cm^{-5})	1530 ± 520	1210 ± 226	− 21%
Pulmonary vascular resistance (dyne.sec.cm^{-5})	119 ± 47	78 ± 22	− 34%
Mean arterial pressure (mmHg)	86 ± 8	90 ± 6	NSC
Pulmonary capillary wedge pressure (mmHg)	6.3 ± 2.1	7.5 ± 1.8	NSC
Central venous pressure (mmHg)	3.7 ± 2.6	3.6 ± 2.5	NSC

NSC = no significant change.
Adapted from: Clark, S. L., Cotton, D. B., Lee, W. *et al.* Central hemodynamic assessment of normal term pregnancy. *Am. J. Obstet. Gynecol.* 1989; **161**: 1439–4.

include severe or progressive dyspnea, progressive orthopnea, paroxysmal nocturnal dyspnea, hemoptysis, syncope with exertion, and chest pain related to effort or emotion. Physical findings strongly suggesting the presence of heart disease include cyanosis, clubbing, persistent neck-vein distension, palpable murmurs, diastolic murmurs, dysrhythmias, and true cardiomegaly.

General management principles of pregnant women with heart disease

1. *Take a detailed history and follow up patients regularly during pregnancy*
   Patients with significant heart disease are usually diagnosed prior to pregnancy and may develop worsening of symptoms during their pregnancy. However, some cardiac lesions associated with few symptoms in the nonpregnant state may become symptomatic for the first time in mid to late pregnancy. The hemodynamic changes that occur in pregnancy represent a

significant stress test. Most women with cardiac disease who remain asymptomatic throughout pregnancy usually tolerate labor and delivery. Conversely, women who are breathless at rest (NYHA IV) and groups 2 and 3 listed in Table 1.3, usually tolerate pregnancy poorly. Functional class NYHA III–IV patients with surgically correctable lesions should be assessed for corrective surgery before pregnancy.

2. *Understand the physiological changes of pregnancy*
   It is essential to understand the impact of physiological changes of pregnancy on the specific heart lesion in order to properly manage these patients.[12]
3. *Multidisciplinary team approach*
   Pregnant women with significant or complex heart disease should be managed by a team in a specialist center.[13] This team should include representatives from obstetrics and perinatology, anesthesiology, neonatology, cardiology, intensive care, nursing, and social work. Patients should be seen regularly throughout their pregnancy and a management plan should be formulated early in pregnancy before the onset of labor. High-risk women should be managed by senior anesthesiologists experienced in treating pregnant patients with cardiac lesions. Pediatric involvement is important, as there is a 5–15% chance that the fetus will be affected by the same cardiac defect.[14] In addition, the fetus may be compromised by the mother's cardiopulmonary insufficiency.[15] In-utero echocardiography at 18 weeks' gestation can detect most fetal cardiac defects.[16,17] Avoidance of pregnancy, or consideration of an early therapeutic termination, in women with very high-risk cardiac disease (e.g., pulmonary hypertension) is prudent.
4. *Infective endocarditis antibiotic prophylaxis*
   Although the risk of bacteremia following normal delivery is low (0–5%),[13] appropriate antibiotic coverage should be provided for high-risk patients (especially those with prosthetic valves or a history of endocarditis) prior to labor, delivery, or other surgical procedures (Tables 1.5 and 1.6).[18]
5. *Anticoagulation during pregnancy and peripartum*
   Pregnancy is a hypercoagulable state, which increases the risk of thromboembolic events, especially in the cardiac patient with a prosthetic heart valve, valvular heart disease, or heart failure.[1] Anticoagulant therapy should be considered in these high-risk patients to prevent thromboembolism or thrombus formation.

Warfarin: The use of oral anticoagulants during pregnancy is relatively contraindicated. Warfarin therapy in the first trimester is associated with an increased incidence of fetal death and birth defects ("warfarin embryopathy"). Warfarin use later in pregnancy is associated with prematurity and low birthweight, as well as neonatal cerebral hemorrhage.[19,20] Despite these risks, warfarin is sometimes administered in combination with low dose aspirin (80–100 mg/day) to patients with mechanical valves because of concerns about the efficacy of heparin in preventing systemic embolism.[21,22] Warfarin can be used in the postpartum period and appears safe in women who breast-feed.[23]

Heparin: Heparin, unfractionated (standard, UFH) or low molecular weight (LMWH), is the drug of choice during pregnancy because it is a large molecule that does not cross the placenta and appears safe in women who breast-feed. Heparin is used to prevent and treat thromboembolism. For UFH, the activated partial thromboplastin time (aPTT) should be monitored because heparin requirements increase as pregnancy progresses. Platelet count should be measured before neuraxial blocks in patients on UFH for more than 4 days because of the risk of heparin-induced thrombocytopenia.[24] For LMWH, monitoring of aPTT or anti-Xa level is not predictive of the risk of bleeding and is therefore not always necessary or recommended.[24] Low molecular weight heparin offers potential advantages over UFH including lack of need for laboratory monitoring, greater bioavailability, once-a-day dosing because of its long half-life, and less thrombocytopenia and osteoporosis. Its efficacy in preventing and treating thromboembolism (as well as the above mentioned advantages) are leading to the widespread use of LMWH in obstetrics.

Thrombolytics: Streptokinase and urokinase are relatively contraindicated in pregnancy because of reports of placental abruption and postpartum hemorrhage.[25] Streptokinase has been used successfully to treat prosthetic mitral valve thrombosis during pregnancy.[26] The thrombosis was confirmed by echocardiography and fluoroscopy at 28 weeks' gestation in a woman with a history of progressive exertional dyspnea. Valve function returned to normal within 18 hours of commencing treatment.

Table 1.5 Endocarditis prophylaxis risk stratification

High-risk category (endocarditis prophylaxis recommended)
Prosthetic cardiac valves, including bioprosthetic and homograft valves
Previous bacterial endocarditis
Complex cyanotic congenital heart disease (e.g. single ventricle states, transposition of the great arteries, Tetralogy of Fallot)
Surgically constructed systemic pulmonary shunts or conduits
Moderate-risk category (endocarditis prophylaxis recommended)
Most other congenital cardiac malformations (other than those above and below)
Acquired valve dysfunction (e.g. rheumatic heart disease)
Hypertrophic cardiomyopathy
Mitral valve prolapse with mitral regurgitation ± thickened leaflets
Negligible-risk category (no greater risk than the general population and endocarditis prophylaxis *not* recommended)
Isolated secundum atrial septal defect
Surgical repair of atrial septal defect, ventricular septal defect, or patent ductus arteriosus (without residua beyond 6 months)
Previous coronary artery bypass graft surgery
Mitral valve prolapse without mitral regurgitation
Physiologic, functional, or innocent heart murmurs
Previous Kawasaki disease without valve dysfunction
Previous rheumatic fever without valve dysfunction
Cardiac pacemakers (intravascular and epicardial) and implanted defibrillators

From: Dajani, A. S., Taubert, K. A., Wilson, W. *et al*. Prevention of bacterial endocarditis. Recommendations by the American Heart Association. *Circulation* 1997; **96**: 358–66.

Table 1.6 Adult antibiotic prophylaxis for genitourinary/gastrointestinal procedures

Situation[a]	Agents	Regimen[b]
High-risk patients	Ampicillin plus gentamicin	Ampicillin 2.0 g i.m. or i.v. plus gentamicin 1.5 mg/kg (not to exceed 120 mg) within 30 min of starting procedure; 6 h later, ampicillin 1 g i.m./i.v. or amoxicillin 1 g orally
High-risk patients allergic to ampicillin/amoxicillin	Vancomycin plus gentamicin	Vancomycin 1.0 g i.v. over 1–2 h plus gentamicin 1.5 mg/kg i.v./i.m. (not to exceed 120 mg); complete injection/infusion within 30 min of starting procedure
Moderate-risk patients	Amoxicillin or ampicillin	Amoxicillin 2.0 g orally 1 h before procedure, or ampicillin 2.0 g i.m./i.v. within 30 min of starting procedure
Moderate-risk patients allergic to ampicillin/amoxicillin	Vancomycin	Vancomycin 1.0 g i.v. over 1–2 h; complete infusion within 30 min of starting procedure

i.m. = intramuscular; i.v. = intravenous

[a] Endocarditis prophylaxis *not* recommended for routine C/S and prophylaxis is optional for high-risk patients undergoing vaginal delivery.

[b] No second dose of vancomycin or gentamicin is recommended.

From: Dajani, A. S., Taubert, K. A., Wilson, W. *et al.* Prevention of bacterial endocarditis. Recommendations by the American Heart Association. *Circulation* 1997; **96**: 358–66.

Table 1.7 ASRA guidelines for regional anesthesia in the anticoagulated patient[a]

Anticoagulant/thrombolytic	Neuraxial placement considerations	After placement / epidural catheter removal
Low dose LMWH[2] (e.g. enoxaparin 0.5 mg/kg/day, dalteparin 120 U/kg q 12 h)	10–12 hours after the last LMWH dose.	After placement: first dose 6–8 hours; second dose no sooner than 24 hours after the first dose. After removal: minimum of 2 hours.
High dose LMWH[b,c] (e.g. enoxaparin 1 mg/kg q 12 h)	No sooner than 24 hours.	After placement: no sooner than 24 hours. Indwelling catheters should be removed prior to starting LMWH. After removal: minimum of 2 hours.
Heparin IV[d,f]	1 hour before any subsequent heparin administration or 2–4 hours after the last heparin dose.	1 hour.
Prophylactic heparin SC[d,e,f]	None.	None.
Warfarin	Discontinue 4–5 days prior; INR <1.5 before considering regional anesthesia.	Neuraxial catheters should be removed when INR <1.5.
Aspirin and NSAIDs	No special dosing or timing considerations.	No special dosing or timing considerations.
Platelet inhibitors (e.g. ticlopidine, clopidogrel, GP IIb/IIIa)	14 days for ticlopidine. 7 days for clopidogrel. Platelet GP IIb/IIIa inhibitors: eptifibatide and tirofiban (8 h) to abciximab (48 h).	14 days for ticlopidine. 7 days for clopidogrel. Platelet GP IIb/IIIa inhibitors: eptifibatide and tirofiban (8 h) to abciximab (48 h).
Thrombolytics (e.g. streptokinase)	Avoid except in highly unusual circumstances.	Avoid except in highly unusual circumstances.

[a] Adapted from the ASRA 2002 published guidelines: Horlocker, T. T., Wedel, D. J., Benzon, H. *et al.* Regional anesthesia in the anticoagulated patient: defining the risks (the second ASRA Consensus Conference on Neuraxial Anesthesia and Anticoagulation). *Reg. Anesth. Pain Med.* 2003; **28**: 172–97.

[b] LMWH therapy should be delayed for 24 hours if the presence of blood during needle and catheter placement occurs.

[c] Higher doses may require more caution.

[d] It may be prudent to confirm that partial thromboplastin time (PTT) is within normal range prior to removal.

[e] The risk of neuraxial bleeding may be reduced by delaying the heparin injection until after the block, and may be increased in debilitated patients or after prolonged therapy.

[f] Due to heparin-induced thrombocytopenia, patients receiving heparin >4 days should have a platelet count prior to neuraxial block.

Anesthetic considerations: Many women with cardiac disease will be treated with anticoagulants to avoid thromboembolism. The decision to perform neuraxial anesthesia in a patient receiving thromboprophylaxis should be made on an individual basis. The American Society of Regional Anesthesiology (ASRA) guidelines should be considered when performing any regional anesthetic on a patient taking anticoagulants (Table 1.7).[24] The patient's coagulation status should be optimized and level of

anticoagulation carefully monitored before spinal or epidural placement and at epidural catheter removal. In patients who have received neuraxial blocks, postprocedure neurological monitoring needs to be carried out at regular intervals (<2 hours between neurologic checks). The epidural infusion should be limited to dilute local anesthetics that minimize sensory and motor block to aid neurological assessment.[24]

6. *Uterotonic agents*
   Care should be exercised when administering oxytocin to patients with cardiac disease since a large bolus can cause hypotension and tachycardia and has been shown to cause increases in cardiac stress.[27] A slow infusion of a dilute oxytocin solution is usually well tolerated. Other uterotonic agents such as ergometrine can induce systemic hypertension and coronary vasoconstriction. Prostaglandin F2-alpha has the potential to cause severe pulmonary hypertension if large doses are injected directly into the circulation.[28]
7. *Peripartum monitoring*
   The level of monitoring, beyond standard American Society of Anesthesiology guidelines, should be appropriate for the severity of the cardiac lesion and the planned obstetric or anesthetic intervention. Invasive monitoring is advised in symptomatic patients with known cardiac defects. Monitoring of radial artery pressure ± central venous pressure (CVP) ± pulmonary artery catheter ± transesophageal echocardiography (TEE) allows precise, continuous measurement of hemodynamic variables and guides appropriate use of fluid and drug therapy. When the pathophysiology of critically ill obstetric patients cannot be explained by noninvasive hemodynamic monitoring and the patient fails to respond to conservative medical management, invasive hemodynamic monitoring may be helpful in guiding further management.[29] The benefits of additional hemodynamic data provided by invasive monitoring should be weighed against the risks associated with invasive line insertion.[30,31]
8. *Basic hemodynamic goals*
   Although care must be individualized to the cardiac lesion and patient condition, basic maintenance of hemodynamic goals are applicable to most cases.
   - Avoid sudden alterations in HR and maintain normal sinus rhythm.
   - Maintain preload and minimize sudden increases or decreases in central blood volume. Pregnant patients with cardiac disease are at increased risk of developing pulmonary edema.
   - Avoid sudden decreases in afterload and SVR. Decreases in SVR are compensated for by increasing HR, which can lead to worsening cardiac function.
9. *Vaginal versus cesarean delivery*
   There are advantages and disadvantages of both vaginal and cesarean section (C/S) with no convincing evidence that either option is clearly superior (Table 1.8).[32] The delivery plan should be individualized according to the woman's condition. Vaginal delivery may be preferable if obstetrically indicated, however, limits to the duration should be discussed and preparations for a potential C/S considered. Assisted delivery is recommended to avoid prolonged pushing, a rapid expulsive phase and Valsalva maneuvers. Although induction of labor in pregnant patients with cardiac disease is safe,[33] there are higher maternal and neonatal complications compared to healthy controls.
10. *The critical postpartum period*
    The immediate postpartum period is critical, especially if pulmonary hypertension is present. Most fatalities occur in the first week after delivery, but others occur as late as three to four weeks postpartum. For this reason invasive monitoring should not be discontinued immediately after delivery, and full therapeutic and monitoring support in a critical care setting should be provided. Postoperative pain management (e.g., epidural analgesia) is useful in reducing the cardiovascular stress response following C/S. In addition, a neuraxial-induced sympathectomy may improve microvascular flow and reduce the risk of perioperative deep vein thrombosis.

Table 1.8 Hemodynamic advantages and disadvantages of vaginal birth and elective cesarean section

	Vaginal birth	Cesarean section
Advantages	Minimize blood loss	Predictable and planned
	Minimize surgical stress	Timed delivery
	Quicker recovery	All personnel immediately available
	Hemodynamic stability	
Disadvantages	Unpredictable timing	Increased surgical stress
	Potentially prolonged	Higher blood loss
	Painful and stressful	Longer recovery
	Potentially "after-hours"	Higher potential postoperative complications

Valvular lesions

Women with stenotic lesions do not tolerate the changes in HR or increases in CO that occur during pregnancy. Any woman with a symptomatic stenotic lesion warrants very close attention and possible correction before or during pregnancy.

Mitral stenosis

Mitral stenosis (MS) accounts for 90% of rheumatic heart disease in pregnancy, with 25% of patients developing symptoms for the first time during late pregnancy. Mitral stenosis is the most common cardiac pathology associated with acute pulmonary edema in pregnancy, followed by aortic valve disease and primary myocardial disease. Symptoms depend on the severity and include fatigue and dyspnea on exertion initially, but may progress to paroxysmal nocturnal dyspnea, orthopnea, and shortness of breath at rest. Mitral stenosis is considered severe when the valve area is 1 cm^2 or less. Overall mortality is around 1% in mild disease or 5–15% in severe mitral valve disease.
Predictors of adverse events include:[7,34,35]

- mitral valve area <1.5 cm^2
- NYHA functional class >II

- left ventricular ejection fraction (LVEF) <40%
- a previous cardiac event.

Pathophysiology

A small mitral valve area causes a decrease in left ventricular (LV) filling and LV output. There is a concomitant increase in left atrial (LA) volume and pressure, with an increased pulmonary capillary wedge pressure (PCWP). These result in irreversible elevation in pulmonary vascular resistance (PVR) over time so that pulmonary edema and pulmonary hypertension can develop. Right ventricular hypertrophy, dilatation, and failure may then occur, causing peripheral edema.

Relative obstruction across the valve increases as pregnancy advances because of the increase in blood volume, HR, and CO. Increased obstruction leads to pulmonary venous congestion and may produce pulmonary edema.

Management principles[36]

- Maintain sinus rhythm and prevent rapid ventricular rates. Atrial fibrillation and tachycardia can also precipitate worsening cardiac function. Aggressively treat new onset atrial fibrillation pharmacologically or with direct cardioversion especially in the hemodynamically compromised patient (see Chapter 2).
- Avoid large, rapid falls in SVR. This is compensated for by increasing HR, which can worsen cardiac function.
- Prevent increases in central blood volume. Careful fluid management and diuresis may be necessary.
- Avoid factors that may increase pulmonary artery pressure (PAP) (see Table 1.9). Prostaglandins, which may be useful in treating uterine atony, can precipitate increases in pulmonary vascular pressure.

Table 1.9 Factors affecting pulmonary vascular resistance (PVR)

Factors decreasing PVR	Factors increasing PVR
↑ PaO_2	Hypoxia
↓ $PaCO_2$	↑ $PaCO_2$
Alkalemia	Acidosis
Medications: phosphodiesterase III inhibitors (e.g. milrinone), prostaglandin E1 and I2, isoprenaline, inhaled nitric oxide	Medications: prostaglandin F2-alpha, nitrous oxide.
Spontaneous ventilation	Positive pressure ventilation and PEEP
	Hypothermia
	Sympathetic stimulation: pain, light anesthesia, anxiety

PEEP = positive end-expiratory pressure

Adapted from: Lovell, A. T. Anaesthetic implications of grown-up congenital heart disease. *Br. J. Anaesth*. 2004; **93**: 129–39.

- The enlarged left atrium promotes thrombus formation and anticoagulation prophylaxis should be used in patients with atrial fibrillation or a prior embolic history.
- Bacterial endocarditis prophylaxis should be administered although its role in an uncomplicated labor and delivery is controversial.
- Beta-blockers may reduce the incidence of pulmonary edema.[37]
- Consider valvuloplasty or valve surgery. Valvuloplasty or valve surgery before pregnancy may reduce the complications during delivery.[38] Patients who develop severe symptoms during early pregnancy may benefit from a second trimester valvuloplasty.[39,40] Intractable heart failure or pulmonary edema are indicators for urgent surgical intervention or balloon valvuloplasty.[41,42] Balloon mitral valvuloplasty should be considered for mitral valve areas <1.5 cm^2 [13] and for refractory pulmonary edema.[43] However, appropriate radiation screening should be provided and plans made in case of sudden valve rupture. Overall percutaneous balloon mitral valvuloplasty carries fewer fetal and maternal risks than open surgical valvotomy and can be performed under local anesthesia with light sedation (e.g., 0.5–1 mg i.v. midazolam).

Anesthetic options

Evidence-based data on the ideal anesthetic and analgesic for the parturient with MS is lacking.[44] Management must be individualized to optimize patient outcome. The degree of monitoring should be based on the severity of the disease and the woman's condition.[44] The concomitant use of invasive hemodynamic monitors is recommended in symptomatic parturients with critical stenosis.[45,46]

It is important to minimize pain and catecholamine release during labor. A carefully titrated epidural for labor and delivery addresses all the above mentioned hemodynamic goals. Epidural analgesia during the first stage of labor can reduce PVR and SVR, lower PAP, and decrease CO to baseline levels.[45] Rapid prehydration should be avoided, and slow titration of local anesthetic solution is recommended to minimize hemodynamic changes. When treating hypotension, phenylephrine is preferred over ephedrine, which may increase the HR. Epinephrine-containing local anesthetic solutions are best avoided due to concerns about potential tachycardia. Combined spinal–epidural (CSE) analgesia may be a good option for these patients.[44,47] An intrathecal opioid combined with a dilute epidural infusion minimizes sympathetic block and concomitant hypotension. Trendelenburg position may help to improve cardiac index and PCWP,[48] but may be uncomfortable for the awake patient. Consider assisted delivery to limit maternal Valsalva maneuvers and expulsive efforts.

Both epidural and general anesthesia (GA) have been described for C/S. Epidural anesthesia has an advantage over a subarachnoid block in that it can be slowly titrated. Epidural anesthesia has been used successfully in women with severe MS undergoing urgent C/S.[48] If GA is required, avoid drugs that produce tachycardia such as atropine, pancuronium, ketamine, and meperidine. Although most anesthetic agents have a negative inotropic effect, (see Table 1.1) patients with mild disease can tolerate a sodium

thiopental induction. Patients with more severe disease may benefit from a "cardiac" anesthetic induction with an intravenous (i.v.) opioid and a cardiostable induction agent (e.g. etomidate). Although opioids (e.g. alfentanil, fentanyl) can provide hemodynamic stability, transplacental drug transfer may cause neonatal respiratory depression.[36] Remifentanil may be the preferred opioid in the peripartum setting due to its short context-sensitive half-life.

The lowest possible dose of uterotonic agent is recommended as it may produce significant adverse cardiovascular effects. The intrapartum and immediate postpartum periods are high risk as the PCWP increases in the presence of severe MS (functional class III and IV).[49] In the appropriate patient, C/S may be followed by immediate corrective surgery, for example closed mitral valvotomy.[50] Postoperative ventilation and intensive care may be necessary. Patients may need inotropic support as well as a pulmonary vasodilator such as nitroglycerin or sodium nitroprusside.

Aortic stenosis

Symptomatic aortic stenosis (AS) is associated with higher neonatal and maternal mortality rates.[51,52] Asymptomatic pregnant patients tolerate pregnancy without complications.[53] Valve area is a better index of severity than gradient estimation, which is often exaggerated in pregnancy due to the high flows.[54] Patients usually become symptomatic (syncope, angina, and dyspnea on exertion) as the valve area decreases to 1 cm^2 and a critical valve area is $<0.6\ cm^2$. A systolic pressure gradient >50 mmHg between the LV and aorta means severe stenosis; however, some patients may not be able to generate large pressure gradients if they have LV dysfunction. Transvalvular gradients increase progressively throughout pregnancy, as a consequence of increased blood volume and reduced SVR. Coexisting coarctation, symptomatic AS at the onset of pregnancy, and cardiac deterioration are considered important risk factors for the woman with AS in pregnancy.[53]

Pathophysiology

A small aortic valve causes increased pressure and work for the LV. Left ventricular hypertrophy results and the thickened myocardial walls are more prone to ischemia. The higher the transvalvular gradient, the greater the risk of myocardial ischemia. These patients have a fixed SV because of the decreased diameter of the aortic valve. Eventually, the LV fails causing a decrease in CO.

Management principles

- Avoid sudden decreases in venous return and LV filling. Decreases in left ventricular end diastolic volume (LVEDV) are poorly tolerated and will cause a decrease in SV and CO in a patient with limited reserve. Augmented preload with i.v. fluids may be of benefit in maintaining a fixed SV. However, pulmonary congestion secondary to LV failure may be exacerbated by fluid loads in the presence of hypervolemia associated with pregnancy.
- Maintain sinus rhythm. Bradycardia is poorly tolerated since these patients have a fixed SV. Patients rely on increases in HR to increase their CO. In addition, the myocardium receives its oxygen supply during diastole and the thickened myocardium is adversely affected by a reduced perfusion time associated with tachycardia.
- Avoid decreases in SVR. A drop in SVR cannot be compensated for by an increase in SV because of the fixed outlet obstruction. Patients with AS increase their HR to maintain CO, but this also increases oxygen consumption and decreases diastolic filling.
- Avoid hypotension. Hypotension causes ischemia in the hypertrophied ventricular muscle. Diastolic BP is important if coronary blood flow is to be maintained.[55]
- Consider valvuloplasty. In some cases, percutaneous balloon aortic valvuloplasty has been performed during pregnancy with good maternal and fetal outcomes.[56] Aortic balloon valvuloplasty in pregnancy may be performed in symptomatic severe AS as a palliative procedure.[57] Valvuloplasty is usually reserved for cases of severe symptomatic AS when aortic valve area is $<1.0\ cm^2$.[13]

Anesthetic options

Some anesthesiologists prefer GA in patients with AS.[55] This is out of concern that sympathectomy from regional anesthesia will reduce SVR and induce tachycardia and hypotension. However, there are a number of case reports advocating carefully titrated epidurals for labor and delivery in parturients with severe AS.[27,53,58] More recently, continuous spinal analgesia and anesthesia have been used successfully for labor and C/S.[59,60] A continuous spinal technique using incremental doses may minimize sympathectomy-induced cardiovascular changes and provide a more controlled hemodynamic profile.[60] When using a regional technique, it is important to slowly titrate the local anesthetic and opioid with invasive monitoring appropriate for the severity of the AS. A single-shot spinal technique is not recommended.[61] Regional anesthesia avoids the tachycardia and stress response from intubation and surgical stimuli associated with GA.

Pain and anxiety can increase SVR and afterload. A slow reduction in SVR with an epidural technique may improve CO in the face of a fixed SV, assuming that the filling pressures are adequate. Some authors recommend avoiding epinephrine-containing epidural local anesthetic solution, while others have used it in the test dose in parturients with cardiac disease.[27] Phenylephrine is the drug of choice to treat hypotension. Unlike ephedrine it improves LV filling without causing tachycardia.[62]

There is no good evidence to show whether regional or GA is safer in patients with AS.[63] If GA is required, an opioid-based anesthetic is useful when LV function is compromised and in cases of severe AS.[55,64] Remifentanil has been used to blunt the hemodynamic response to intubation in patients with AS undergoing C/S under GA.[65] In one report, remifentanil provided cardiovascular stability in conjunction with rapid emergence from anesthesia with minimal neonatal side effects.[65] A standard general anesthetic rapid sequence induction with sodium thiopental and succinyl choline may decrease CO.[63] The use of etomidate as an induction agent may be preferable to avoid myocardial depression from sodium thiopental, and tachycardia associated

with ketamine (see Table 1.1). It must be emphasized that a cautious anesthetic technique is necessary in conjunction with invasive monitoring to guide appropriate therapy in the event of adverse hemodynamic changes.

All uterotonic agents should be used cautiously as they may produce significant cardiovascular effects. Postpartum monitoring is vital as mortality has been reported up to three to five days following delivery.[55]

Regurgitant valvular lesions

Chronic mitral or aortic regurgitation is usually well tolerated during pregnancy if the patient remains asymptomatic or only mildly symptomatic.[66] The physiological changes of pregnancy with reduction in SVR and tachycardia favor forward flow and limit the regurgitant back flow. However, clinical deterioration and heart failure are possible during pregnancy, particularly in patients with LV dysfunction and a reduced ejection fraction.[67]

Mitral regurgitation or insufficiency

Mitral regurgitation (MR) is usually well tolerated and patients can be asymptomatic for many years. Left ventricle dysfunction and heart failure eventually develop if the condition is left untreated. The increased intravascular volume associated with pregnancy and delivery may worsen LV volume overload. Patients are also at risk for atrial fibrillation, pulmonary edema, emboli formation, and endocarditis.

Pathophysiology

Regurgitation of blood from the LV into the LA occurs during systole. This causes LA enlargement with eventual increases in LA pressure. This pressure is transmitted to the pulmonary circulation causing elevations in pulmonary venous pressure and PCWP. This eventually causes pulmonary edema and may lead to RV failure. The LV may also fail secondary to an increase in volume load. Pain and surgical stimulation can increase SVR, which might decrease forward flow across the valve.

Management principles

- Prevent increases in SVR, as an elevated SVR can impair forward flow. Treatment should be aimed at afterload reduction.
- Maintain a normal to slightly elevated HR, avoiding bradycardia. A slow HR prolongs diastole and allows for a longer period of regurgitation. Ephedrine may be a good drug to use in this setting to prevent and treat hypotension and avoid bradycardia associated with alpha-agonists. Treat dysrhythmias aggressively if they occur.

Anesthetic options

Asymptomatic patients probably do not need invasive monitoring, but severely compromised patients should have invasive monitoring to guide fluid and drug therapy. Epidural analgesia is favored for labor pain because it attenuates an increase in SVR from peripheral vasoconstriction secondary to the pain of labor. Reducing SVR increases the forward flow component across the valve.

If patients tolerate the supine position with left uterine tilt, then regional anesthesia is a good choice for C/S. If GA is necessary, try avoiding anesthetic agents with significant myocardial depressant effects (see Table 1.1), especially in patients with LV dysfunction. Techniques that cause a slight increase in HR may be beneficial (e.g. ketamine).

Aortic regurgitation or insufficiency

Most patients with aortic regurgitation (AR) tolerate the cardiovascular demands of pregnancy, although patients with significant LV enlargement and dysfunction may develop heart failure.

Pathophysiology

Left ventricular volume overload causes LV dilatation and increased LV volume, work that eventually leads to LV dysfunction. The regurgitant volume depends upon the diastolic pressure gradient between the aorta and the LV, as well as the duration of diastole. The decrease in SVR seen in pregnancy can improve AR by decreasing the regurgitant volume. However, the increase in intravascular volume associated with pregnancy and uterine contractions can lead to volume overload and LV dysfunction.

Management principles and anesthetic options

The management principles and anesthetic options for AR are the same as for patients with MR (see above).

Mixed valvular lesions

Mixed valvular lesions often present a dilemma as to which lesion to treat and which hemodynamic goals to adopt. As a general rule, therapy should be directed to the management of the dominant, most severe valvular lesion. For example, if a woman presents with severe MR and mild MS then management should be directed to treat the regurgitant lesion, even if this conflicts with the usual treatment of MS.

Management principles

General management goals and monitoring outlined earlier in the chapter should be followed and should be appropriate for the patient's condition. Often a compromise is reached for maintenance of hemodynamic objectives in mixed lesions.[68] Importantly, avoid rapid HR and treat dysrhythmias aggressively. Maintain preload, minimize sudden increases in central blood volume and avoid sudden decreases in SVR. Use cardiovascular monitoring appropriate for the severity of the underlying lesion and the patient's clinical condition.

Anesthetic options

Refer to the anesthetic management options for specific valvular lesions discussed earlier. Treatment must be individualized and no absolute recommendations can be made because evidence-based data are lacking. However, there are a number of case reports describing the successful management of pregnant women with mixed valvular lesions. In one such case report, a woman with moderate to severe MR and mild MS was managed with epidural analgesia for induced labor and ventouse-assisted vaginal delivery.[69] Other reports have described the use of epidural analgesia for labor and delivery in women with combined mitral and aortic regurgitation,[70] and combined MS and AS.[71] More recently, a parturient with mixed pulmonary stenosis and aortic incompetence had a C/S under epidural anesthesia.[68]

Valvulotomy and prosthetic valves

There have been many reports of successful pregnancy following valvular surgery.[72] Generally, women who are asymptomatic before pregnancy are able to tolerate pregnancy and delivery.[67] Symptomatic patients with underlying LV dysfunction and/or pulmonary hypertension may not tolerate the stresses of pregnancy. Compared to pregnant women with prosthetic valves, patients with previous valvotomies have fewer complications and less fetal morbidity.[73] Women with prosthetic valves are at higher risk of complications including valve infection, thromboembolism, and bleeding due to anticoagulant therapy.[74]

Women with aortic valve replacement have a lower incidence of complications than those with a mitral valve prosthesis,[75,76] possibly due to better ventricular function and less stringent anticoagulation compared to mitral valve lesions.[73] All women with prosthetic valves are at risk for valvular infection and clinicians should consider bacterial endocarditis prophylaxis (see Tables 1.5 and 1.6). Anticoagulation should be considered throughout pregnancy due to the high risk of thromboembolism. American College of Cardiology (ACC) and American Heart Association (AHA) Guidelines should be considered,[21] although they were produced before data regarding LMWH for pregnant patients with prosthetic valves were available.[77]

ACC/AHA recommendations[21]

From week 1 to week 36 of pregnancy, high-risk women (thromboembolic history or older generation mechanical mitral valves) should be maintained on warfarin (± low dose aspirin) to keep the INR between 2–3.[21] After week 36, warfarin should be discontinued. However, because of the risk of warfarin embryopathy some women opt to use heparin as an alternative therapy during pregnancy. High-risk patients not taking warfarin should receive continuous UFH keeping aPTT levels around two to three times control.[21,66] Low-risk women can receive subcutaneous heparin. In the absence of bleeding, heparin or warfarin can be restarted four to six hours after delivery.[21] Some institutions use LMWH maintaining peak anti-Xa levels between 0.8 to 1.5 and trough levels at least 0.7.[77] Anti-Xa levels should be checked twice monthly and adjusted as necessary.[77] Patients still on anticoagulants are at risk for postpartum hemorrhage. If regional anesthesia is planned, allow an adequate time between anticoagulation administration and regional (epidural and/or spinal) anesthesia (see Table 1.7).

Regular assessment of signs and symptoms may help detect any residual or new valve dysfunction. It is important to exclude residual myocardial dysfunction or pulmonary hypertension that may exist despite correction of the valvular lesion. Consider invasive monitoring where significant residual myocardial dysfunction or pulmonary hypertension exists. Patients with a valve prosthesis are at higher risk for developing dysrhythmias, especially atrial fibrillation. Management goals and anesthetic considerations should be individualized according to the lesion. (See specific valvular lesions.)

Mitral valve prolapse

Mitral valve prolapse (MVP) is the most common valvular lesion – occurring in approximately 2–4% of the general population – and is most prevalent in young women. A benign course can be expected in 85% of patients with MVP,[78] but 15% develop MR over time. Most patients progress uneventfully during pregnancy and the peripartum period;[79,80] however, some patients may sustain cardiac dysrhythmias (e.g. supraventricular and ventricular tachydysrhythmias, bradydysrhythmias, and conduction blocks). The role of routine endocarditis prophylaxis for labor and delivery is controversial.[79] The current recommendation is that bacterial endocarditis prophylaxis is only necessary in MVP with MR and/or thickened leaflets (see Tables 1.5 and 1.6).

Management principles

Avoid decreases in preload by providing adequate volume replacement and left uterine displacement. Maintain afterload and avoid increases in HR. Hypovolemia, venodilation, increased airway pressure, and tachycardia all decrease LV volume causing an earlier prolapse of the valve leaflets and thus increasing MR. Conditions that increase LV volume, such as bradycardia, afterload augmentation, hypervolemia, or negative inotropic agents, cause later prolapse, with a delayed click.

Asymptomatic patients with MVP require only routine management.[73] Continue antidysrhythmic therapy and make provisions for urgent management of dysrhythmias (see Chapter 2). In patients with MVP and associated symptomatic mitral regurgitation, the hemodynamic goals are similar to those for MR.

Anesthetic options

For pain relief in labor, epidural analgesia is a good choice for patients with MVP and MR. Avoid epinephrine-containing local anesthetics in patients with dysrhythmias.

Regional anesthesia for C/S in parturients with MVP has been reported.[81] Adequate volume loading prior to placement of a regional anesthetic is necessary to avoid LV volume reduction and an increase in MV prolapse. Light GA accompanied by tachycardia