

Evaluation and Management of the Cyanotic Neonate

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The infant presenting to the emergency department with cyanosis requires rapid assessment, diagnosis, and initiation of therapy. In this article, the potential challenges in recognizing cyanosis are discussed, including the presence of higher concentrations of fetal hemoglobin and its oxygen binding characteristics. A systematic approach to the diagnosis of cyanosis is presented, based on an understanding of the normal transitional physiology, and how diseases of the airway, lung, and circulatory system may disrupt these processes. Strategies for initial emergency department management of lung and cardiac disease are presented.

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Cyanosis, derived from the Greek word *kuaneos* meaning dark blue, refers to the bluish discoloration of the skin, nailbeds, or mucous membranes. If cyanosis is limited to the extremities, it is referred to as acrocyanosis or peripheral cyanosis. This is relatively common in young infants and is generally a physiologic finding owing to the large arteriovenous oxygen difference that results during slow flow through peripheral capillary beds. In contrast to acrocyanosis, central cyanosis is present throughout the body and is evident in the mucous membranes and tongue. Central cyanosis indicates the presence of potentially serious and life-threatening disease, and requires immediate evaluation. The clinician will need to rapidly consider respiratory, central nervous system, hematologic, cardiac, and metabolic causes [1].

It is often a challenge to define an optimal PaO_2 in the newborn with mild cyanosis or respiratory distress. The focus should not necessarily be on achieving an exact number, but rather on avoiding tissue hypoxia by providing adequate oxygen transport to the body tissues. Oxygen is carried in the blood in 2 forms. Virtually all of the oxygen content in the blood is that carried by

hemoglobin: each gram of hemoglobin can combine with 1.34 mL of oxygen. In contrast, the amount of oxygen dissolved in the plasma (0.003 mL per 100 mL of plasma) is clinically insignificant. Therefore, the goal should be to achieve adequate hemoglobin saturation and perfusion of the tissues.

While oxygenated hemoglobin is bright red, reduced hemoglobin is dark blue or purple in color and is what produces the dusky or blue color of the skin and mucous membranes. An important concept is that cyanosis is dependent upon the absolute concentration of reduced hemoglobin, rather than on the oxygen saturation or the ratio of reduced hemoglobin to oxyhemoglobin [2]. With careful observation, cyanosis may become apparent when the deoxygenated hemoglobin content is as little as 3 g per 100 mL. Therefore, infants with polycythemia may exhibit cyanosis at relatively high arterial saturations, whereas it is more difficult to discern cyanosis in a severely anemic infant unless the oxygen saturation is extremely low (Table 1). In general, the relatively high hemoglobin of the normal infant tends to facilitate the recognition of cyanosis.

At the same time, the relative concentration of fetal hemoglobin and its unique characteristics of oxygen binding need to be considered, as these factors may impair the recognition of cyanosis. The ratio of fetal to adult hemoglobin varies from infant to infant, and the proportions of each hemoglobin affect the oxygen saturation resulting at any given PaO_2 . Thus, if a baby has mostly adult hemoglobin, central cyanosis (arterial saturation,

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Table 1 Effect of hemoglobin concentration on the recognition of cyanosis.

Hgb (g)	Reduced Hgb (g)	Sao ₂	Total Hgb-reduced Hgb/total Hgb
20	3	85	(20-3)/20
8	3	62	(8-3)/20

These data show the expected levels of saturation for 2 hypothetical babies: one with a normal hemoglobin (20 g/dL) vs one with a low hemoglobin (8 g/dL). Both babies have a fixed reduced hemoglobin level of 3 g. The infant with the hemoglobin of 20 will have a saturation of 85% and may appear cyanotic. However, the severely anemic infant may not appear cyanotic until the saturation is critically low.

75% to 85%) will be observed when the PaO₂ falls below 50 mm Hg. In contrast, if the baby has mostly fetal hemoglobin, central cyanosis may not be observed until the PaO₂ drops well below 40 mm Hg. Thus, infants with a high proportion of fetal hemoglobin may have a serious reduction in oxygenation before cyanosis is clinically apparent (Figure 1).

Normal Cardiopulmonary Adaptation at Birth

At birth, profound changes in the cardiovascular and respiratory systems occur to allow the infant to adapt to air breathing. An understanding of these normal transitional changes is important in evaluating a cyanotic infant, as their disruption is likely to lead to cyanosis [3].

The fetus has a unique circulatory pattern because the placenta, not the lung, serves as the organ of gas exchange. Less than 10% of the cardiac output is circulated through the pulmonary vascular bed, and the placenta, as the organ of gas exchange, receives nearly half of the cardiac output. Pulmonary blood flow remains low owing to elevated pulmonary vascular resistance; pulmonary pressure is equivalent to systemic pressure because of active vasoconstriction. Fetal circulation shunts blood from the right to the left atrium across the foramen ovale and from the pulmonary artery to the descending aorta through the ductus arteriosus providing direct blood flow to the placenta.

The fetal lungs produce fluid that fills the alveoli, bronchi, and trachea. At birth, catecholamines and other hormones that increase during labor cause a rapid switch from net secretion to net absorption of liquid in alveolar spaces. As the lungs fill with air, lung fluid is removed via the trachea and absorption by the pulmonary capillaries and lymphatics. Pulmonary vascular resistance drops dramatically and permits an 8- to 10-fold rise in pulmonary blood flow. Simultaneously, the low vascular resistance bed of the placenta is removed and systemic vascular resistance increases. As pulmonary pressure falls to less than systemic pressure, pulmonary blood flow increases and blood flow through the patent ductus arteriosus reverses direction.

Functional closure of the ductus occurs over the first several hours of life, largely in response to the increased oxygen tension. Left atrial pressure also increases leading to closure of the foramen ovale. These events therefore eliminate the fetal right to left shunts and establish the normal postnatal circulatory pattern of pulmonary and systemic circulations. Within 24 hours after birth, pulmonary artery pressure typically decreases to approximately 50% of mean systemic arterial pressure and continues to drop over the next 2 to 6 weeks until adult values are attained.

The ABCs of Differential Diagnosis in the Cyanotic Infant

Using an airway, breathing, circulation (ABC) algorithm of evaluation will allow the emergency department (ED) practitioner to systematically consider the most common causes of cyanosis in the newborn period (Table 2).

A: Airway-Upper and Lower Airway Disease

Although airway conditions will generally present shortly after birth, these should be considered during the initial evaluation of the infant presenting to the ED with respiratory distress [4]. Choanal atresia occurs in ~1:5000 infants, with unilateral disease being more common. Choanal atresia should be suspected when an infant's distress is more obvious in a quiet state and

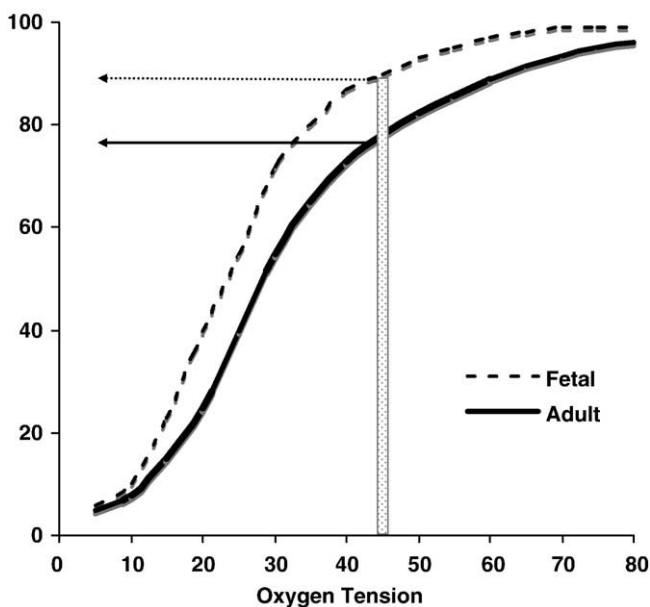


Figure 1 Representation of the different characteristics of oxygen binding in fetal vs adult hemoglobin. For a hypothetical PaO₂ of 45, the saturation of adult hemoglobin would fall below 80%, typically creating a cyanotic appearance. However, the binding characteristics of fetal hemoglobin would allow for the saturation to remain in the mid-80s, which may not be associated with overt cyanosis.

Table 2 Causes of cyanosis.

A	B	C
Airway	Breathing	Circulation
Choanal atresia	Pneumonia	Oxygen carrying capacity
Micrognathia	Congenital diaphragmatic hernia	Polycythemia
Pierre Robin sequence	Congenital cystic adenomatoid malformation	Anemia
Laryngomalacia	Pulmonary sequestration	Methemoglobinemia
Vocal cord paralysis	Congenital lobar emphysema	Congenital heart disease
Tracheal stenosis	Pulmonary hypoplasia	<i>Decreased pulmonary blood flow</i>
Vascular slings/rings	Phrenic nerve palsy	Tricuspid atresia
Cystic hygroma	Hypoventilation	Pulmonary atresia
Hemangioma		Pulmonary stenosis
Other neck masses		Tetralogy of Fallot
		Ebstein's anomaly
		<i>Inadequate mixing</i>
		Transposition of the great arteries
		Persistent pulmonary hypertension

improves during crying. It can be confirmed by the inability to pass a suction catheter through the nares into the oropharynx, as well as via medical imaging, with computed tomography scanning currently serving as the radiographic procedure of choice. Placement of an oral airway should provide immediate improvement. Other associated anomalies are very common; in particular, CHARGE sequence (coloboma, heart disease, atresia of choana, retarded growth and development, genitourinary anomalies, ear/hearing anomalies) should be considered.

Micrognathia, retrognathia, or the Pierre Robin sequence generally presents early in life and will be obvious on physical examination. The airway obstruction from the posterior tongue is more pronounced in the supine position. When present, a cleft palate does not cause respiratory distress unless feeding difficulties are severe. These infants may require tracheostomy for several years until the mandible grows enough to maintain the tongue in a more anterior position.

Laryngomalacia is a congenital abnormality of the larynx and is the most common cause of inspiratory stridor in infants. Although it may be noted immediately after birth, it commonly presents at several weeks of age. Airway symptoms typically worsen with crying, feeding, and respiratory infections. Gastroesophageal reflux is a common association. Subglottic stenosis may occur as a congenital malformation or be acquired after prior airway manipulation. Infants present with stridor, respiratory distress, or obstructive apnea.

Vocal cord paralysis may be associated with birth or surgical trauma and is another common cause of stridor in the newborn. It is typically unilateral, causing a hoarse cry and minimal respiratory symptoms. In contrast, bilateral vocal cord paralysis can cause severe respiratory distress, and a tracheostomy may be required. In these cases, central nervous system anomalies such as the Arnold-Chiari malformation should be considered.

Other conditions may cause intrinsic or extrinsic compression of the trachea. Tracheal stenosis is characterized by expiratory stridor, respiratory distress, wheezing, or persistent cough. Symptoms typically worsen after an upper airway infection. The diagnosis is confirmed by direct bronchoscopic visualization. Tracheal stenosis is often associated with complete tracheal rings, which may require extensive surgical repair in case of multiple rings or long segment stenosis. A number of conditions may produce extrinsic airway compression. Vascular rings and slings caused by abnormal development of mediastinal vessels can compress or deviate the trachea causing airway obstruction. An anomalous distal origin of the innominate artery from the aortic arch is the most common cause, but other anomalies include double aortic arch or an aberrant right subclavian artery. Specialized cardiac computed tomography or magnetic resonance imaging studies are helpful in accurately defining the anatomy. Neck or mediastinal masses such as teratomas and cystic hygromas represent large lesions that can cause extrinsic compression of the trachea; these are typically associated with visible neck masses. Subglottic hemangiomas should be considered in infants that have skin hemangiomas. As hemangiomas typically increase in size over the first 6 to 12 months of life, symptoms often emerge after an initially benign history.

B: Breathing—Lung Disease

Neonatal pneumonia is most commonly acquired at the time of birth and usually causes diffuse rather than lobar infiltrates. The initial radiograph is frequently indistinguishable from the ground glass appearance of respiratory distress syndrome, although pleural effusions are more characteristic of pneumonia. Bacterial pneumonia is most common, and frequent pathogens include group B β -hemolytic streptococci and Gram-negative

enteric bacilli (*Escherichia coli*, *Klebsiella*, *Enterobacter*). Important elements of the maternal history will include colonization with group B β -hemolytic streptococci with or without adequate intrapartum prophylaxis (>2 doses of penicillin before delivery), as well as a history of prolonged rupture of membranes (>18 hours), or a history of maternal fever or chorioamnionitis. Herpes simplex and cytomegalovirus are viral causes of neonatal pneumonia, but typically present as components of disseminated infections. Congenital chlamydia infections can cause pneumonia that presents between 2 and 8 weeks of age, typically with upper respiratory symptoms associated with a cough and apnea.

Congenital lung abnormalities are rare but important causes of respiratory distress in the newborn [4]. In many cases, infants are initially asymptomatic, with respiratory distress developing over time. Careful review of the chest x-ray should reveal these lesions. Congenital diaphragmatic hernia is a relatively common birth defect, but because of its frequent association with significant pulmonary hypoplasia and significant pulmonary hypertension, it almost always presents shortly after birth. Congenital cystic adenomatoid malformations are extremely rare lung abnormalities composed of cystic lung tissue with communication to the bronchial tree. Medical imaging will help to differentiate this lesion from a congenital diaphragmatic hernia. Pulmonary sequestration is a rare condition characterized by nonfunctioning primitive lung tissue that does not communicate with the tracheobronchial tree and receives vascular supply from the systemic circulation (thoracic or abdominal aorta). Sequestrations may occasionally present in the neonatal period with signs of congestive heart failure owing to the “run-off” circulation, but more commonly present later in life with recurrent infections. Congenital lobar emphysema is an overinflated, hyperplastic area of the lung surrounded by otherwise normal lung tissue. These are most common in the upper lobes. Symptoms are typically progressive, but may be rarely present at birth. Surgical excision is usually curative, although overinflation of remaining lung areas can occur.

It is important to remember that respiratory failure and cyanosis may occur secondary to other organ system dysfunction. For instance, birth injury associated with neurologic depression or hypoxic-ischemic encephalopathy is commonly associated with hypoventilation. Phrenic nerve injury may cause diaphragmatic paresis. In addition, excessive oral secretions and inadequate swallowing may obstruct the airway and cause respiratory distress. Hypoglycemia may cause central nervous system depression and secondary respiratory distress; this is most commonly seen in small-for-gestational-age infants, large-for-gestational-age infants, infants of diabetic mothers, birth asphyxia, or in rare cases due to primary hyperinsulinism (eg, nesidioblastosis or Beck-with-Wiedemann syndrome). Abdominal distension may

compress the thorax and interfere with normal respiration. This may be seen as a result of gastrointestinal pathology (obstruction) or large intra-abdominal mass effect (renal/genitourinary masses, severe ascites). Finally, late preterm (34 - 37 weeks gestation) or even term infants may present with apneic episodes as a cause of cyanosis.

C: Circulation—Cardiac and Circulatory Causes

The hemoglobin circulating in the vasculature plays an important role in oxygenation. Both high and low levels of hemoglobin may lead to cyanosis, although for different reasons. Polycythemia can cause pulmonary hypertension owing to increased viscosity of the blood interfering with pulmonary perfusion. This may be seen in infants of diabetic mothers, delayed clamping of the umbilical cord, chronic fetal hypoxia (eg, placental insufficiency, preeclampsia); in recipient twins of a twin-to-twin transfusion syndrome; and in conditions such as trisomy 21. Conversely, severe anemia can cause respiratory distress because inadequate oxygen delivery to tissues can lead to cellular hypoxia. Anemia may be due to hemolytic disease of the newborn, fetal blood loss due to external hemorrhage (placental abruption, umbilical cord rupture), or fetal-maternal hemorrhage, or may be seen in donor twins in twin-to-twin transfusion syndrome.

Abnormalities of the hemoglobin molecule itself may interfere with the normal chemical combination of hemoglobin with oxygen. The most common cause is methemoglobinemia, which results from the oxidation of hemoglobin molecules from the normal ferrous to ferric state. Infants are more susceptible as fetal hemoglobin is more easily oxidized than is adult hemoglobin, and because levels of methemoglobin reductase are relatively low in infants. Methemoglobinemia may result from exposure to oxidants (eg, nitrites, sulfonamides, prilocaine, metoclopropamide) or rarely from congenital deficiency of methemoglobin reductase. The characteristic clinical scenario is a blue-gray-appearing infant without respiratory distress who has decreased oxygen saturation, but normal arterial oxygen tension.

Severe cyanosis is a prominent feature in congenital heart disease associated with diminished pulmonary blood flow or in babies with separate circulations and poor mixing [5]. Diminished pulmonary blood flow is characteristic of tricuspid atresia, pulmonary atresia, pulmonary stenosis, tetralogy of Fallot (TOF), and Ebstein's anomaly. Tetralogy of Fallot represents approximately 10% of cases of congenital heart disease and is one of the most common cyanotic congenital heart lesions presenting in the newborn period. The pulmonary outflow stenosis in TOF tends to be progressive, meaning that clinically significant cyanosis

is present at birth in approximately 25% of infants, but 75% become cyanotic by 1 year of age. In all of these conditions, pulmonary blood flow will initially be dependent on blood directed to the lungs through a patent ductus arteriosus. Therefore, cyanosis worsens at the time of ductal closure and tends to improve rapidly after the ductus is reopened after initiation of prostaglandin E₁ (PGE₁).

Transposition of the great arteries (TGA) is another relatively common congenital heart lesion that presents with severe cyanosis. The systemic and pulmonary circulations are normally in series with each other, but in complete transposition, the circulations are in parallel. Therefore, deoxygenated systemic venous blood returns to the right atrium, enters the right ventricle, and exits through the aorta. Infants with TGA are dependent on communications between these 2 circuits for mixing. If the ventricular septum is intact, life-threatening cyanosis will develop when the foramen ovale and ductus arteriosus close in the hours or days after birth. Although a patent ductus arteriosus will improve atrial mixing to a variable degree, adequate inter-atrial communication is what allows for adequate mixing and oxygenation. Infants with a large ventricular septal defect may present to the ED after the first few days of life because there is more potential for mixing even as other shunts close.

Cardiac disease associated with complete mixing may be associated with a variable degree of cyanosis. Examples include truncus arteriosus and total anomalous pulmonary venous return, lesions which are characterized by pulmonary overcirculation. Because pulmonary blood flow is normal to increased, cyanosis is usually not as significant and does not respond to PGE₁. In fact, measures that increase pulmonary blood flow (PGE₁, supplemental oxygen) should be avoided as they may worsen pulmonary overcirculation and thus decrease systemic blood flow. In rare cases, total anomalous pulmonary venous return may be associated with obstruction, which leads to decreased pulmonary blood flow and severe cyanosis.

Persistent pulmonary hypertension of the newborn (PPHN) describes the failure of the normal circulatory transition that occurs after birth [3]. It is characterized by marked pulmonary hypertension that causes hypoxemia and right-to-left extrapulmonary shunting of blood through fetal channels (foramen ovale and ductus arteriosus). The combination of inadequate pulmonary perfusion and extrapulmonary shunting leads to refractory hypoxemia. Persistent pulmonary hypertension often complicates parenchymal lung disease in newborn infants, because pulmonary vessels readily constrict in response to alveolar hypoxia. However, PPHN can also occur idiosyncratically in the absence of underlying parenchymal disease. In these cases, the syndrome is believed to be the result of an abnormally remodeled vasculature that develops in utero in response to prolonged fetal stress, hypoxia, and/or pulmonary hypertension. PPHN is

commonly associated with lung hypoplasia, as seen in congenital diaphragmatic hernia.

Initial Evaluation

The evaluation should systematically assess the infant for airway, pulmonary, and circulatory causes as described above. The history should include an assessment of the pregnancy, labor, and newborn risk factors. A history of maternal diabetes increases the risk of congenital heart disease, as well as polycythemia and hypoglycemia, which may be associated with lethargy and hypoventilation. The presence of oligohydramnios may suggest renal abnormalities associated with hypoplastic lungs, whereas polyhydramnios may suggest airway, esophageal, or neurologic abnormalities. Screening results for cervical colonization of group B streptococcus should be sought, although it is important to realize that infection is possible even if the antenatal culture was negative. Prolonged rupture of membranes may suggest bacterial infection, and a history of a difficult delivery may result in intracranial hemorrhage or phrenic nerve paralysis.

The physical examination should be performed when the infant is appropriately warmed and quieted. The growth characteristics should be noted, as infants who are small or large for gestational age are more prone to polycythemia. The primary focus will be on determining the degree of respiratory distress, as its absence will suggest the presence of congenital heart disease or methemoglobinemia. Respiratory insufficiency due to pulmonary disease is typically characterized by rapid respirations accompanied by retractions and nasal flaring. Neurologic conditions are potential causes of cyanosis because of hypoventilation and may be associated with slow or irregular respirations. It is also important to evaluate the infant's tone and activity, and to assess the infant for periodic breathing and/or apneic spells. The examination may reveal findings of birth trauma, such as an Erb's palsy or stridulous cry.

The cardiac exam should include an assessment of the infant's heart rate, peripheral pulses, and perfusion. Auscultation of the heart should focus on the second heart sound, which will be loud and single (or narrowly split) in pulmonary hypertension, as well as in transposition and pulmonary atresia. The auscultation of heart murmurs is often not helpful: serious lesions such as transposition are not associated with murmurs, and loud murmurs are frequently due to a relatively benign lesion such as a small ventricular septal defect. A notable exception is that a harsh ejection murmur is characteristic of pulmonary stenosis.

As noted above, the oxygen saturation is the percent of hemoglobin that is chemically combined with oxygen, which represents the vast majority of oxygen content in the blood. Pulse oximetry provides excellent noninvasive and continuous assessment of oxygen saturation. New

generation pulse oximeters appear to improve performance during low perfusion states. It is often useful to obtain simultaneous measurements from the right hand and a foot to determine flow patterns through the ductus arteriosus. As the left subclavian artery may have a preductal or postductal origin from the aorta, it is best not to use the left hand for pulse oximetry monitoring. Although measurement of arterial blood gas oxygen tension is standard practice, the pain of an arterial puncture may produce agitation and changes in ventilation and oxygenation. A venous blood gas may be useful for the assessment of pH and PaCO₂, but should not be used to determine oxygenation. In either case, the presence of a significant metabolic acidosis may indicate cardiac failure, sepsis, asphyxia, or metabolic disorders. Many microsampling blood-gas analyzers now include lactate in their measured parameters, providing additional useful information about global perfusion and oxygenation.

A chest radiograph is an integral part of the initial assessment of the cyanotic newborn. The locations of stomach, liver, and heart should be determined to rule out dextrocardia and situs inversus. Examining the lung fields may reveal parenchymal lung disease (remembering that the newborn with pneumonia typically has diffuse rather than focal infiltrates) or lung abnormalities such as cystic adenomatoid malformation. Elevation of either hemidiaphragm by more than 2 intercostal spaces relative to the opposite side suggests diaphragmatic paralysis due to phrenic nerve injury. Hyperinflated lung fields are seen occasionally in lobar emphysema or cystic lesions of the

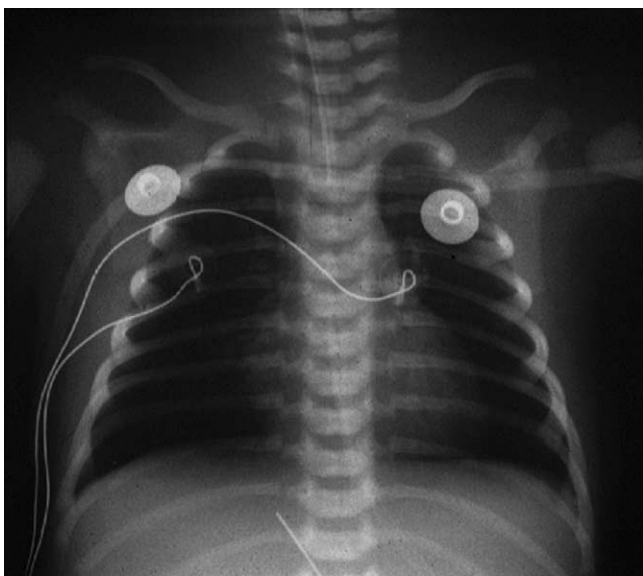


Figure 2 Chest x-ray of an infant with idiopathic persistent pulmonary hypertension. Note the clear lung fields with decreased vascularity. Similarly, oligemic lung fields would also be expected in conditions with low pulmonary blood flow, such as pulmonary atresia.

lungs. Decreased pulmonary vascular markings are characteristic of pulmonary stenosis or pulmonary atresia with inadequate ductal shunting and may be seen in infants with idiopathic persistent pulmonary hypertension of the newborn (Figure 2). The size and shape of the heart may yield some clues to the diagnosis: for instance, the “boot shape” heart of TOF, and the “egg on string” appearance of transposition, and the characteristic massive cardiomegaly of Ebstein's anomaly.

An electrocardiogram is useful for the diagnosis of cardiac arrhythmias. However, normal newborns have a predominance of right-sided forces, and moderate right ventricular hypertrophy is a common finding with many types of respiratory and cardiac disease. Therefore, the electrocardiogram is seldom helpful in the evaluation of the infant with congenital heart disease and is often completely normal even in infants with serious disease such as transposition. A notable exception would be the infant with left axis deviation due to left ventricular hypertrophy, which would strongly suggest tricuspid atresia.

Some advocate for the hyperoxia test as a clinical tool to differentiate between pulmonary and cardiac disease in cyanotic infants. The test is based on the principle that in the absence of fixed cardiac shunts, 100% oxygen will increase alveolar PO₂, leading to an increase in pulmonary venous and systemic arterial PO₂. In cyanotic congenital heart disease (eg, decreased pulmonary blood flow or TGA), little or no rise in PaO₂ would be expected after breathing 100% O₂. However, the same finding may occur in infants with significant pulmonary hypertension if significant right-to-left shunting persists through extrapulmonary shunts (ductus arteriosus and foramen ovale). Given the wide availability of echocardiography, the hyperoxia test should rarely (if ever) be necessary and should only be considered after discussion with a cardiologist.

Initial Management in the Emergency Department

Severe cyanosis requires urgent supportive therapy while a diagnosis is established. This will include intravenous fluids and withholding of enteral feedings. The infant should be maintained in a thermoneutral environment using a radiant warmer. Hypoglycemia is common in critically ill infants, therefore glucose levels should be monitored and glucose infusions provided to maintain a blood glucose of greater than 55 mg/dL. An airway and assisted ventilation should be considered for infants with respiratory distress, but may be deferred for the comfortable infant. Severe acidosis should be corrected with infusions of sodium bicarbonate, but only after adequate gas exchange has been established. If the infant is less than 10 days old and the umbilical stump is still attached, umbilical venous and arterial lines can frequently be placed

by experienced practitioners for rapid central access. Hypocalcemia is often associated with cardiac disease and critical illness, and should be corrected based on the ionized calcium.

Oxygen should be provided, although there are increasing concerns about the potential risks associated with this therapy [6]. Even brief (30-minute) exposures to extreme hyperoxia are increasingly recognized to increase oxidative stress and potentially damage lung parenchymal and vascular function, even in term infants [7,8]. Therefore, the use of 100% O₂ should generally be avoided at the outset. Initiating oxygen therapy with 40% to 60% O₂ will allow the caregiver to provide support, assess for improvement, and seek advice from a cardiologist. This point is particularly important if an infant has only a minimal response to oxygen, as this may indicate potential cardiac disease and need for PGE₁. In addition, it is important to remember that oxygen may promote ductal closure. This may not be a major concern for lesions that limit pulmonary blood flow, as the pulmonary venous PO₂ would not be expected to rise. However, admixture lesions such as hypoplastic left heart syndrome may present with moderate cyanosis. These conditions are dependent on a patent ductus to maintain systemic blood flow. Oxygen may not only promote ductal closure, but may increase pulmonary and decrease systemic blood flow.

In the infant who does not require assisted ventilation, oxygen may be delivered via a head hood or nasal cannula [9]. A head hood is the only method that allows the FiO₂ to be determined precisely. The oxygen concentration should be measured by an oxygen analyzer placed near the baby's mouth. Relatively high flows are needed to achieve adequate concentrations of oxygen and avoid carbon dioxide accumulation, although humidification is generally not necessary. Although head box oxygen is generally well tolerated, this method limits the infant's mobility, and oxygen concentrations fall quickly when the hood is lifted to provide care to the infant. Therefore, this method is typically not used when prolonged oxygen treatment is required.

Oxygen is frequently delivered by a nasal cannula. The disadvantage of this method is that the infant entrains variable amounts of room air around the nasal cannula. Therefore, it cannot provide 100% oxygen, and the oxygen concentration in the hypopharynx (a good proxy for the tracheal concentration) will be much lower than the concentration of oxygen at the cannula inlet. Both the oxygen concentration and the cannula flow rate will be the major factors that will determine the fraction of oxygen actually delivered. Therefore, it is generally better to titrate delivery to achieve the desired oxygen saturation levels, generally 90% to 95% by pulse oximetry.

Prostaglandin E₁ is clinically effective for infants dependent on ductal patency to maintain pulmonary blood flow or sufficient mixing. It is given intravenously by constant infusion, and the initial dose is typically 0.05 µg/kg per minute. Apnea is a common side effect after initiation of PGE₁, and some recommend intubation if the infant will require transport shortly after beginning the infusion. Other common side effects include flushing and diarrhea. There are no absolute contraindications to beginning prostaglandin, although it may worsen the pulmonary edema associated with obstructed total anomalous pulmonary venous return.

Summary

The infant presenting to the ED with cyanosis requires urgent assessment, diagnosis, and initiation of therapy. A systematic, rational approach to the diagnosis of neonatal cyanosis is essential. An understanding of the normal transitional physiology, and how diseases of the airway, lung, and circulatory system may disrupt these processes, will enable the ED practitioner to determine whether the underlying cause is related to airway obstruction, parenchymal disease, hypoventilation due to central nervous system disease or apnea, or due to cardiac disease. Management is based on the clinical diagnosis and attention to hemodynamic stability, judicious oxygen administration, and referral to the appropriate inpatient hospital setting. Although prognosis depends on the diagnosis, it is generally good with prompt recognition and intervention.

References

1. Sasidharan P. An approach to diagnosis and management of cyanosis and tachypnea in term infants. *Pediatr Clin North Am* 2004;51:999-1021.
2. Lees MH. Cyanosis of the newborn infant. Recognition and clinical evaluation. *J Pediatr* 1970;77:484-98.
3. Farrow KN, Fliman P, Steinhorn RH. The diseases treated with ECMO: focus on PPHN. *Semin Perinatol* 2005;29:8-14.
4. Porta NF. Respiratory disorders of the newborn. In: Green T, Franklin W, Tanz R, editors. *Pediatrics: Just the Facts*. New York: McGraw-Hill; 2005. p. 99-108.
5. Zahka K, Lane J. Approach to the neonate with cardiovascular disease. In: Martin RJ, Fanaroff A, Walsh MC, editors. *Fanaroff and Martin's Neonatal-Perinatal Medicine*. 8th ed. Philadelphia, PA: Mosby; 2005. p. 1112-20.
6. Saugstad OD, Ramji S, Vento M. Oxygen for newborn resuscitation: How much is enough? *Pediatrics* 2006;118:789-92.
7. Lakshminrusimha S, Russell JA, Steinhorn RH, et al. Pulmonary arterial contractility in neonatal lambs increases with 100% oxygen resuscitation. *Pediatr Res* 2006;59:137-41.
8. Lakshminrusimha S, Russell JA, Steinhorn RH, et al. Pulmonary hemodynamics in neonatal lambs resuscitated with 21%, 50%, and 100% oxygen. *Pediatr Res* 2007;62:313-8.
9. Frey B, Shann F. Oxygen administration in infants. *Arch Dis Child Fetal Neonatal Ed* 2003;88:F84-8.