



# Lesson 259: PreAnesthetic Assessment of a Micropremie With Necrotizing Enterocolitis

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**NEEDS STATEMENT**

Advancements in medical knowledge and technology enable low- and very low-birth-weight infants to survive the critical neonatal period, when they are susceptible to many medical complications that may require emergency, or urgent, surgical interventions. Because of their small size and complex medical problems, these babies pose a tremendous challenge to the anesthesiologist. Knowledge of the care of the critically ill neonate has been identified by committee and questionnaire as important information for the clinical anesthesiologist.

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**LEARNING OBJECTIVES**

At the end of this activity, the participant should be able to:

1. State the incidence of premature births in the United States.
2. Identify the most important anomalies associated with premature birth.
3. Explain the disease process and treatment of enterocolitis.
4. Assess changes in fetal circulation at birth.
5. Discuss an appropriate preanesthetic plan for micropremies.
6. List relevant tests for these patients.
7. Outline an anesthetic plan for micropremies.
8. Manage fluids and blood replacement in these patients.
9. Describe the pathophysiology and appropriate management of pulmonary hypertension.
10. Present a plan for the postoperative care of micropremies.

**CASE HISTORY**

A 10-day-old neonate with a very low birth weight (932 g) and necrotizing enterocolitis (NEC) was scheduled for urgent laparotomy. She had been born during week 28 of gestation by normal vaginal delivery as a twin. Intrauterine infection had been identified as a possible cause of the premature delivery. When the patient was 6 days old, NEC was diagnosed. Because of respiratory distress syndrome, she had required ventilatory support since birth. Additionally, cardiac dysfunction had developed secondary to pulmonary hypertension, and the patient was being maintained on an infusion of dopamine. At birth, her platelet count had been normal, at approximately 247,000/mm<sup>3</sup>. On day 7, with the development of sepsis secondary to NEC, her platelet count decreased to about 30,000/mm<sup>3</sup>, and a platelet transfusion was required.



Babies are classified according to their weight at birth. Normal, full-term infants are born between 37 and 42 weeks after conception and weigh more than 2,500 g. Premature or preterm infants are born earlier than 37 weeks and weigh less than 2,500 g. There were 4,019,280 births recorded in the United States in 2002; of those, 7.8% were of premature babies weighing less than 2,500 g.<sup>1</sup>

Low-birth-weight infants are

those born between 31 and 35 weeks and weighing between 1,000 and 1,500 g. Infants born at about 26 to 30 weeks and weighing less than 1,000 g are referred to as very low-birth-weight infants. Those weighing less than 500 g and born before 26 weeks of gestation are referred to as extremely low-birth-weight infants. Infants weighing less than 1,000 g are usually referred to as *micropremies*.<sup>2,3</sup> Approximately 25,000 births (0.6%) in the United States in 2002 were of micropremies (Table 1).<sup>1</sup>

**Very Low-Birth-Weight Babies (Micropremies)**

Of all premature newborns, 12% are micropremies. At any institution, about 5 to 6 of every 1,000 neonates will be classified as micropremies. They are at risk for many complications, including respiratory distress syndrome, retinopathy of prematurity, intraventricular hemorrhage, necrotizing enterocolitis (NEC), chronic lung disease (also called bronchopulmonary dysplasia), cerebral palsy, jaundice, infection, anemia, persistent patent ductus arteriosus (DA), and apnea. The precise etiology of some of these complications has not

**Table 1. Classification of Low-Birth-Weight Infants**

	Gestational Age, wk	Weight at Birth, g
Low birth weight	31-35	1,000-1,500
Very low birth weight	26-30	<1,000
Extremely low birth weight	<26	<500

**PREANESTHETIC ASSESSMENT**

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been determined. However, prematurity is considered to be the leading identifiable risk factor. Recent studies have indicated that although cerebral palsy may develop very early in gestation, the cause of this anomaly is not clearly understood.<sup>4,5</sup>

## Neonatal Necrotizing Enterocolitis

NEC develops in 15% of premies weighing less than 1,500 g; their mortality rate is about 30%. NEC, a fulminant neonatal disease, is characterized by infection that leads to ulceration, necrosis, and perforation of the small bowel and colon.<sup>6</sup> Perforation results in gangrene, fluid loss, peritonitis, septicemia, and disseminated intravascular coagulation (DIC). NEC is the most common neonatal gastrointestinal emergency. The incidence is 2.4 in every 1,000 live births, but premature infants are predominantly affected. Fewer than 10% of affected newborns are term infants. NEC usually develops within 2 weeks after birth.

Although its etiology remains unclear, NEC usually develops in the premature newborns of mothers who have had a toxemic pregnancy. In animal models, hypoxia (particularly when combined with an artificial feed) has been shown to reduce blood flow in mesenteric vessels and induce the pathologic equivalent of NEC. Formulas for newborns have been implicated because the disease is less common in breast-fed infants. Breast milk is rich in secretory immunoglobulin A (IgA), which acts on the gastrointestinal mucosa to prevent bacterial adherence and thus impede invasion. When breast milk is cooled, frozen, or heat-treated (pasteurized or boiled), many of its antibacterial properties are diminished. Asphyxia, respiratory distress, exchange transfusion, and congenital cardiac disease have also been implicated as causative factors.

If an infection becomes severe, intestinal perforation with peritonitis, septicemia, metabolic acidosis, and hypovolemia may develop. Clinically, NEC has multiple systemic manifestations, including severe hematopoietic disturbances. Associated hematologic abnormalities include thrombocytopenia with or without DIC, neutrophilia or neutropenia, and hemolytic anemia. It may be necessary to administer a massive amount of blood products to treat the hematopoietic disturbances of patients with NEC.

Hematologic complications contribute significantly to mortality; several conditions are associated. Babies with NEC are hypotensive, and respiratory distress syndrome develops in 69% of them.<sup>6</sup> The DA may be open, and a significant percentage of the blood may enter the DA and bypass the lungs, causing hypoxemia. Babies with NEC are also septic, hyperglycemic, acidotic, azotemic, and thrombocytopenic (35%), and they have DIC.<sup>6</sup>

## Signs and Symptoms

The signs and symptoms are consistent with intestinal obstruction, including lethargy, anorexia, vomiting, abdominal distention, and the passage of bloody stool. Radiographs of the abdomen may show dilated loops of bowel, pneumatosis intestinalis (intramural gas), ascites, and air in the peritoneum or gas in the portal vein. Magnetic resonance imaging of the abdomen can assist in the diagnosis of bowel necrosis. Blood and stool cultures may help identify aerobic or anaerobic organisms. A low platelet count and the presence of fibrinogen degradation products may indicate thrombocytopenia and DIC.

## Treatment

Treatment consists of I.V. feeding, antibiotics, and nasogastric suctioning. Surgery is indicated if peritonitis and perforation develop; laparotomy with bowel resection or simple peritoneal drainage may be required. A study by Azarow et

al<sup>7</sup> evaluated 86 newborns with NEC who were treated either with laparotomy involving bowel resection and the creation of a temporary stoma or with a peritoneal drain performed under local anesthesia. The survival rate of babies in the laparotomy group was 57%, versus 59% in the group treated by peritoneal drainage. However, when the authors considered the neonates according to their weight, specifically those weighing less than 1,000 g, survival in the drainage group was 69%, compared with 22% in the laparotomy group ( $P < 0.01$ ). As neonatal weight increased to more than 1,000 g, survival in the laparotomy group increased to 67%. The risk for neonatal mortality was highest among babies weighing less than 1,000 g at birth with a gestational age of less than 30 weeks. With peritoneal drainage, survival rates in this group can approach those of larger neonates who undergo laparotomy.

## Preoperative Evaluation

Babies with NEC have multiple problems that should be addressed and corrected—if at all possible—before surgery. In addition to the sepsis and hematologic abnormalities associated with the disease, these children should be evaluated for the cardiac and respiratory aberrations of prematurity and their management optimized.

### Respiratory System

Premature babies born around 24 weeks have approximately 69% of the normal level of surfactant. Normal levels are reached at about 36 weeks. Inadequate levels of surfactant cause alveolar collapse and result in ventilation-perfusion mismatch and decreased lung compliance (Table 2). Thus, the work of breathing to maintain adequate oxygenation is increased. Babies may require surfactant therapy, supplementary oxygen, and ventilatory support.

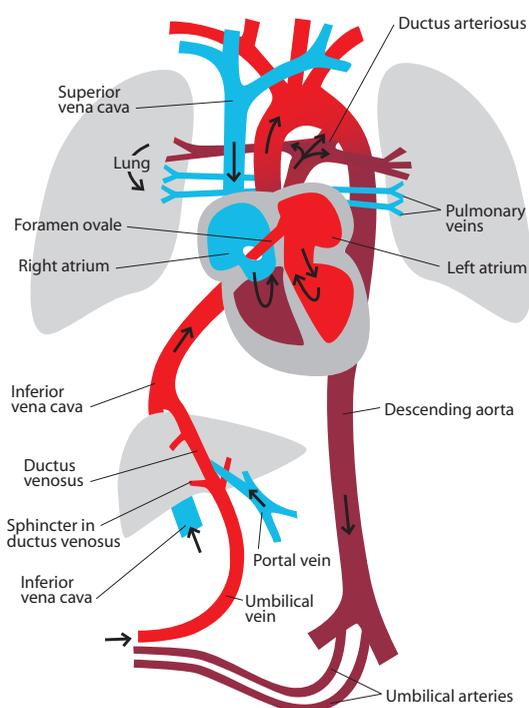
### Cardiovascular System

Anomalies in the cardiovascular system affect anesthetic care.<sup>8,9</sup> The fetal heart has more connective tissue and fewer contractile elements than the adult heart. Therefore, the ventricles of preterm babies are stiff, relax slowly, and have poor diastolic function compared with those of a full-term baby. The resting heart rate is high, so the ability to compensate with tachycardia is limited. In the fetal circulation, about 10% of the blood passes through the lungs, and 90% flows directly via the DA into systemic circulation (Figure). Blood is oxygenated in the placenta; the lungs are nonfunctional. Within 48 hours after birth, the lungs have opened, placental prostaglandins have disappeared, arterial oxygenation has increased, and thus the pulmonary vascular resistance decreases. Venous blood from the right ventricle now passes via the pulmonary artery into the lungs and is oxygenated. This state is conducive to functional closure of the DA. The foramen ovale also closes functionally by 12 hours after birth. Thus, transitional circulation and the first step toward adult circulation are established. The anatomic or permanent closure of the DA occurs by 2 to 3 weeks; closure of the foramen ovale usually takes 1 year. In 25% of adults, the foramen ovale remains probe-patent.<sup>10</sup>

The transitional circulation is dynamic and in a reversible state. If pulmonary hypertension worsens, venous blood from the right ventricle takes the path of least resistance, flowing back into the systemic circulation through a reopened DA rather than through the highly resistant lungs (Figure). The diversion of deoxygenated venous blood into the postductal systemic circulation causes hypoxia—a situation that may be detected by the placement of a pulse oximeter at a postductal site. In addition, venous blood is shunted via the foramen ovale to the left atrium. The

## Table 2. Pathophysiologic Features of the Respiratory System of a Premature Infant

- Alveolar collapse
- Decreased lung compliance
- Hypoxemia
- Low surfactant levels
- Ventilation-perfusion mismatch



**Figure. Fetal circulation.**

Note the main pulmonary artery leading into 3 conduits—the right and left pulmonary arteries and the ductus arteriosus (DA). After birth, in the transitional circulatory stage, the DA closes, and blood is directed into the pulmonary arteries. If pulmonary hypertension develops, venous blood from the right ventricle forces open the DA and flows into the descending aorta, the conduit of least resistance.

## Table 3. Therapeutic Modalities for Neonatal Pulmonary Hypertension

- Alkalosis via hyperventilation
- Alkalosis via sodium bicarbonate
- Dopamine and dobutamine to increase blood pressure by increasing cardiac output
- Fluid restriction, diuretics
- Improve oxygenation:  
  - $FiO_2$ , surfactant, tidal volume
- Isoproterenol
- Nitric oxide (short-acting vasodilator)
- Prostaglandin  $E_1$  and tolazoline (vasodilators)

$FiO_2$ , fraction of inspired oxygen

**Table 4. Factors That Contribute to Perioperative Cardiovascular Collapse In Premies**

Cause	Effect
Anesthetics	Depressant effects on myocardium and baroreceptors
Barotrauma	Pneumothorax, hypoxemia
Hypovolemia	Fluid and blood loss; small blood volume with no reserve; fast heart rate with no ability to compensate
Pulmonary hypertension, hypoxemia	Heart failure
Transfusion of blood or fresh-frozen plasma	Hyperkalemia or hypocalcemia

combination of venous admixture and reduced pulmonary blood flow results in systemic cyanosis and acidosis.

Pulmonary hypertension is associated with prematurity, hypoxemia, hypercarbia, acidosis, fluid overload, and hypothermia. Some of these events can develop in the operating room with catastrophic consequences. Several therapeutic modalities are available to decrease pulmonary hypertension (Table 3). Improving oxygenation decreases pulmonary hypertension. Hyperventilation, or preferably sodium bicarbonate therapy (bolus of 2-3 mg/kg), can be used to induce alkalosis to prevent hypoxic pulmonary vasoconstriction. Fluid restriction or the administration of diuretics increases systemic resistance and thus impedes flow through the DA, diverting venous blood to the pulmonary circulation. Increasing cardiac output by the administration of dopamine (2-20 mcg/kg per minute) or dobutamine (5-19 mcg/kg per minute) also improves the pulmonary circulation. Dobutamine, in addition to increasing cardiac output, decreases pulmonary and systemic vascular resistance.

Pulmonary vasodilation can be achieved with the I.V. administration of tolazoline (an  $\alpha$ -adrenergic blocker that is no longer available in the United States) at a dose of 1 to 2 mg/kg, or with an infusion of prostaglandin E<sub>1</sub> at a rate of 0.05-0.1 mcg/kg per minute. Isoproterenol (0.05-1 mcg/kg per minute) and nitric oxide have also been used.<sup>9</sup> Nitric oxide is a short-acting vasodilator that when given as an inhaler acts only on the vessels of the lungs. However, it is expensive, and a special delivery system is required for therapeutic use.

Hemodynamic collapse tends to occur readily in these patients for many reasons, including the depressant effects of anesthetics on baroreceptors and the myocardium, the small blood volume (100-120 mL/kg) of these babies, and their high resting heart rate with no ability to compensate. If for any reason pulmonary hypertension develops, blood is shunted through the DA and patent foramen ovale of the transitional circulation, resulting in hypoxemia. Pulmonary hypertension and hypoxemia are additional contributors to cardiovascular collapse. Other possible causes of cardiovascular collapse include acidosis and the sequelae of blood transfusion (Table 4).

Other cardiac anomalies may coexist. During the preoperative evaluation of these patients, echocardiography is useful to assess the cardiac function, state of the DA, degree of pulmonary hypertension, and any other cardiac problems that may be present.

### Hematopoietic Disturbances

Hematopoietic changes observed in infants with NEC include thrombocytopenia with or without DIC, neutrophilia or neutropenia, and hemolytic anemia (Table 5).<sup>11</sup> Thrombocytopenia develops in infants with severe NEC. Lower platelet counts have been associated with more severe disease. In a recent study by Kling and Hutter, the incidence of thrombocytopenia in NEC was 65% to 90%.<sup>11</sup> In survivors, the median time to achieve a platelet count above 150,000/mm<sup>3</sup> was 7 to 10 days. Thrombocytopenia is common with any neonatal infection. In premature infants weighing less than 1,500 g at birth, bacterial sepsis is associated with a 70% incidence of moderate to severe thrombocytopenia.

Although the minority of patients with NEC have documented DIC with thrombocytopenia, there are data to support increased platelet consumption rather than decreased platelet production as the major contributor to thrombocytopenia. Bone marrow obtained from 7 infants at autopsy showed a normal number of megakaryocytes and normal maturation.<sup>11</sup> In patients with NEC, therapeutic transfusions of platelets are commonly associated with a short-lived response only—up to 48 hours.

The treatment of thrombocytopenia remains supportive, with platelet transfusion. Before surgery, a platelet count should be obtained, and it should be maintained above 50,000/mm<sup>3</sup>. An infusion of platelets at 0.1 unit/kg increases the count by 20,000/mm<sup>3</sup>.<sup>12</sup>

The defenses of a host with severe infection and shock increase the activity of tissue factor and the release of cytokines and modulate the coagulation and fibrinolytic systems, ultimately resulting in DIC. The standard recommended treatment for coagulopathy, although not specific, includes the administration of fresh-frozen plasma and/or cryoprecipitate.

Anemia in NEC is multifactorial in origin; the causes include hemolysis, hemorrhage, iatrogenic blood sampling, and a relative deficiency of erythropoietin production. Treatment is supportive, with transfusion of erythrocytes.

### Preanesthetic Preparation

Several factors must be addressed in the preanesthetic preparation of patients with NEC (Table 6). Transporting these very small patients to the operating room is not an easy task. Babies must be kept in warm incubators, and the presence of skilled personnel is required to prevent the dis-

**Table 5. Potential Hematopoietic Disturbances in Babies With Necrotizing Enterocolitis**

- Disseminated intravascular coagulation
- Hemolytic anemia
- Neutrophilia or neutropenia
- Thrombocytopenia

lodgement of endotracheal tubes and I.V. cannulae. At many institutions, when a baby is critically ill and decompensating because of a persistent patent DA, surgical ligation of the patent DA is performed in the neonatal intensive care unit.<sup>13</sup>

Hypovolemia—caused by either insufficient replacement of lost blood or inadequate I.V. access—is a frequent cause of cardiac arrest in pediatric patients.<sup>14</sup> Therefore, reliable I.V. access routes (preferably two) should be established before these patients undergo surgery. Cardiovascular collapse during surgery may occur for many reasons, one of which is decreased blood volume (Table 4). A Broviac catheter placed in the femoral vein, with its tip extending into the thorax if possible, can be used to assess volume status. In some cases, ultrasound guidance may be necessary to establish access routes. In patients with NEC, cannulation of the umbilical site is usually avoided because it may become a nidus of infection and is located within the operative field.

### Anesthetic Management

It is important to anticipate potential complications and pay attention to details in the anesthetic management of patients with NEC. Anesthesia for the micropremie involves many considerations beyond those needed for the full-term neonate. Most challenging to the anesthesiologist is the micropremie's small size. In addition, immature respiratory mechanisms and respiratory control increase the risk for apnea, hypoxemia, and hypercapnia, both intraoperatively and postoperatively. Anesthetics depress myocardial contractility and impair baroreflexes in the micropremie and increase the risk for hypotension during anesthesia. Drug metabolism is slow because the liver and kidneys are immature. Lesser amounts of drugs are required in the brain to achieve an anesthetized state.<sup>3,15</sup> As a result, smaller and less frequent doses are required for the micropremie than for the full-term neonate.

### Temperature Regulation

It is important to maintain body temperature and avoid hypothermia (<35.8°C) in the micropremie. The best way to prevent heat loss is to maintain the room temperature between 78°F and 80°F. In premies, hypothermia stimulates the release of norepinephrine, which stimulates the metabolism of brown fat to produce heat. Norepinephrine also may cause pulmonary hypertension. The consumption of glucose during the hypothermia-induced metabolism of brown fat may cause hypoglycemia. In addition, nonshivering

**Table 6. Preoperative Assessment and Optimization of Conditions**

Condition	Optimization
Blood sugar	Dextrose infusion
Cardiac function	Volume or inotropic support
Disseminated intravascular coagulation status	Fresh-frozen plasma therapy
Hematocrit	Blood transfusion to achieve value >30%-35%
Patent ductus arteriosus flow and pulmonary hypertension	Echocardiography to quantify
Platelet count	Platelet infusion if <50,000/mm <sup>3</sup>
Respiratory status	Surfactant, oxygen, or ventilatory support
Sepsis secondary to necrotizing enterocolitis	Assess volume and hemodynamic status; antibiotic coverage
Volume status	Central venous pressure, blood pressure, urine output

**Table 7. Ventilator Setup for Premies**

Follow a checklist to establish correct ventilator settings:

- Set pressure cycle mode at 20 cm H<sub>2</sub>O
- PEEP may be required
- Check to confirm leaks around the cuff at pressure of 20 cm H<sub>2</sub>O; I:E ratio, 1:2
- Set fresh gas flow to fill bellows quickly (to the tidal volume)
- Set ventilator at appropriate flow rate to empty bellows slowly (peak flow rate)
- Adjust respiratory rate to achieve ET<sub>CO</sub><sub>2</sub> of 28-30 mm Hg (use NICU data)
- Adjust F<sub>IO</sub><sub>2</sub> with air-oxygen mixture to achieve saturation around 94%-95% on the preductal pulse oximeter

ET<sub>CO</sub><sub>2</sub>, end-tidal carbon dioxide concentration; F<sub>IO</sub><sub>2</sub>, fraction of inspired oxygen; I:E, inspiratory/expiratory; NICU, neonatal intensive care unit; PEEP, positive end-expiratory pressure

thermogenesis may occur through glucose metabolism and gluconeogenesis, both leading to hypoglycemia.

### Monitoring

Standard patient monitoring for micropremies, as required by the American Society of Anesthesiologists, consists of electrocardiography, blood pressure monitoring with a neonatal automatic noninvasive device, measurement of the rectal or esophageal temperature, pulse oximetry, and measurement of end-tidal CO<sub>2</sub>. The pulse oximeter should be monitored at 2 sites—a preductal site (right arm or ears) and a postductal site (lower extremities). The preductal pulse oximeter monitors oxygenation of the brain and eyes, so that oxygenation of these vulnerable organs can be optimized.

Monitoring at dual sites provides a backup and allows the anesthesiologist to identify the cause of desaturation. If desaturation results from ventilatory or cardiac dysfunction, both pulse oximeters will reflect a change. If blood flow via the DA increases because of pulmonary hypertension, then saturation according to postductal pulse oximetry may decline to a greater degree. In infants, blood pressure and heart rate are indicators of volume status. Central venous pressure monitoring, if available, is useful to assess volume status. A central venous pressure catheter also provides a route to withdraw blood from the micropremie to monitor the blood sugar, hematocrit, and coagulation profile. With a handheld analyzer, a drop of blood is sufficient to gather blood data. An arterial cannula is useful for monitoring blood pressure and blood gases.

### Respiratory System

A micropremie undergoing surgery requires tracheal intubation and ventilatory support. Often, assisted ventilation is already in place. In a small (2.5 mm) endotracheal tube, resistance to flow is high (inversely proportional to the radius to the fourth power); therefore, the work of breathing is increased. The combination of decreased lung compliance, ventilation-perfusion mismatch, abdominal surgery, and resistance in the narrow endotracheal tube mandates ventilatory support of the patient with or without positive

end-expiratory pressure to maintain adequate oxygenation. During surgery, the small endotracheal tube may become partly occluded by mucous plugs or kinking. Constant vigilance is necessary, and immediate corrective measures are essential.

During positive-pressure ventilation, high airway pressures may cause barotrauma, pneumomediastinum, pneumothorax, or damage to the alveolar endothelial barrier, leading to hypoxemia and sudden cardiovascular collapse. Positive-pressure ventilation has also been implicated as a cause of intraventricular hemorrhage. Therefore, it is prudent to limit airway pressures to less than 20 cm H<sub>2</sub>O, if possible. For infants with poor compliance, higher inflation pressures may be required to achieve adequate oxygenation.

### Anesthetic Circuits and Ventilation

A pediatric circle system is commonly used in most institutions. An adult ventilator with pressure limited mode can be safely used even in neonates, who require small tidal volumes and have very poor lung compliance.<sup>16</sup> The expected tidal volume on the ventilator may not be delivered to the patient for many reasons, including the following: leaks around the endotracheal tube, loss of volume in the circuit (100 mL for the pediatric circle system), and loss of volume for measurement of the end-tidal carbon dioxide (ET<sub>CO</sub><sub>2</sub>) by capnography (150 mL/min).

It is important to observe chest movement to confirm the delivery of adequate tidal volume to the baby. The initial settings on pressure ventilators may be selected based on pressure generated during bag ventilation. Settings on volume ventilators are chosen based on minute ventilation requirements (eg, a rate of about 20 breaths per minute with a tidal volume of about 7 mL/kg; Table 7).

The adequacy of ventilation can be monitored by analyzing arterial blood gases. (Normal values are shown in Table 8.) Capillary or venous blood tends to have a low pH, depending on peripheral perfusion. When a conventional ventilator is used, monitoring of the ET<sub>CO</sub><sub>2</sub> is a valuable, noninvasive method for estimating ventilation—although this method may give inaccurate readings in the presence of lung disease. In a normal, healthy, full-term infant, ideal val-

ues for arterial blood might be the following: pH, 7.4; Pa<sub>CO</sub><sub>2</sub>, 40 mm Hg; Pa<sub>O</sub><sub>2</sub>, 60 mm Hg (Table 8). In a small, preterm infant (<1,000 g), mild hypercapnea may be permitted (Pa<sub>CO</sub><sub>2</sub>, 45-55 mm Hg) to minimize lung injury caused by mechanical ventilation.<sup>17</sup> By contrast, if pulmonary hypertension develops in these preterm infants, hyperventilation to achieve a Pa<sub>CO</sub><sub>2</sub> of less than 28 or 30 mm Hg may be appropriate to attenuate hypoxic pulmonary vasoconstriction.

Oxygen toxicity, among other factors, has been implicated as a possible cause of retinopathy of prematurity in infants younger than 44 weeks of gestational age. The inspired oxygen concentration (F<sub>IO</sub><sub>2</sub>) should be adjusted to obtain a saturation level by preductal pulse oximetry of about 95%.

The appropriateness of initial ventilator support needs to be rapidly confirmed by measuring blood gas values (within 15-20 minutes, if possible) and making adjustments accordingly. Oxygenation can be improved by increasing the F<sub>IO</sub><sub>2</sub> or tidal volume, or by instituting positive end-expiratory pressure. If the level of arterial CO<sub>2</sub> requires adjustment, it may be corrected by increasing the minute ventilation—either by changing the tidal volume or by increasing the pressure setting or the respiratory rate.

### Anesthetic Plan

Anesthetic requirements for this surgery include continued resuscitation, a provision for abdominal relaxation, and careful titration of anesthetic drugs.<sup>3,12</sup> These infants are often so critically ill that they barely tolerate minimal anesthesia. Small doses of ketamine, 0.5 to 2 mg/kg, can be administered every 20 to 30 minutes to micropremies who are hemodynamically unstable. Ketamine can also be given as an infusion at a rate of 50 to 100 mcg/kg per minute.

Morphine causes histamine to be released and may cause a precipitous fall in blood pressure. If the premie is hemodynamically stable, fentanyl at a dose of 2 to 3 mcg/kg can be administered—up to a total dose of 10 to 30 mcg/kg. In premature babies undergoing cardiac surgery, 10 to 30 mcg/kg of fentanyl is commonly administered. As much as 50 mcg/kg of fentanyl is used after hydration with

**Table 8. Blood Gas and Hemodynamic Values**

	Arterial pH	Pao <sub>2</sub> , mm Hg	Paco <sub>2</sub> , mm Hg	Heart Rate, beats/min	Systolic BP, mm Hg
Fetus	7.25	10-25	40-55	–	–
Preterm newborn	7.3	60	38	120-160	50
Term newborn	7.2-7.4	50-75	35-48	100-140	65-95

Note: Normal ranges during the perinatal period are indicated.

10 mL/kg of crystalloids. Hypotension is not usually seen with these high doses if hydration is adequate.<sup>3</sup> In micro-preemies, the elimination half-life is 6 to 32 hours, compared with 2 to 3 hours in children and adults. Postoperative ventilation of the patient is required.

If the condition of the infant improves, small doses of volatile anesthetics can also be administered. Micropreemies delivered before 32 weeks of gestation require a lower dose of anesthetic than premature or full-term infants. Sevoflurane preserves the functioning of baroreceptors and causes less myocardial depression than halothane.<sup>15</sup> Halothane, at 1 minimum alveolar concentration (MAC), decreases the blood pressure by 30% to 50%. Isoflurane, at 1 MAC, decreases the blood pressure by 20% to 30%.<sup>18,19</sup>

The use of nitrous oxide should be avoided because of the frequent presence of gas pockets in the abdomen.

Suitable muscle relaxants include pancuronium (0.1 mg/kg), vecuronium (0.1 mg/kg), and atracurium (0.5 mg/kg).

### Fluid Management

Fluid loss may be extensive. Babies require an isotonic, balanced salt solution for the maintenance of blood pressure and urine output. Hypovolemia is difficult to detect during surgery and usually manifests as hypotension. There may also be other reasons for hypotension (Table 4). Monitoring of the central venous pressure may help in the diagnosis.

The Holiday-Segar formula (4 mL/kg per hour) is used to determine the maintenance fluid requirements. The third-space loss can be 7 mL/kg per hour at a minimum and 30 mL/kg per hour at a maximum. If sepsis develops secondary to peritonitis, the I.V. administration of fluids at 100 mL/kg per hour may be required.<sup>3</sup>

### Blood Replacement

The volume of blood in these patients is approximately 100 to 120 mL/kg. If blood is not adequately replaced, hypotension and desaturation will develop. The amount of intraoperative blood loss should be estimated by observing the surgical field and frequently monitoring the baby's hematocrit. Unlike that in adults and older children, blood replacement in preemies may lead to complications and therefore needs to be carefully planned. In cases of a small amount of blood loss, albumin 5% or crystalloids are used for replacement. The hematocrit should be maintained between 30% and 40%. In selecting the group specificity of the blood, it is important to remember that maternal antibodies are present in the baby's circulation during the neonatal period. The recommended replacement blood

group for such preemies is O Rh-negative.

If the volume of replaced blood is more than 1 to 1.5 times the baby's blood volume, coagulopathy and DIC may develop and will need to be promptly treated. Ideally, to prevent coagulopathy—when 30% of the volume of lost blood is replaced with packed red cells—a coagulation profile should be determined.

If the profile is abnormal, fresh-frozen plasma of the AB group should be administered. However, when the rate of administration of citrated fresh-frozen plasma exceeds 1 mL/kg per minute, resulting hypocalcemia may cause hypotension.<sup>12</sup> The treatment is to administer calcium, 2 to 5 mg/kg.

A rapid infusion of blood at a rate exceeding 2 mL/kg per minute causes hyperkalemia. Hyperkalemia during a massive blood transfusion is reported as a cause of cardiac arrest in pediatric patients.<sup>14</sup> Hyperkalemia is prevented by using fresh packed cells and avoiding whole blood. The potassium level of the fresh packed cells should be measured before transfusion. Irradiated red cells should be avoided because they contain more potassium.<sup>20</sup>

Treatment for hyperkalemia consists of hyperventilation and the administration of calcium, sodium bicarbonate, glucose, and insulin. Bradycardiac arrest develops in most babies with hyperkalemia. If ventricular tachycardia or fibrillation develops, defibrillation (with 2-4 J/kg) and cardiopulmonary resuscitation must be started immediately and continued until normal potassium levels are achieved.

The prevention of hyperkalemia is an easier task than resuscitation of an arrested heart. Hypothermia develops after blood transfusion if the blood is not prewarmed. Therefore, a complex chain of events—DIC, hypocalcemia, hyperkalemia, and hypothermia—can occur with blood transfusion in pediatric patients. Anticipation of these adverse events and prompt corrective measures are needed to avoid severe coagulopathy and hypotension.

### Blood Glucose

Although defined ranges for hypoglycemia are lacking, a blood sugar level below 20 mg/dL in the first 3 days is considered hypoglycemic. Neonates with a blood sugar level below 30 to 40 mg/dL require treatment and observation. The approximate rate of hypoglycemia is 4.4 per 1,000 births, and it occurs particularly in infants of diabetic mothers, low-birth-weight infants, and infants who have sustained intrapartum asphyxia.

When the placental supply of glucose ceases, hepatic glucose production and nutrition from feeding become the primary sources of glucose. These babies have limited glucose reserves, in addition to a sluggish regulatory mecha-

nism for glucose. Hyperinsulinism is common in the neonatal period.<sup>21</sup> If the demand for glucose increases (eg, with hypothermia, delayed feeding, or infection), babies easily become hypoglycemic.

The processes that ensure the availability of glucose and other fuels are collectively described as counterregulation. Preterm babies and babies who are small for gestational age show a restricted counterregulatory response to hypoglycemia.<sup>22</sup> Activation of the autonomic nervous system as a result of hypoglycemia classically causes sweating, trembling, flushing, hypothermia, apnea, and bradycardia. A second group of symptoms is caused by neuroglycopenia and includes weakness, drowsiness, and convulsions. Micropreemies may not manifest all these symptoms. The signs and symptoms of hypoglycemia are difficult to detect in the perioperative period, particularly in an anesthetized preterm baby. Some hypoglycemic infants may be asymptomatic.

A hyperglycemic state is also undesirable because it may cause diuresis and lead to hypovolemia, which has been implicated as a cause of intraventricular hemorrhage. Therefore, blood glucose levels should be monitored frequently with the use of glucose reagent strips. A continuous infusion of 10% glucose at a rate of 4 to 6 mg/kg per minute is administered throughout the perioperative period to maintain the blood sugar level at about 45 to 90 mg/dL.

### Intraventricular Hemorrhage

Hemorrhage in and around the ventricles of the brain is common in premature babies, especially those with a very low birth weight. The exact etiology is not clear, but blood vessels in premature babies are immature and may easily rupture. Fluctuations in cerebral blood flow and volume and cerebral venous pressure have all been implicated. Immature cerebral autoregulation may not be able to constrain the fluctuations in the cerebral circulation. Babies on ventilatory support, and those who become hypovolemic, are susceptible to intraventricular hemorrhage. Maintaining stable hemodynamics and ventilation may minimize such fluctuations.

### Postoperative Management

Micropreemies with NEC are usually septic and have undergone major surgical procedures with massive fluid shifts. Residual levels of anesthetics and opioids may impair respiration. Spells of apnea are frequently seen postoperatively in premature infants after general anesthesia. Therefore, continued ventilatory support in the immediate postoperative period is usually the rational approach.

These babies feel pain and require treatment for it. For adequate pain management, opioids are necessary. In micropremies, the elimination half-life of opioids is prolonged, and their immature respiratory mechanics make them susceptible to respiratory depression. An infusion of fentanyl at 0.5 to 2 mcg/kg per hour (or morphine at 10 mcg/kg per hour) with continued ventilator support for several hours is reasonable.

## Management of the Case Presented

The baby was scheduled for emergency laparotomy. Preoperatively, her trachea was intubated because she required ventilatory support. Dopamine was infused for right-sided heart failure. Platelets and red cells were given to correct thrombocytopenia and anemia. Hypoglycemia was prevented by the administration of 10% glucose.

The pediatric team transported the patient to the OR in a warm incubator. The OR had been warmed to 78°F before the baby's arrival. Monitors (pulse oximetry, blood pressure measurement, electrocardiography, temperature measurement, and end-tidal capnography) were applied, and the endotracheal tube was connected to a pressure-limited ventilator. Anesthesia was induced by titrating doses of fentanyl and sevoflurane in an oxygen-air mixture. The  $FiO_2$  was adjusted to maintain productal oxygen saturation at about 95%. Before the surgical incision was made, a Broviac catheter was inserted via the femoral vein. Intraoperatively, the patient received crystalloids and albumin. The amount of blood lost was estimated at 1 to 2 mL. Two segments of the small bowel and the ascending colon were perforated, and the sigmoid colon was necrotic. The perforated segments of the bowel and the necrotic areas were resected. The procedure lasted approximately 120 minutes.

Postoperatively, the patient was transported in the warm incubator to the neonatal intensive care unit, where monitoring and ventilatory support continued. She received

an infusion of morphine for postoperative pain relief.

## Conclusion

An anesthesiologist may be called on to care for a micro-premie for routine or emergency surgery. Micropremies—babies weighing less than 1,000 g and born around 26 to 30 weeks of gestation—require support, particularly for the heart and lungs, because of their small size and the transitional state of maturation of their organs. Preoperative preparation is essential. The selection of appropriate anesthetics for surgery to avoid cardiovascular collapse is challenging. The micropremie requires even more vigilant intraoperative care than is usually given to neonates and premature babies, particularly in regard to maintaining normal body temperature, blood glucose level, blood volume, and hemoglobin level.

In the perioperative period, factors that may contribute to intraventricular hemorrhage and retinopathy of prematurity are a concern; measures must be taken to avoid or minimize them. In the postoperative period, the treatment of pain and prevention of apnea must be addressed. The management of these babies can demand the utmost of an anesthesiologist's technical and cognitive skills.

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## Post-test

1. **Necrotizing enterocolitis (NEC) is associated with all of the following systemic clinical manifestations, except:**
  - a. septicemia
  - b. disseminated intravascular coagulation
  - c. gastric ulcers
  - d. hypovolemia
2. **Forms of coagulopathy associated with NEC include:**
  - a. hemolytic anemia
  - b. disseminated intravascular coagulation
  - c. thrombocytopenia
  - d. all of the above
3. **The pulmonary function of premature babies is characterized by which of the following:**
  - a. absence of surfactant in the alveoli at 28 weeks of gestation
  - b. ventilation-perfusion mismatch
  - c.  $Pao_2$  significantly higher than 100 mm Hg (room air)
  - d. good lung compliance
4. **Which of the following is a true statement of cardiac function in a premature baby?**
  - a. There is good diastolic function.
  - b. The closure of a patent ductus arteriosus after birth is related solely to arterial levels of  $CO_2$ .
  - c. Pulmonary vascular resistance is less than systemic arterial resistance in the fetal circulation.
  - d. Placental prostaglandins maintain an open ductus arteriosus.

5. **Complications related to blood transfusion in the premie include all of the following, except:**
  - a. hyponatremia
  - b. hyperkalemia
  - c. disseminated intravascular coagulation
  - d. hypothermia
6. **The treatment of pulmonary hypertension in preterm babies includes:**
  - a. permissive hypercarbia
  - b. nitric oxide
  - c. aspirin
  - d. atropine
7. **In preterm babies, hypothermia during anesthesia causes which of the following:**
  - a. hyperkalemia secondary to shivering
  - b. hypercalcemia secondary to hypoglycemia
  - c. an increased need for anesthetics
  - d. pulmonary hypertension

8. **Neonatal hypoglycemia:**
  - a. is defined as a blood glucose level below 50 mg/dL
  - b. is caused by the decreased hepatic production of glucose
  - c. occurs in about 20% of births
  - d. may be relieved by the development of infection and hypothermia
9. **Which of the following is a true statement concerning full-term newborns?**
  - a. The ductus arteriosus closes functionally within a few hours after birth.
  - b. Normal blood pressure is 120/80 mm Hg.
  - c. Blood volume averages 60 mL/kg.
  - d.  $Paco_2$  is 30 mm Hg as a result of hyperventilation.
10. **Intraoperative hypoxemia may be caused by:**
  - a. pulmonary hypertension
  - b. kinking of the endotracheal tube
  - c. hypovolemia
  - d. all of the above