Intensive care in obstetrics: An evidence-based review

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The necessity for critical care support and admission to an intensive care unit (ICU) is a relatively infrequent occurrence during pregnancy and the postpartum period. The exact incidence is unclear because of the variety of reporting methods and definitions, with estimates that range from 0.17% to 1.1% of pregnant patients.1-9 All of the published series to date are small; the largest series includes 131 obstetric critical care patients.8 Zeeman et al10 described their experience with 483 patients who were treated in an obstetric intermediate care unit. This series represented 1.7% of deliveries during a 2-year period, which is a substantially higher rate than reported in other studies. This high percentage likely reflects the inclusion of some patients with lower acuity who were admitted for “intermediate care” who otherwise would not have required transfer to a traditional ICU. Of the 34 patients who were transferred to the ICU, most patients (71%) required ventilatory support.

Obstetric complications account for most ICU admissions in pregnant patients, which range from 47% to 93%.1,4-6,10 Hemorrhage and hypertensive disorders (primarily preeclampsia and eclampsia) constitute most obstetric ICU admissions during the puerperium stage. Other common causes include respiratory failure and sepsis. Common nonobstetric indications for ICU admission include maternal cardiac disease, trauma, anesthetic complications, cerebrovascular accidents, and drug overdosage. In most series, most obstetric ICU admissions occur in the immediate postpartum period and are most likely to be due to complications of acute hemorrhage. In a study by El-Solh and Grant,11 the outcome of 93 obstetric patients who were admitted to the ICU was compared with nonobstetric admissions. Unlike most of the published literature, antepartum patients in this series represented 62% of the obstetric ICU admissions. Obstetric complications were described as the indication for ICU admission in only 19% of the patients. Respiratory complications were most common (32%), but the article does not differentiate clearly antepartum or postpartum patients and does not delineate clearly which complications are considered obstetric versus nonobstetric pulmonary complications. For example, amniotic fluid embolus is listed as a respiratory complication, not an obstetric complication.

Most patients (49% to 90%) who are admitted to an ICU during the postpartum period underwent cesarean delivery.1,5,6,8 Unfortunately, few studies detail the ICU course of antepartum patients, so limited data exist on the incidence of, the indications for, the timing of, and the route of delivery in antepartum ICU admissions. When ICU admission is necessary in an undelivered
patient, the primary reason usually is related to preeclampsia, infection, or respiratory failure. In 1 study, 82% of antepartum admissions resulted in delivery, most (78%) of which were by cesarean delivery.\(^5\) Perinatal mortality rates are reported to be as high as 11% in several studies.\(^5,6\)

### Prediction of maternal death

Overall, maternal mortality rates in critically ill pregnant women who are admitted to an ICU ranges from 0 to 20%, with most series reporting maternal mortality rates of <5% of all obstetric ICU admissions.\(^1,3-5,8\) As expected, mortality rates in poorly developed countries are substantially higher than in developed countries (1% vs 0.1%) and grossly under reported in the obstetric literature.\(^12\) Several scoring systems are used routinely in critical care settings in an attempt to describe objectively the severity of the critical illness and to predict accurately mortality risks. The acute physiologic and chronic health evaluation (APACHE) scoring system, simplified acute physiologic score (SAPS), and mortality prediction model (MPM) are 3 widely used methods that track a variety of variables. The APACHE II scoring system has been most thoroughly studied, although a newer version (APACHE III) is available. The APACHE II score considers physiologic and historic variables that are entered into a formula. Its major limitations include the underestimation of mortality rates in transported patients and an inability to predict mortality rates by disease category. The APACHE III includes more variables, which include transport data, and is able to predict accurately mortality risk (within 3% of observed) for 95% of patients, based on severity of illness in the first 24 hours.\(^13\) The program allows for daily updates of mortality risk. The use of the APACHE III system, however, requires the purchase of a proprietary formula and computer software.

SAPS II predicts mortality risk based on 12 physiologic variables, patient age, and diagnosis; the formula is widely available. Its major limitation is accuracy in the prediction of mortality risk in patients who are not admitted for cardiovascular disease. Another reliable tool to predict ICU mortality rate is the MPM II score. The MPM II is assigned on admission to the ICU; it provides risk rates based not only on physiologic variables but also takes into consideration the use of CPR, the need for ventilatory support, and acute and chronic diagnoses. Several authors have evaluated the applicability of these scoring systems in critically ill pregnant patients.\(^11,14\) In the largest series, 93 pregnant women were compared with 96 nonpregnant women. The overall mortality rate in the obstetric population was 10.8% in this population. The APACHE II, SAPS II, and MPM II scoring systems each performed well in the prediction of death (14.7%, 7.8%, and 9.1%, respectively).\(^11\) Of note, the predicted mortality rate was significantly higher in obstetric patients compared with nonobstetric patients for each of the 3 scoring tools, despite no difference in actual mortality rates between the 2 groups (10.8% vs 10.4%).

It should be noted that none of these scoring systems include adjustments for normal obstetric physiologic changes, such as decreased blood pressure and increased respiratory rate. Particular laboratory abnormal results such as elevated liver function tests and low platelet count (which are common in obstetric disorders such as HELLP [hemolysis, elevated liver enzymes, and low platelet count] syndrome) are also not included in the assessment and may limit their potential applicability. In summary, currently available critical care mortality scoring systems can be applied to the obstetric population and have the potential to overestimate mortality risk in the critically ill pregnant woman. The applicability of the APACHE III scoring system has not been studied in an obstetric population.

### Invasive central hemodynamic monitoring

Since its introduction in the early 1970s, invasive hemodynamic monitoring in the form of the pulmonary artery (PA) catheter has become quite common in critically ill patients. The PA catheter allows for direct monitoring of central venous pressure (right ventricular preload), pulmonary capillary wedge pressure (left ventricular preload), cardiac output, systemic vascular resistance (afterload), PA pressures, and mixed venous oxygen saturation. A central venous catheter may be inserted to provide information on central venous pressure and central venous access for fluid replacement or medication administration. Although the central venous pressure is estimated to be roughly equivalent to the pulmonary capillary wedge pressure in nonpregnant patients, there may be poor correlation between these pressures during pregnancy. Central venous and PA catheters (balloon-tipped pulmonary artery catheter) are inserted typically through the subclavian or internal jugular veins and advanced into the heart. Complications can occur at insertion, advancement, or after prolonged placement. Overall, complications occur in up to 5% of patients and include arterial puncture, pneumothorax, arrhythmias, infection, and thrombosis.

Until recently, randomized trials that demonstrate a clear benefit of PA catheter–directed care were lacking, and much of the available data were conflicting and involved heterogeneous groups of patients. Several small studies have suggested a decrease in mortality rates when PA catheters are used to direct therapies.\(^15-17\) However, other authors have reported either an increase in mortality rates that were associated with the use of PA catheters\(^18-21\) or no benefit.\(^22-24\) As a result of this controversy, some prospective randomized trials have been performed to assess the usefulness of invasive hemodynamic
monitoring in various high-risk clinical scenarios. The Canadian Critical Care Clinical Trials Group prospectively randomized 1994 high-risk surgical patients to receive a PA catheter to direct therapy or standard therapy. They reported no survival benefit when therapy was directed by a PA catheter (7.8% vs 7.7% in control subjects). Additional randomized trials are necessary to better understand which critically ill patients, if any, will benefit from therapy that is guided by a PA catheter.

The most common reported indications for PA catheter placement in the obstetric population include severe mitral or aortic valvular stenosis, New York Heart Association class III or IV heart disease in labor, intraoperative or intrapartum cardiac failure, massive hemorrhage, refractory pulmonary edema, refractory oliguria, septic shock, adult respiratory distress syndrome, and preeclampsia with refractory oliguria or pulmonary edema. As previously mentioned, it is essential to understand the physiologic changes brought on by pregnancy and to have a working familiarity with the normal hemodynamic parameters for the pregnant patient to interpret results accurately. Table I shows the expected cardiovascular changes in pregnancy. Minimal data are available that address specific complication rates that are associated with PA catheter usage in pregnant women. It is important to note that complication rates that are associated with PA catheter usage will benefit from therapy that is guided by a PA catheter. Therefore, only properly trained personnel should insert catheters for invasive hemodynamic monitoring.

Preeclampsia and its complications, such as oliguria and/or pulmonary edema, may prompt central venous access. However, several authors have described poor correlation between the central venous catheter and pulmonary capillary wedge pressure in women with pregnancy-induced hypertension. Therefore, if an accurate assessment of left ventricular preload is deemed important in the treatment of the patient’s cardiovascular complications, the insertion of a PA catheter is indicated.

## Sepsis and septic shock

Sepsis accounts for 9.3% of the deaths that occur in the United States and complicates approximately 1 in 8000 deliveries. Fortunately, only a small percentage of these deaths are due to gynecologic or obstetric problems. A paucity of current literature that addresses the management of septic shock in obstetric patients likely reflects the decrease in septic abortions after the legalization of abortion in the United States. However, several recent publications report new approaches to the management of sepsis that demonstrate improved outcomes for nonpregnant patients. These new approaches include early “goal-directed resuscitation,” aggressive control of hyperglycemia, directed corticosteroid therapy, and the use of activated protein.

### Definitions

The American College of Chest Physicians and the Society of Critical Care Medicine published consensus guidelines in 1991 that were designed to create consistency in the definitions that are used to describe septic conditions. These definitions represent the understanding that these conditions exist along a continuum of increasing severity while sharing a common pathophysiologic condition. This continuum begins after the body has a systemic response to an infection and may progress to multiorgan dysfunction with hemodynamic instability and even death (systemic inflammatory response syndrome, sepsis, severe sepsis, and septic shock). The systemic inflammatory response syndrome is defined as the clinical response to infection that is manifested by a systemic inflammatory response syndrome, sepsis, severe sepsis, and septic shock.

The definitions of sepsis, severe sepsis, and septic shock are as follows:

1. **Sepsis**
   - A life-threatening organ dysfunction caused by a dysregulated immune response to infection.
   - New York Heart Association class III or IV heart disease in labor, intraoperative or intrapartum cardiac failure, massive hemorrhage, refractory pulmonary edema, refractory oliguria, septic shock, adult respiratory distress syndrome, and preeclampsia with refractory oliguria or pulmonary edema.

2. **Severe sepsis**
   - Sepsis with AKI, adult respiratory distress syndrome, or severe organ dysfunction.
   - New York Heart Association class III or IV heart disease in labor, intraoperative or intrapartum cardiac failure, massive hemorrhage, refractory pulmonary edema, refractory oliguria, septic shock, adult respiratory distress syndrome, and preeclampsia with refractory oliguria or pulmonary edema.

3. **Septic shock**
   - Sepsis with hypotension or use of vasoactive infection.
   - New York Heart Association class III or IV heart disease in labor, intraoperative or intrapartum cardiac failure, massive hemorrhage, refractory pulmonary edema, refractory oliguria, septic shock, adult respiratory distress syndrome, and preeclampsia with refractory oliguria or pulmonary edema.

### Table I

**Expected cardiovascular changes in normal pregnancy**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Normal value</th>
<th>Change in pregnancy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (beats/min)</td>
<td>71 ± 10</td>
<td>+10-20</td>
</tr>
<tr>
<td>Stroke volume (mL)*</td>
<td>73 ± 10</td>
<td>+10</td>
</tr>
<tr>
<td>Cardiac output (L/min)*</td>
<td>4.3 ± 0.9</td>
<td>+10-50</td>
</tr>
<tr>
<td>Blood volume (L)</td>
<td>5</td>
<td>+10-50</td>
</tr>
<tr>
<td>Central venous pressure (mm Hg)*</td>
<td>4 ± 3</td>
<td>Not significant</td>
</tr>
<tr>
<td>Pulmonary capillary wedge pressure (mm Hg)*</td>
<td>6 ± 2</td>
<td>Not significant</td>
</tr>
<tr>
<td>Systemic vascular resistance (dyne/cm/sec)*</td>
<td>1530 ± 520</td>
<td>−20</td>
</tr>
<tr>
<td>Pulmonary vascular resistance (mm Hg)*</td>
<td>119 ± 47</td>
<td>−20</td>
</tr>
<tr>
<td>Mean arterial pressure (mm Hg)*</td>
<td>86 ± 8</td>
<td>Not significant</td>
</tr>
<tr>
<td>Oxygen consumption (mL/min)</td>
<td>250</td>
<td>+10-30</td>
</tr>
<tr>
<td>CO (mm Hg)*</td>
<td>20.8 ± 1.0</td>
<td>−14</td>
</tr>
<tr>
<td>COP - pulmonary capillary wedge pressure gradient (mm Hg)*</td>
<td>14.5 ± 2.5</td>
<td>−20</td>
</tr>
</tbody>
</table>

Left ventricular stroke work index (g/min/m²)*

41 ± 8 Not significant


* Data are given as mean ± SD.
neutrophils. When systemic inflammatory response syndrome criteria are met and infection is confirmed or suspected, the patient’s condition is then considered to be septic. Severe sepsis occurs when sepsis is accompanied by the dysfunction of at least 1 organ system. Septic shock is defined as sepsis with accompanying hypotension (<90 mm Hg), despite fluid resuscitation. It should be noted that these definitions do not take into account the physiologic changes of pregnancy and therefore may overdiagnose sepsis.

Pyelonephritis is the most common cause of septic shock during pregnancy, followed by chorioamnionitis and postpartum endometritis. Commonly isolated organisms from pregnant patients in septic shock include *Escherichia coli*, groups A and B streptococcus, *Klebsiella* species, and *Staphylococcus aureus*.  

**New approaches to sepsis management**

Care of the patient with sepsis consists of supportive care (which includes aggressive fluid resuscitation and blood pressure and respiratory support, as indicated), with the identification of the source of infection and responsible organism and appropriate treatment with antibiotics. Several recent studies have been published that have focused on novel approaches to the management of severe sepsis and septic shock.

**Early goal-directed therapy**

Early goal-directed therapy involves the tailoring of treatments and resuscitative efforts to achieve specified end points (which include normal mixed venous oxygen saturation, arterial lactate concentration, base deficit, and pH), in an effort to reduce end-organ dysfunction and ultimately death.

In 2001, Rivers et al published a prospective randomized trial of early goal-directed treatment compared with standard therapy of patients in septic shock. The fundamental differences between the 2 groups was the institution of therapy in the emergency room setting before transfer to the ICU and the use of central venous catheters with the ability to measure continuous venous oxygen saturation (ScVO2). In the treatment group, a goal of ScVO2 of >70% was established in addition to the standard goals of the maintenance of a central venous pressure of >8 to 12 mm Hg, a mean arterial pressure of >65 mm Hg, and a urine output of >0.5 mL/kg/hr. To achieve this goal, red blood cell transfusions were administered, if necessary, to maintain a hematocrit level of ≥30%; and inotropic agents were added if the ScVO2 was inadequately corrected. Patients in the group that received goal-directed therapy had significantly better end points (such as mean arterial pressure, ScVO2, lactate concentrations, and pH) compared with the patient group that received standard supportive therapy. In addition, despite no statistically significant differences in disease severity between the 2 groups at the commencement of the study, those patients in the goal-directed group had less severe end-organ damage, as evidenced by several assessment measures. These improvements translated to a decrease in mortality rates of 16% (30.5% vs 46.5%) that were attributed to goal-directed therapy. It should be noted that pregnant women were excluded from this study; therefore, it remains to be seen whether this approach will result in improved outcomes in this population. Similarly, the precise goals that may be appropriate for a pregnant population also remain to be defined. However, the addition of ScVO2 monitoring and early goal-directed therapy may well have a role in the treatment of the pregnant patient with severe sepsis or septic shock.

**Insulin therapy**

Outcomes in patients with sepsis and diabetes mellitus are linked closely to the degree of glycemic control. In patients with diabetes mellitus and acute myocardial infarction, aggressive glycemic control with insulin decreased mortality rates by 11%. 40 In the critically ill population, hyperglycemia often develops because of insulin resistance and can lead to other complications, even in the absence of diabetes mellitus. In 2001, van den Berghe et al published a prospective randomized trial of aggressive glycemic control with insulin therapy. A group of 1548 critically ill patients were assigned randomly to tight glycemic control (blood glucose, 80-110 mg/dL) versus conventional control (insulin only if blood glucose was > 215 mg/dL). Aggressive glycemic control decreased overall mortality rates by 34%, with a remarkable 76% reduction in mortality rate for patients with sepsis. Other significant benefits to tight glycemic control included fewer ventilator days, less time in the ICU, and a reduced need for dialysis. The treated patients were also 46% less likely to have septicemia. But if septicemia did develop, the mortality rate was diminished from 29.5% to 12.5% with insulin treatment.

Again, pregnant patients were not included in this study. Pregnant women are well known to be more resistant to insulin and to have higher circulating insulin levels as compared with their nonpregnant counterparts. They are also predisposed to the development of fasting hypoglycemia because of the higher levels of insulin and continuous delivery of glucose to the fetus. In this study, hypoglycemia occurred in 5% of the treated patients and did not result in significant morbidity. The incidence and impact of hypoglycemia in pregnant critically ill patients who were treated with tight glycemic control have not been evaluated. The impact of tight glycemic control in the prevention of fetal complications such as macrosomia, stillbirth, and neonatal hypoglycemia is well recognized. However, whether the degree of glycemic
control will result in improved maternal outcomes in the critical care setting remains to be studied.

**Corticosteroids**

Empiric administration of corticosteroids in high doses does not improve survival in unselected septic patients and, in fact, may worsen outcomes because of secondary infection. However, as the pathophysiologic condition of sepsis has become more clearly understood, the contribution of “relative” adrenal insufficiency in critically ill patients and the potential benefit of corticosteroid replacement have reemerged.

Stresses such as pain, fever, hypovolemia, or severe illness will cause marked increases in cortisol levels. In the patient with septic shock, the adrenal gland may not respond to adrenocorticotropic hormone stimulus appropriately. In the normal patient, the administration of adrenocorticotropic hormone should stimulate an increase in cortisol levels. In the setting of septic shock, however, the levels of cortisol may be increased overall, but the magnitude of increase after adrenocorticotropic hormone administration may be blunted. This phenomenon is described as “relative” adrenal insufficiency. This group of patients is being evaluated now for the potential benefit from physiologic doses of corticosteroids. Annane et al recently reported improved survival in a prospective, randomized trial of 300 patients with septic shock who were treated with low-dose hydrocortisone and fludrocortisone. Steroid therapy significantly improved survival compared with control subjects (47% vs. 37%) and shortened the requirement for pressors in the group of patients with documented blunted adrenal responsiveness. It should be noted that all of these patients had elevated baseline cortisol levels. No additional studies have duplicated this finding, and no studies have been done in pregnant women. At least 1 report describes adrenal suppression in pregnant women after the administration of betamethasone to enhance fetal lung maturity. The impact of adrenal suppression on the usefulness of low-dose steroids or death in patients with obstetric septic shock is unknown.

**Activated protein C (APC)**

At least 20 trials have been performed that involve various agents that include antithrombin III and tissue factor–pathway inhibitor, without successful identification of a treatment to reduce mortality rates in patients with septic shock. APC is the latest anticoagulant/anti-inflammatory agent to offer promise in the reduction of mortality rates in the patients with septic shock. There are several mechanisms by which APC is felt to mediate the effects of sepsis. Patients with sepsis have decreased APC levels. APC stimulates fibrinolysis and inactivates factors Va and VIIIa, which results in the inhibition of thrombin formation. Decreased thrombin formation then leads to decreased inflammation by inhibiting platelet activation, neutrophil recruitment, and mast-cell degranulation. In a multicenter randomized trial, APC administration to patients in septic shock decreased the mortality rate from 30.8% in the placebo group to 24.7% (P = .005) in the study group. This represents a 6.1% absolute reduction in overall mortality rate because of septic shock and a 13% reduction in the groups with the highest predicted mortality rate that was based on APACHE II scores. As might be expected from its potent anticoagulant properties, the risk of hemorrhage is increased in patients receiving APC. In this study, 3.5% of patients who received APC had a significant hemorrhagic event, such as intracranial hemorrhage or need for transfusion, compared with a 2% incidence in the control group. Because of this risk, APC is not indicated for all patients with septic shock, and its use should be limited to patients with the greatest risk of death (APACHE II score, ≥25). The role of APC use in obstetric patients has not been established. Significant changes in the coagulation cascade occur and include elevated factor VIII levels. The impact of these changes on the responsiveness to APC is unknown; however, pregnancy is not a contraindication to its use.

**Cardiac disease**

Only 4% of pregnancies will be complicated by cardiac disease; however, these patients are vulnerable to a number of potential complications because of the significant hemodynamic changes that are associated with pregnancy and delivery. ICU admissions because of maternal cardiac disease comprise ≤15% of obstetric ICU admissions, yet these patients account for up to 50% of all maternal deaths in the ICU. According to the most recent Centers for Disease Control and Prevention report on maternal mortality rates in the United States between 1991 and 1999, deaths because of cardiac disease remain a significant problem. A recent survey of maternal deaths in North Carolina found that 40% of maternal deaths from cardiovascular disease and 22% of deaths from cardiomyopathy were preventable. Substantial physiologic changes occur during pregnancy and place the pregnant patient with cardiac disease at particular risk for complications.

Cardiac output increases to 30% to 50% above prepregnancy levels by the third trimester in a normal pregnancy and may increase by an additional 50% in the second stage of labor. Strikingly, one half of the increase in cardiac output occurs by 8 weeks of gestation. The total blood volume and plasma volume both increase by approximately 50%. However, the red cell mass rises by only 33%, which ultimately results in a decreased hemoglobin concentration and hematocrit level and therefore diminished oxygen carrying capacity.
The heart is able to accommodate the increased preload primarily because of a decrease in afterload as a result of decreased systemic vascular resistance. Consequently, systolic and diastolic blood pressures drop during pregnancy (5-10 mm Hg and 10-15 mm Hg, respectively) and reach a nadir at 24 to 32 weeks of gestation. Alterations in the coagulation cascade occur as well and include elevated levels of fibrinogen and factor VIII, which predisposes patients to the development of a thromboembolic disease. Patients with atrial fibrillation or an artificial valve are at particular risk for thrombus development while pregnant.

In the Cardiac Disease in Pregnancy (CARPREG) study, Siu et al. identified 4 major risk factors for adverse pregnancy outcome that are based on a prospective evaluation of 617 pregnancies that were complicated by maternal cardiac disease. The 4 strongest predictors of maternal complications were (1) a history of heart failure, transient ischemic attack, stroke, or arrhythmia; (2) pre-pregnancy New York Heart Association class >II; (3) left heart obstruction (mitral valve area, <2 cm²; aortic valve area, <1.5 cm²; peak left outflow gradient, >30 mm Hg), and (4) ejection fraction <40%. The risk of maternal complications was directly proportional to the numbers of risk factors that were identified. Five percent of patients with none of the 4 predictors experienced a complication, whereas the addition of only 1 risk factor increased the adverse event rate to 27%. The incidence of complications increased to 75% in patients with >1 predictor. Pulmonary edema and arrhythmias were the most commonly encountered complications. The route of delivery did not affect the complication rate. Six patients (1%) died of stroke or cardiac decompensation. In the same study, the strongest predictors for neonatal complications were New York Heart Association class >II, heparin or warfarin (Coumadin) use during pregnancy, smoking, multiple gestation, and left heart obstruction. Twenty percent of the pregnancies in this study were delivered of small-for-gestational-age infants or delivered prematurely.

In a subsequent study, the same author prospectively compared 300 pregnant women with cardiac disease to control subjects, primarily to evaluate neonatal and cardiac outcomes. In this group of patients, 64% had a variety of congenital cardiac lesions, 28% with acquired lesions and the remaining 8% had dysrhythmias. Forty-one percent of the pregnant women had undergone previous surgical interventions. As expected, the rate of miscarriage and neonatal complications such as intraventricular hemorrhage, delivery before 34 weeks of gestation, and neonatal death occurred more commonly in pregnant women with cardiac disease compared with control subjects. However, the addition of risk factors such as smoking, anticoagulant use, and multiple gestations in a patient with cardiac disease further escalated the risk of neonatal complications to twice that of the control group. Seventeen percent of patients with cardiac disease in this study had a cardiac complication, 94% of which were due to cardiac failure or dysrhythmias. In this study, delivery by cesarean section occurred more commonly in patients with cardiac disease (29% vs 23%), but preeclampsia and hemorrhage developed with equal frequency in patients with and without cardiac disease.

### Table II

<table>
<thead>
<tr>
<th>Situation</th>
<th>Regimen</th>
</tr>
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<tbody>
<tr>
<td>High-risk patients</td>
<td>Ampicillin 2 g intramuscularly/intravenously plus gentamicin 1.5 mg/kg (not to exceed 120 mg) within 30 minutes of starting procedure; 6 hours later, ampicillin 1 g intramuscularly/intravenously or amoxicillin 1 g orally</td>
</tr>
<tr>
<td>High-risk patients with penicillin allergy</td>
<td>Vancomycin 1 g intravenously over 1-2 hours plus gentamicin 1.5 mg/kg intramuscularly/intravenously (not to exceed 120 mg), complete infusion within 30 minutes of starting procedure</td>
</tr>
<tr>
<td>Moderate-risk patients</td>
<td>Amoxicillin 2 g orally 1 hour before starting procedure or amoxicillin 2 g intramuscularly/intravenously within 30 minutes of starting procedure</td>
</tr>
<tr>
<td>Moderate-risk patients with penicillin allergy</td>
<td>Vancomycin 1 g intravenously over 1-2 hours, complete infusion within 30 minutes of starting procedure</td>
</tr>
</tbody>
</table>

Adapted from Dajani et al. 55

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**Valvular heart disease**

Acquired valvular lesions are typically sequelae of rheumatic fever; however, valvular endocarditis because of intravenous drug use is not uncommon. During pregnancy, most morbidity and death from these lesions is associated with dysrhythmias and congestive failure with pulmonary edema. The degree of risk for the development of complications depends on the specific valve lesion and the degree of valvular obstruction, particularly of the mitral and aortic valves. The presence of multiple valve involvement further complicates prognosis. However, pregnancy does not appear to affect adversely long-term sequelae for women with rheumatic heart disease who survive the pregnancy. Certain patients with structural cardiac abnormalities are candidates for antibiotic prophylaxis for bacterial endocarditis at the time of delivery. Tables II and III provide the current antibiotic prophylaxis recommendations. 55
Mitral stenosis

Mitral stenosis is the most common rheumatic valvular lesion to be encountered in pregnancy. When the valve area falls below 1.5 cm$^2$, filling of the left ventricle during diastole is limited severely, which results in a fixed cardiac output. Prevention of tachycardia and maintenance of adequate left ventricular preload are essential in these patients. As the heart rate increases, less time is allowed for the left atrium to empty adequately and to fill the left ventricle during diastole. The left atrium may become over-distended and result in dysrhythmias (primarily atrial fibrillation, which will increase the risk of thromboembolic complications) or pulmonary edema. Adequate preload, however, is essential to maintain left ventricular filling pressure. Alternatively, if preload is excessive, then pulmonary edema and atrial dysrhythmias may also result. Patients with severe limitations of the valve area may not tolerate the normal increase in cardiac output, blood volume, and heart rate of pregnancy and should ideally have the valve repaired before pregnancy. Frequently however, mitral stenosis is diagnosed during pregnancy because the normal physiologic changes place an additional burden on a previously unchallenged heart. In these patients, atrial fibrillation and/or pulmonary edema may be the initial diagnostically correct clue to underlying mitral stenosis. Thus, new onset pulmonary edema during pregnancy should prompt evaluation for underlying mitral disease.

Medical treatment of these patients involves activity restriction, treatment of dysrhythmias, β-blockers to control heart rate, and careful diuretic use. The goal of diuretic therapy is to treat pulmonary edema, with care taken not to overly reduce left ventricular preload. Patients who remain symptomatic despite conservative treatment may be candidates for surgical intervention during pregnancy. Case reports of > 100 women describe percutaneous balloon mitral valvuloplasty as a safe procedure during pregnancy.

Pulmonic and tricuspid lesions

Rheumatic heart disease does not lead typically to isolated right-sided valvular lesions. Acquired pulmonic and tricuspid valvular abnormalities more commonly are due to valvular endocarditis from intravenous drug use. The physiologic changes of pregnancy are tolerated well by patients with pulmonic or tricuspid valvular abnormalities. Whittmore et al. reported congestive heart failure in only 2.8% of patients with pulmonic stenosis. Cautious fluid administration is recommended, but more invasive therapy or monitoring is rarely necessary.

Mitral and aortic insufficiency

Mitral and aortic insufficiencies are usually rheumatic in origin and often occur together. Mitral regurgitation is well tolerated in pregnancy; congestive heart failure is a rare occurrence. However, patients with long-standing mitral insufficiency may have significant left atrial enlargement that places them at risk for the development of atrial fibrillation. If this occurs, antiarrhythmic therapy is indicated, and anticoagulation should be considered. Aortic insufficiency is also tolerated quite well in pregnancy. The increased heart rate decreases time for regurgitant blood flow during diastole, and the lower systemic vascular resistance favors forward blood flow. No special pregnancy or labor precautions are warranted. Deaths in patients with mitral and/or aortic regurgitation are rare, unless stenosis is also present.

<table>
<thead>
<tr>
<th>Table III</th>
<th>American Heart Association and American College of Cardiology Task Force recommendations on chemoprophylaxis for bacterial endocarditis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endocarditis risk</td>
<td>Need for prophylaxis</td>
</tr>
<tr>
<td>High risk</td>
<td></td>
</tr>
<tr>
<td>Prosthetic cardiac valve</td>
<td>Optional</td>
</tr>
<tr>
<td>Previous bacterial endocarditis</td>
<td></td>
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<tr>
<td>Complex congenital cyanotic heart disease</td>
<td></td>
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<tr>
<td>Surgically constructed shunts</td>
<td></td>
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<tr>
<td>Moderate risk</td>
<td>Not recommended</td>
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<tr>
<td>Other congenital cardiac malformations</td>
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<tr>
<td>Rheumatic heart disease (or other acquired valvular disease)</td>
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<tr>
<td>Hypertrophic cardiomyopathy</td>
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<tr>
<td>Mitral valve prolapse with leaflet thickening and/or regurgitation</td>
<td></td>
</tr>
<tr>
<td>Negligible risk</td>
<td>Not recommended</td>
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<tr>
<td>Mitral valve prolapse without regurgitation</td>
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<tr>
<td>Physiologic, functional, or innocent murmurs</td>
<td></td>
</tr>
<tr>
<td>Previous rheumatic fever without valvular dysfunction</td>
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</tbody>
</table>

Adapted from Dajani et al.55

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cardiac output, adequate venous return to the heart is crucial. Decreased venous return can result from excess blood loss, hypotension, and ganglionic blockade from a regional anesthetic or even vena caval occlusion in the supine position. PA catheterization may be indicated in patients with significant aortic stenosis to accurately estimate intravascular volume and guide fluid replacement. Historically, the risk of death in pregnant patients with aortic stenosis is as high as 17%. Fortunately, more recent data indicate that patients with aortic stenosis but without coronary artery disease who receive adequate care have a minimal risk of dying.60

**Peripartum cardiomyopathy (PPCM)**

PPCM is defined by the development of heart failure in the last month of pregnancy or within 5 months of delivery in the absence of an identifiable cause or pre-existing heart disease. Additional specific criteria for diagnosing PPCM include evidence of left ventricular systolic dysfunction as demonstrated by classic echocardiographic criteria: ejection fraction, <45%; shortening fraction, <30%; and left ventricular end-diastolic dimension, >2.7 cm/m² body surface area.61 Table IV provides a summary of these diagnostic criteria.

Although PPCM is rare (occurring in only 1 in 5000 live births), it is associated with mortality rates as high as 50% and accounts for 8% of all maternal death. PPCM is 1 of the few causes of maternal death that is rising.50,62 Forty-eight percent of patients who die of PPCM will die in the first 6 weeks after the delivery. Fifty percent of PPCM deaths occur in the ensuing 1 year after the delivery.63 Classic risk factors for PPCM include multiparity, advanced maternal age, multifetal gestation (4-fold increased risk), preeclampsia, hypertension, and black race.

The cause of PPCM has not been determined definitively. The most current available evidence suggests a viral myocarditis. One study reported endomyocardial biopsy results that were consistent with myocarditis in 76% of patients.64 The altered immune response of pregnancy is also hypothesized to play a role in the development PPCM by allowing greater viral replication. Evidence of autoantibodies against cardiac tissue proteins in patients with PPCM also supports a role for an autoimmune phenomenon.

Treatment of these patients is aimed at reducing preload with diuretic therapy, reducing afterload with vasodilators, and improving contractility with inotropic agents. Dietary sodium restriction is also important. Approximately one half of the patients will experience significant improvement after delivery. The prognosis for patients with PPCM is poor if left ventricular function does not normalize within 6 months after the delivery. In this group of patients, mortality rates

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**Table IV** Criteria for diagnosis of PPCM

<table>
<thead>
<tr>
<th>Variable</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classic</td>
<td>Development of cardiac failure in last month or within 5 months after delivery</td>
</tr>
<tr>
<td></td>
<td>Absence of an identifiable cause for cardiac failure</td>
</tr>
<tr>
<td></td>
<td>Absence of recognizable heart disease before last month of pregnancy</td>
</tr>
<tr>
<td>Echocardiographic findings</td>
<td>Ejection fraction &lt;45%</td>
</tr>
<tr>
<td></td>
<td>Shortening fraction &lt;30%</td>
</tr>
<tr>
<td></td>
<td>Left ventricular end-diastolic dimension &gt;2.7 cm/m² body surface area</td>
</tr>
</tbody>
</table>

Adapted from Pearson et al.61
approach 85% by 5 years. Death usually results from dysrhythmias, thromboembolic phenomena, or progressive heart failure. Cardiac transplantation is an option for patients whose condition does not improve within 6 months after the delivery.

Controversy exists regarding the risk of subsequent pregnancy in patients who have recovered from PPCM. Even in patients whose left ventricular function has returned to normal, recurrent PPCM has been described. Lampert et al demonstrated deficient contractile reserve in response to a dobutamine challenge in patients with a history of PPCM and apparently normal resting cardiac function on echocardiogram. In a very small series, Sutton et al reported no adverse events in 4 pregnancies in patients with a history of PPCM. In contrast, Elkayam et al recently detailed outcomes in 35 ongoing pregnancies in women with a history of PPCM. Of those patients with apparently normal pre-pregnancy cardiac function (as measured by an ejection fraction of >50%), cardiac symptoms recurred in 6% of the patients, and 17% of the patients experienced deteriorating cardiac function during gestation. This deterioration persisted in 9% of the patients, but no deaths occurred in this group. Those patients with evidence of compromised left ventricular performance (ejection fraction, <50%) before pregnancy had significant complications during gestation, with cardiac symptoms developing in 50% of the women, deterioration of cardiac function developing in 33% of the women, persistent decompensation developing in 42% of the women, and death occurring in 25% of women in this group. Women who consider pregnancy after PPCM remain at high risk for cardiac complications, even if apparently recovered.

**Myocardial infarction**

Myocardial infarction that occurs during pregnancy and the puerperium is rare, affecting approximately 1 in 35,000 pregnancies. The incidence can be expected to increase, however, as more women postpone childbearing into the fourth and fifth decades of life, when risk factors for coronary artery disease are more prevalent. In fact, a recent population-based study of myocardial infarction in pregnancy between 1991 and 2000 demonstrated an increasing incidence across the decade. In this study of 151 patients, the mortality rate was 7.3%, which was significantly lower than reported in previous studies. The improved mortality rate may reflect a larger sample size that included postpartum patients or more modern care. The 3 strongest predictors of myocardial infarction in this study were chronic hypertension, advancing maternal age, and diabetes mellitus. Sixty-six percent of the myocardial infarctions occurred in women who were older than 30 years. Only 21% of myocardial infarctions were diagnosed intrapartum; the remainder were divided evenly between the antepartum and postpartum periods. Patients who received a diagnosis of myocardial infarction intrapartum had the highest mortality rate and incidence of severe preeclampsia and eclampsia. None of the deaths occurred during the postpartum period. Myocardial infarction that occurred before or after labor was more likely to be related to diabetes mellitus, coronary artery disease, and lipid disorders.

Despite an improved mortality rate, these findings are similar to a 1996 review that described the pregnancy outcomes of 125 pregnant women who had been diagnosed with myocardial infarction. Most myocardial infarctions occurred in women who were older than 33 years and during the third trimester of pregnancy. In this study, the maternal death rate was 21%, and the overall fetal mortality rate was 13%. Atherosclerotic disease was identified in 43% of patients, and coronary thrombus was present in 21% of patients; 29% of patients had apparently normal coronary arteries.

After myocardial infarction, delivery should be postponed, if possible, to allow adequate healing of the myocardium. The increased myocardial demand in labor may lead to cardiac decompensation in patients with a recent infarction. Efforts should be directed at the minimization of myocardial demands by control of the heart rate, blood pressure, and intravascular volume changes. Some evidence exists that suggests that mortality rate is increased with cesarean delivery; however, the optimal route for delivery is controversial and should be individualized. Oxytocin and ergonovine have potential to cause coronary vasospasm and should be used with caution.

**Dysrhythmias**

Interpretation of an electrocardiogram for a pregnant patient must take into account the common gestational changes that are encountered, which include increased heart rate, shortened PR and QT interval, left axis deviation, and nonspecific ST changes. Asymptomatic arrhythmias occur with surprising frequency in laboring patients. Hemodynamically significant abnormalities and pre-existing arrhythmias are much less common. A history of supraventricular tachycardia increases the risk of supraventricular tachycardia occurring during the pregnancy. Although new onset supraventricular tachycardia has been described, the absolute risk remains controversial. A diagnosis of atrial fibrillation or flutter should prompt an evaluation for structural cardiac disease, hyperthyroidism, or electrolyte disturbances, because these arrhythmias are rare during pregnancy in the absence of 1 of these findings. Bradyarrhythmias are far less common in pregnancy than tachyarrhythmias and are generally well-tolerated. Pacemakers may be placed safely during gestation, if necessary.
Pharmacologic management of dysrhythmias in pregnancy is tailored to the specific diagnosis and is usually not altered by pregnancy. Many of these medications can be used also to treat fetal arrhythmias and pose minimal fetal risk in therapeutic doses. Commonly used medications such as adenosine, β-blockers, digoxin, diltiazem, lidocaine, procainamide, and quinidine may be used safely in pregnancy but may require dosage adjustments because of the increased plasma volume, decreased protein binding, and increased renal excretion. Patients with ventricular or supraventricular tachyarrhythmias that result in hemodynamic instability that does not respond to medical treatment are candidates for electric cardioversion. This treatment is effective and considered safe in pregnancy.

Ideally, patients with pre-existing dysrhythmias should be evaluated preconceptionally to determine whether therapies such as radiofrequency ablation, pacemaker placement, or an implantable cardioverter-defibrillator is appropriate and to review the risks of fetal exposure to cardiac medications during pregnancy. Anticoagulation should be considered for patients with chronic atrial fibrillation, particularly in the setting of rheumatic heart disease.

### Respiratory failure

Substantial anatomic and physiologic changes occur over the course of pregnancy that impact respiratory function. Minute ventilation increases in a normal pregnancy and is determined by respiratory rate and tidal volume. The 40% increase in tidal volume (the amount of air exchanged during a cycle of inspiration and expiration) primarily drives the increase in minute ventilation. As a result, the levels of carbon dioxide decline and create an alkalotic state. To accommodate for the decrease in carbon dioxide, the kidneys excrete HCO$_3^-$.

An arterial blood gas in a normal pregnant woman therefore will reflect a slightly increased pH, decreased Pco$_2$, and decreased serum Hco$_3^-$ (respiratory alkalosis with compensatory metabolic acidosis) as shown in Table V. As the pregnancy progresses, increasing abdominal girth leads to an upward displacement of the diaphragm, widening of the subcostal angle by 50% and increasing chest circumference. The end result is a decrease in the functional residual capacity by 20%. Functional residual capacity reflects the amount of air remaining in the alveoli at the completion of expiration. As functional residual capacity decreases, alveoli collapse and gas exchange decreases.

Common causes for respiratory failure in pregnancy include pulmonary edema, asthma, infection, and pulmonary embolus (PE). In a recently published series of 43 pregnant women whose condition required mechanical ventilation while undelivered, 86% of the women were delivered during the admission; of these, 65% of the women underwent cesarean delivery, with an associated mortality rate of 36% in those women who were delivered by cesarean delivery. Overall, maternal and perinatal mortality rates were high (14% and 11%, respectively).

After a 1990 report that described improved ventilator settings in a pregnant patient immediately after delivery, debate has continued whether delivery actually improves respiratory status in these patients. Tomlinson et al described their experience with 10 patients who were delivered while being receiving mechanical ventilation. In all but 1 patient, the cause of respiratory failure was pneumonia. The only demonstrable benefit after delivery was a 28% reduction in FiO$_2$ in the ensuing 24 hours. The author concluded that routine delivery of these patients is not recommended. This is the only study published to date that was designed specifically to address this question. However, data from other series support the conclusion that delivery does not result uniformly in significant maternal improvement. Mortality rates after the delivery of women who require ventilatory support range from 14% to 58%, and cesarean delivery may further increase this risk.

### Pulmonary edema

Pregnant women are predisposed to the development of pulmonary edema for various reasons, which include increased plasma volume and cardiac output in conjunction with decreased colloid oncotic pressure (COP), which occurs normally over the course of pregnancy. Alterations in the balance of hydrostatic and oncotic pressure between the pulmonary vessels and the interstitial spaces can lead to an egress of fluid from the vascular space into the interstitium and manifest clinically as pulmonary edema. Approximately 1 in 1000 pregnancies will be complicated by pulmonary edema. In a review of almost 63,000 pregnancies, Sciscione et al report pulmonary edema occurring most often during the antepartum period (47%) and in the postpartum period (39%), and the remaining 14% occurred during the intrapartum period. In this series, the 2 most common attributable causes of pulmonary edema were cardiac

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pregnant</th>
<th>Nonpregnant</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.4-7.46</td>
<td>7.38-7.42</td>
</tr>
<tr>
<td>Pco$_2$ (mm Hg)</td>
<td>26-32</td>
<td>38-45</td>
</tr>
<tr>
<td>Pco$_2$ (mm Hg)</td>
<td>75-106</td>
<td>70-100</td>
</tr>
<tr>
<td>Hco$_3^-$ (mmol/L)</td>
<td>18-21</td>
<td>24-31</td>
</tr>
<tr>
<td>Oxygen saturation (%)</td>
<td>95-100</td>
<td>95-100</td>
</tr>
</tbody>
</table>

Adapted from Dizon-Townson et al.
disease and tocolytic use (25.5% each). The remainder of the causes were due to fluid overload (21.5%) and preeclampsia (18%). The treatment of patients with pulmonary edema is focused on the establishment of the diagnosis, determination of the cause of the pulmonary edema, and the improvement of oxygenation.

### Hydrostatic (cardiogenic) pulmonary edema

Pulmonary edema because of primary cardiac issues (cardiogenic) with or without alterations in COP is referred to as hydrostatic or cardiogenic pulmonary edema. Cardiac output is controlled through continuous adjustments in heart rate and stroke volume. According to Starling’s Laws, however, the ability of the heart to increase output is limited. At some point, the heart will no longer be able to compensate, either because of intrinsic cardiac abnormalities or excessive fluid administration, which results in overload. If the left side of the heart is obstructed, then the blood that empties from the lungs into the left atrium will remain in the pulmonary vasculature that is reflected by an increased pulmonary capillary wedge pressure, left ventricular end-diastolic pressure, and PA pressure. The net result is an increase in the pulmonary intravascular hydrostatic pressure. When this pressure exceeds the interstitial pressures, fluid will be forced out of the pulmonary vasculature into the interstitial spaces and result in pulmonary edema.

An echocardiogram is essential to distinguish whether pulmonary edema is cardiogenic in origin. Evidence of poor ventricular systolic function will be identified by a decreased ejection fraction, as seen in patients with a cardiomyopathy. Echocardiography may also identify valvular abnormalities that may lead to compromised cardiac function and predispose patients to pulmonary edema, such as aortic or mitral stenosis.

### COP abnormalities

COP is the force that is exerted by red blood cells, albumin, and other proteins and functions to hold fluid within the vascular space. Hydrostatic forces exert the opposite effect and are present within the vessel and the interstitium. The normal COP in a term pregnancy is 22 mm Hg. This is approximately 3 mm Hg lower than prepregnancy values as a result of the dilutional effect from plasma expansion. An isolated decrease in oncotic pressure, as might occur in pregnancy or in patients with nephrotic syndrome, is usually well compensated and does not lead to pulmonary edema, unless it is complicated by additional factors such as increased intravascular pressure or pulmonary injury that results in vascular permeability. Excessive intravenous fluids, blood loss, and the postpartum autotransfusion effect can place patients at further increased risk for pulmonary edema.

### Pulmonary edema in the setting of preeclampsia

Pulmonary edema develops in approximately 2.5% of patients with preeclampsia, most commonly in the postpartum period. The cause is not understood completely but likely results from a combination of problems. Impaired left ventricular function may be a result of chronic hypertension, particularly if it develops in the antepartum period. Substantially increased systemic vascular resistance may also impair left ventricular function and lead to pulmonary edema, especially in the setting of iatrogenic fluid overload. Furthermore, patients with preeclampsia often lose significant amounts of albumin through the urine and exhibit decreased albumin production, both of which will lower COP. In patients with preeclampsia, COP can decrease to 18 mm Hg by term and drop further after the delivery to 14 mm Hg. Endothelial damage also leads to increased capillary permeability. Vasoconstriction and intravascular depletion may result in oliguria. Patients with preeclampsia with pulmonary edema that fails to respond to oxygen, diuresis, and fluid restriction (especially when combined with oliguria) may require PA catheterization to guide further therapy.

### Tocolytic-induced pulmonary edema

In the past, the use of parenteral β-agonists such as terbutaline and ritodrine was more common and became associated with the development of pulmonary edema. Several mechanisms have been proposed to explain this observation. β-agonists cause cardiac stimulation that may lead to ischemia or arrhythmias or unmask pre-existing cardiac disease, such as mitral stenosis. Underlying undiagnosed infection, particularly occult chorioamnionitis or pyelonephritis with resultant premature labor, may also increase the patient’s risk for pulmonary edema. These agents appear to stimulate the release of anti-diuretic hormone, which predisposes to water retention. Intravenous fluid administration may contribute to this effect as a result of increased hydrostatic pressure.

Because intravenous magnesium sulfate has supplanted the use of intravenous β-agonists for tocolysis, the incidence of pulmonary edema that is related to tocolytic use appears to have diminished. Magnesium does not appear to increase independently the risk of pulmonary edema.

### PE

PE complicates 0.5 to 1 in 1000 pregnancies and currently is the leading cause of maternal death. PE usually originates from a thrombus in the deep veins...
of the legs and pelvis (internal iliac, femoral and popliteal veins). Pregnant women are at particular risk for the development of a deep venous thrombosis and subsequent PE because of increases in factors II, VII, VIII, X and fibrinogen and a decrease in protein S, which creates a propensity for clot formation. Physical obstruction by the gravid uterus leads to stasis, and delivery causes endothelial damage, both of which increase the risk of deep venous thrombosis formation. Pregnant patients who require bedrest, use tobacco, are obese, or have a thrombophilia are at considerable increased risk for deep venous thrombosis and PE. Recognition and appropriate treatment of PE decreases mortality rates from 30% to 0.7%. However, diagnosis can be challenging; in the nonpregnant population, only 35% of patients who are suspected of having a PE actually have a PE confirmed by testing. Diagnosis in pregnant patients may be more challenging because of increased complaints of shortness of breath, chest pain, and tachycardia.

**Diagnosis of PE**

When PE is suspected, evaluation should begin immediately. Data that evaluate the efficacy of compression ultrasound, ventilation perfusion (V/Q) scanning, pulmonary angiography, and spiral computerized tomography (CT) scanning in the evaluation of a pregnant patient are limited. In the nonpregnant patient, the likelihood of the patient having a PE is established clinically and then confirmed by V/Q scanning and/or D-dimer testing. Further testing such as spiral CT, compression ultrasonography of the lower extremities, or pulmonary angiography are at considerable increased risk for deep venous thrombosis and PE.

Conversely, if the scan is interpreted as high probability in a patient with a moderate-to-high clinical suspicion for PE, treatment can be instituted without further evaluation. Unfortunately, in the largest published study of V/Q scans in pregnancy (n = 120 scans), only 3.3% (4/120) of the V/Q scans were interpreted as high probability. In the same study, 24.2% scans (29/120) were read as nondiagnostic and requiring further evaluation, and the remaining 72.5% of scans (87/120) were considered normal. No treatment was instituted in 105 of the 111 patients with nondiagnostic or normal V/Q scans, and in follow-up 20 months later, no evidence of venous thromboembolism was found, which suggests that the V/Q scan results were accurate. These findings differ substantially from findings in nonpregnant patients. As demonstrated by this study and others, the prevalence of high probability scans is low in pregnant patients compared with nonpregnant patients (3.3% vs 8%-14%); normal scans occur more frequently (72.5% vs 27%-36%), and nondiagnostic scans are less common (24.2% vs 47%-59%). Concerns about radiation exposure to the developing fetus as a result of V/Q scanning persist among patients and clinicians. However, the fetal radiation exposure is minimal (370 μGy; 0.037 rad) and is well below the threshold that has been identified as posing risk.

D-dimer levels are also used commonly in the evaluation of venous thromboembolism in nonpregnant patients. D-dimer is produced as a result of cross-linked fibrin breakdown and is elevated therefore in the presence of a pulmonary embolism. A negative D-dimer assay has been shown to reliably exclude PE in nonpregnant patients with a low clinical probability of having a PE. However, the sensitivity of this test varies considerably because of variations in the accuracy of the assay used. During pregnancy, however, D-dimers increase progressively as the gestation advances. Normal D-dimer levels in pregnancy have not been established definitively, but at least 1 study suggests that levels more than double from baseline by the third trimester. Therefore, the role of D-dimer testing in the evaluation of a pregnant patient who is suspected of having a PE is unknown and should not be used routinely.

In the nonpregnant population, a normal alveolar-arterial oxygen gradient reliably excludes the possibility of PE, although an alveolar-arterial oxygen gradient of >15 mm Hg is considered abnormal, which suggests limitations in the exchange of oxygen within the lung. However, this is not always the case in pregnancy. Powrie et al reported that 50% of pregnant patients with a documented PE had a normal alveolar-arterial oxygen gradient. Therefore, this test has limited utility in evaluation of the pregnant patient.

Spiral CT is becoming more accepted and widely used as a tool for diagnosing PE. Like V/Q scanning, intravenous contrast is required, but the radiation exposure to the fetus is minimal (131 μGy; 0.0131 rad) and is lower than the exposure from a V/Q scan. In a recent review of the literature that included 15 studies and >3500 nonpregnant patients, spiral CT was reported to be equivalent to pulmonary angiography in excluding PE. In this evaluation, a negative spiral CT excluded PE in 99.1% of patients. Doyle et al performed a cost-effectiveness analysis for the evaluation of suspected PE in pregnant patients. Because of the paucity of available data in a pregnant population, baseline assumptions for
treatment of nonmassive PE. Equiv-
calent to intravenous unfractionated heparin for after delivery because of the high risk of recurrence. Continue throughout gestation and up to 6 to 8 weeks if the diagnosis made during pregnancy, treatment should subcutaneous regimen. Treatment is recommended to with intravenous unfractionated heparin or low molec-
ular-weight heparin (LMWH). Most authors recom-
end an initial course of intravenous unfractionated heparin, because it generally does not require laboratory monitoring when dosed according to weight in patients without renal impairment. It also appears to entail less risk of heparin-induced thrombocytopenia and osteoporosis, compared with unfractionated heparin, and because it has a longer half-life, only 1 or 2 injections per day are required.

In the pregnant population, however, some author-
ies recommend that the anticoagulant effects of LMWH be monitored. Because the activated partial thrombo-
plastin time does not reflect anticoagulation status with LMWH, anti–Xa levels must be measured instead. For full anticoagulation, the goal is a peak anti–Xa level (3 hours after injection) of 0.5 to 1.2 U/mL. One disadvantage of LMWH is that protamine sulfate is less effective in reversing its anticoagulant effects (protamine neutralizes only 60% of the circulating drug), which limits the usefulness of LMWH in patients who may require emergent surgery. Neither heparin nor LMWH cross the placenta or enter breast milk. After delivery, patients may continue to receive heparin therapy or LMWH or be switched to Coumadin therapy. Coumadin is compatible with breastfeeding but should generally be avoided during pregnancy because it crosses the placenta; it is teratogenic in the first trimester (causing Coumadin embryopathy) and may lead to fetal hemorrhage and thus disruption of developing tissues during the second and third trimesters.

Acute respiratory distress syndrome (ARDS)

ARDS is characterized by the rapid onset of progressive respiratory distress. Evaluation reveals bilateral pul-
monary infiltrates without evidence of cardiac failure or increased hydrostatic pressure (pulmonary capillary wedge pressure, <18 mm Hg). These patients require high concentrations of oxygen and frequently need intubation. ARDS is also defined by a diminished ratio of the partial pressure of oxygen to the fraction of inspired oxygen (Pao2/Fio2 ≤ 200). If the ratio falls between 200 and 300, then acute lung injury is present that is not yet severe enough to be called ARDS.

In pregnant women, infections such as varicella or herpes simplex virus, severe preeclampsia, eclampsia, and hemorrhage most commonly precipitate respiratory failure.77,111 Patients with sepsis are at particular risk for the development of acute pulmonary injury and ARDS as a consequence of pulmonary vascular damage, which facilitates the leakage of intravascular fluid into the pulmonary interstitial spaces. Mortality rates are quite high, and those patients who survive often have compromised pulmonary function because of fibrosis and scarring of pulmonary tissue.

The treatment of ARDS focuses on the identification and treatment of underlying causes such as infection, then provides respiratory, hemodynamic, and nutritional support to facilitate lung healing. Respiratory support may precipitate additional lung injury; therefore, efforts to maintain adequate oxygen delivery...
should also minimize lung trauma in an effort to facilitate healing of the lungs.

Management of respiratory failure in nonpregnant critically ill patients historically has used a goal of maintaining a tidal volume of 10 to 15 mL/kg. In ARDS, high tidal volumes may lead to alveolar over-distension or repeated recruitment and collapse of alveoli, which predisposes to alveolar damage and the release of inflammatory mediators that worsen pulmonary damage. In 2000, the Acute Respiratory Distress Syndrome Network published results of 861 patients with ARDS who were randomly assigned to traditional tidal volumes (12 mL/kg) versus a low tidal volume of 6 mL/kg. The traditional tidal volume group also maintained a goal of ≤50 cm of water versus lower peak pressures of 30 cm of water in the low tidal volume group. Low tidal volumes and lower peak pressures were associated with lower mortality rates (31% vs 40%) and a shorter period of intubation, compared with conventional tidal volumes and peak pressure goals. As described earlier, increased tidal volume and other normal changes in pulmonary physiologic condition may impact the utility of this approach in pregnant women.

### Anaphylactoid syndrome of pregnancy (amniotic fluid embolus)

Amniotic fluid embolism is a rare but devastating complication of pregnancy that is characterized by acute onset of hypoxia, hypotension or cardiac arrest, and coagulopathy that occur during labor and delivery or within 30 minutes after delivery. This same constellation of findings may be caused by other causes such as hemorrhage, uterine rupture, or sepsis, each of which should be excluded before assignment of a diagnosis of amniotic fluid embolism. The combination of sudden cardiovascular and respiratory collapse with a coagulopathy is quite similar to that observed in patients with anaphylactic or septic shock. In each of these settings, a foreign substance (eg, endotoxin) is introduced into the circulation. This incites a cascade of events that result in the activation and release of mediators such as histamines, thromboxane and prostaglandins, which lead to disseminated coagulation, hypotension, and hypoxia. In this scenario, the inciting factor is presumed to be present in amniotic fluid that is introduced into the maternal circulation, yet the precise factors that initiate the sequence have yet to be identified. It is a commonly held misconception that the presence of fetal debris in the pulmonary circulation is diagnostic of an amniotic fluid embolus. In fact, fetal debris can be found in the pulmonary circulation in a predominance of normal laboring patients and is only identified in 78% of those patients who meet the criteria for the diagnosis of amniotic fluid embolism. Management of amniotic fluid embolism is entirely supportive. Replacement of blood and clotting factors, adequate hydration and blood pressure support, ventilatory support, and invasive cardiac monitoring in addition to resuscitation efforts are all generally required for these patients. Recent data suggest mortality rates approach 61%. Most patients do not survive the initial course and die within 5 days. Of those patients who survive, neurologic impairment is common.

### Summary

Pregnant women may require intensive care because of complications of the pregnancy itself or as a result of nonobstetric conditions. In either setting, care of the critically ill pregnant woman requires knowledge of the primary disease process and its treatment in nonpregnant patients and a thorough understanding of maternal physiologic adaptations to pregnancy. Because there are frequently no data or literature that could guide intensive care of the pregnant patient, knowledge of maternal physiologic condition must be used to interpret and implement therapies that are studied only in nonpregnant patients. Thus, care should be provided by or in consultation with a maternal fetal medicine specialist or obstetrician who is thoroughly familiar with the management of high-risk pregnancies.

### References


