CHAPTER **2A**

Lung Pathology: Respiratory Distress Syndrome and Its Complications

CONTENT AND OBJECTIVES

Objectives:

1. List the four characteristics of respiratory distress syndrome (RDS) seen on an x-ray film.
2. Discuss the differential diagnosis of RDS.
3. Explain how the pathology of bronchopulmonary dysplasia causes the changes seen on the neonate's x-ray.
4. Discuss the common causes of pneumothorax, pneumomediastinum, and pneumopericardium.
5. Describe the x-ray findings of an infant with a pneumothorax.

2A

Lung Pathology:
Respiratory Distress Syndrome
and Its Complications

EDITOR

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Chest X-Ray Findings in Respiratory Distress Syndrome

Respiratory distress syndrome (RDS), or hyaline membrane disease (HMD), is the most common cause of respiratory distress in the premature neonate. The radiographic appearance of the lungs of neonates with RDS is distinctive and characteristic. Most neonates with this disorder demonstrate clinical findings of respiratory distress in the delivery room or during the first few hours of life. Neonates with severe disease usually present with both early clinical findings and x-ray changes indicating diffuse atelectasis. The appearance of the chest x-ray varies depending upon the grade and severity of the disease; the ventilatory support applied; the use of exogenous surfactant therapy; and other complications of prematurity, such as a patent ductus arteriosus. It is important to remember that RDS is normally a diffuse, bilaterally occurring disease, with both lung fields having a similar appearance. Pneumonia, which may mimic the x-ray picture of RDS, can occasionally be differentiated from it by the lack of a symmetrical appearance of the lung fields.

X-RAY PRESENTATION

The four characteristic features of the x-ray presentation in RDS are:
1. Reduced lung volume
2. Air bronchograms
3. Reticulogranularity
4. Increased lung opacification

Reduced Lung Volume

Atelectasis occurs because of a lack of surfactant activity or availability; as a consequence, chest expansion is reduced. This reduction in lung volume is most obvious in neonates who are not receiving continuous positive airway pressure or mechanical ventilation and who have not received exogenous surfactant. On x-ray, the diaphragms are high and sometimes domed, and the intercostal spaces are narrow. Lung expansion may be only to the fifth, sixth, or seventh thoracic vertebra rather than to the eighth or ninth, as found in the normally expanded chest.

Air Bronchograms

Air bronchograms (Figure 2A-1) are the outlines of air-filled secondary and tertiary bronchi seen over abnormal lung fields. Air bronchograms are usually visible only over the heart because it is of water density; on x-ray, air-filled bronchi are visible against a background of greater density. Because normally expanded lungs are of air density and the overlying bronchi are also of air density, air bronchograms are not seen in the lung fields on a normal chest x-ray. When atelectasis occurs with RDS, the lung density becomes water/tissue density, and lucent air is seen outlining the peripheral bronchi over the more opaque lung. With severe atelectasis, air in the lung is greatly reduced, leading to loss of the air bronchogram sign and more diffusely opaque lung fields.

Reticulogranularity

A reticulogranular pattern, or ground glass appearance, uniformly distributed throughout both lung fields is characteristic of RDS. Because of surfactant deficiency, alveoli

FIGURE 2A-1 ■ Air bronchograms extending into the lung fields are visible.

FIGURE 2A-2 ■ A fine reticulogranular pattern is present, and air bronchograms are apparent near the diaphragm.
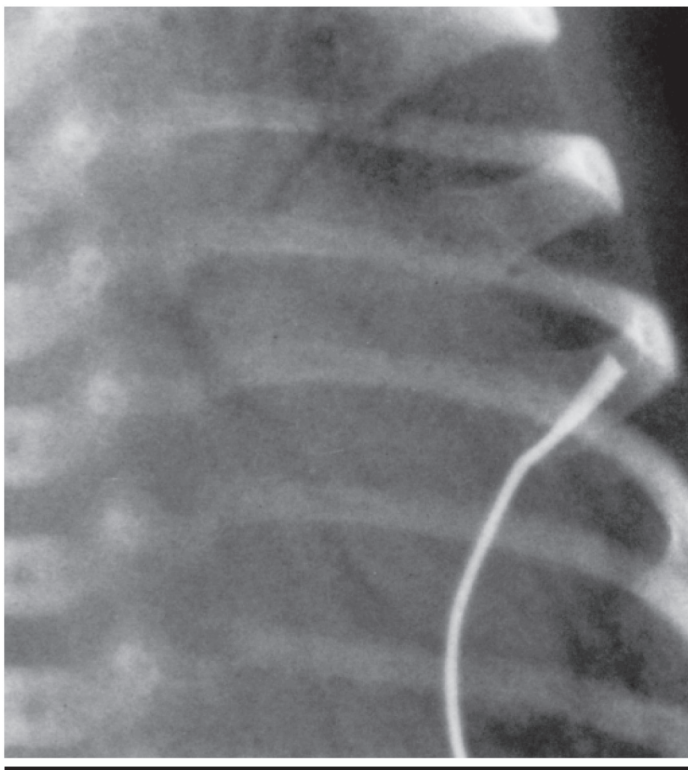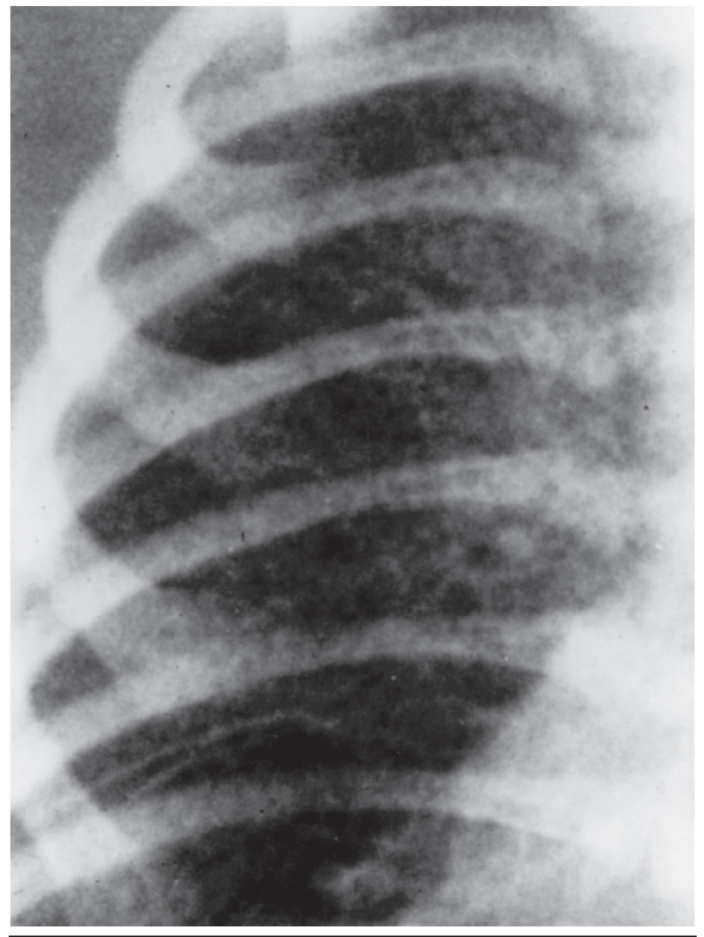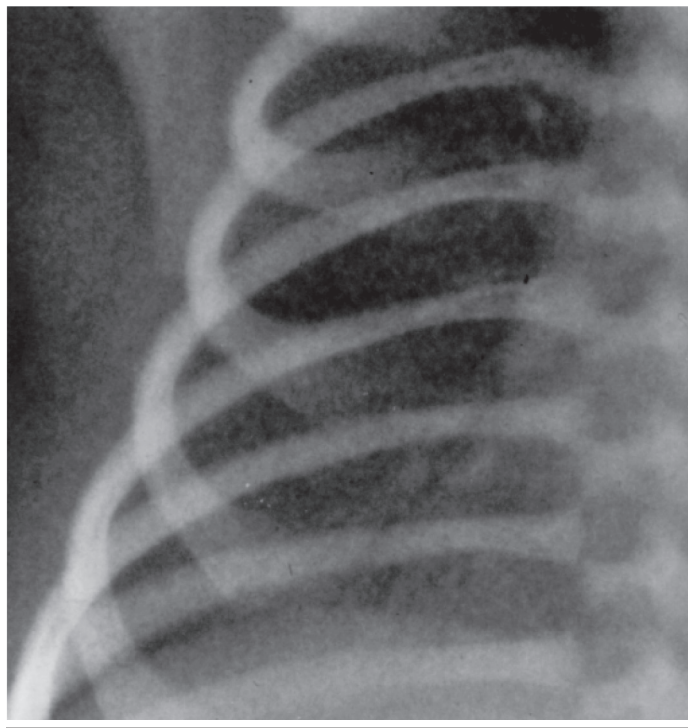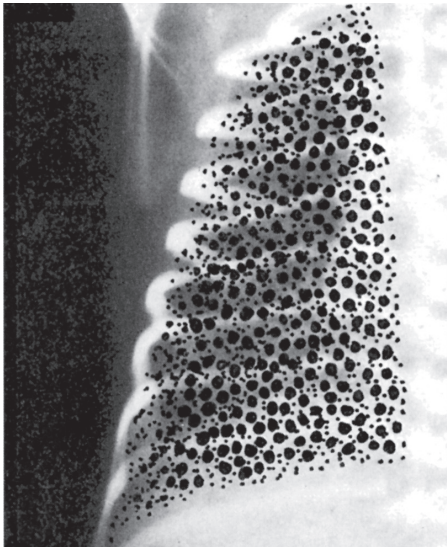

FIGURE 2A-3 ■ Rounded spherical lucencies of the Type I bubble can be seen, as well as air bronchograms.

throughout the lung have high surface tension, and some are collapsed. The alveoli that remain distended have lower surface tension; air that enters the lung will go to the area of lowest pressure, that is, the partially distended alveoli. The atelectatic alveoli have high surface tension, requiring high opening pressures. When inspiration occurs, the terminal airways (ducts leading to the alveoli and the terminal bronchioles) distend because they are more elastic than the collapsed alveoli. The expanded alveoli and terminal airways against a background of atelectasis appear on x-ray as a fine reticulogranular pattern (Figure 2A-2).

A more distinct granular or bubble pattern may be seen in neonates with RDS. Fine spherical bubbles of 1 to 2 mm in diameter have been designated Type I bubbles consistent with respiratory distress syndrome (Figures 2A-3 and 2A-4).[1] These bubbles are seen bilaterally and represent a stage of lung disease in which there is widespread alveolar collapse. Inspiration results in overdistention of the terminal airways, bronchioles, and alveolar ducts rather than of the more high-pressure alveolar units. This x-ray appearance is usually

From: Swischuk LE. 1977. Bubbles in hyaline membrane disease: Differentiation of three types. *Radiology* 122(2): 417. Reprinted by permission.

FIGURE 2A-5 ■ Diagrammatic representation of Type II bubble demonstrating air in the interstitium radiating out from the hilus of the lung.
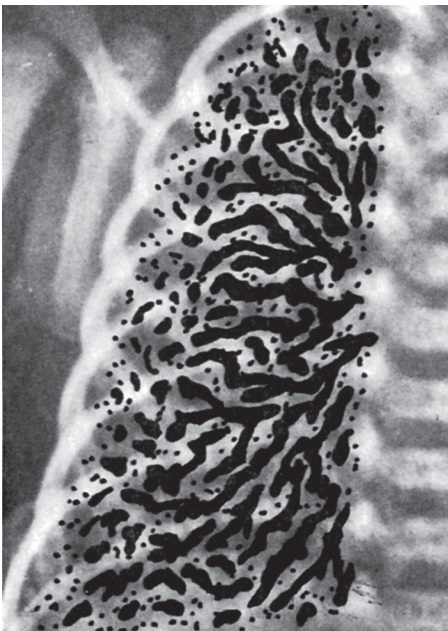
From: Swischuk LE. 1977. Bubbles in hyaline membrane disease: Differentiation of three types. *Radiology* 122(2): 417. Reprinted by permission.

seen in the ventilated neonate, but has also been seen in larger neonates with RDS who are not receiving mechanical ventilation.

It is theorized that spontaneous respiration with grunting leads to increased intraluminal pressure during exhalation, resulting in distended airways in these neonates. As atelectasis increases and ventilation is more impaired in these nonventilated neonates, this pattern may be replaced by more diffuse opacity. The Type I bubble is also frequently seen soon after the institution of mechanical ventilation or continuous positive airway pressure. In these neonates, surfactant activity or availability is diminished, the pressure within the alveoli is high, atelectasis is widespread, and the addition of positive pressure ventilation leads to distention of the more elastic terminal bronchioles and alveolar ducts rather than distention of the alveoli themselves. In these neonates, the prior x-ray picture may have been one of greater opacity; the appearance of the Type I bubble pattern may give the impression of clearing. However, this is referred to as "pseudoclearing," because, although the x-ray does look less opaque, gas exchange at the alveolar unit has not improved, and the blood gas and clinical picture remain unchanged.

The Type I bubble must be discriminated from the bubble of interstitial emphysema, the Type II bubble. The appearance of the bubble of interstitial emphysema is nodular and wormy, rather than smoothly spherical, in most cases. Also the Type II bubble is often first seen unilaterally in the hilar region radiating outward (Figures 2A-5 and 2A-6).

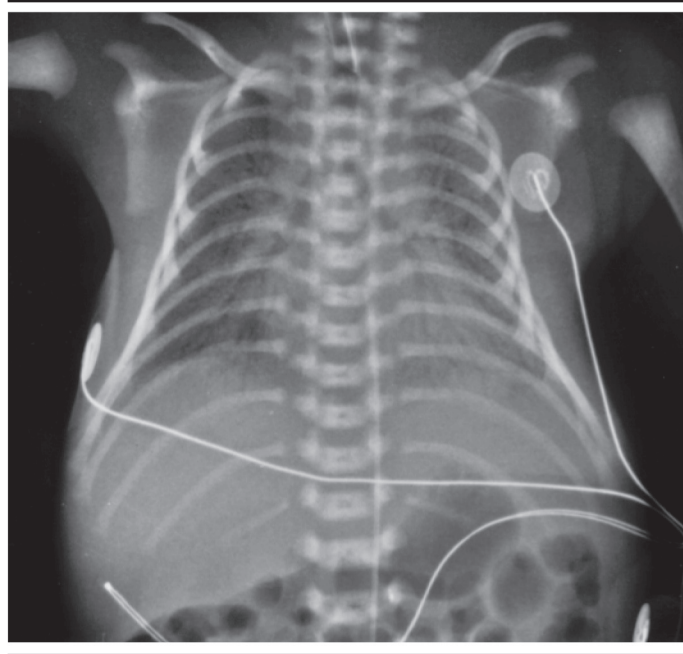FIGURE 2A-6 ■ The Type II bubble of pulmonary interstitial emphysema.

FIGURE 2A-7 ■ The chest x-ray of this neonate with RDS shows a reticulogranular pattern with air bronchograms.

There is increasing opacity in this film compared with previous films, and the heart borders are beginning to become less distinct.
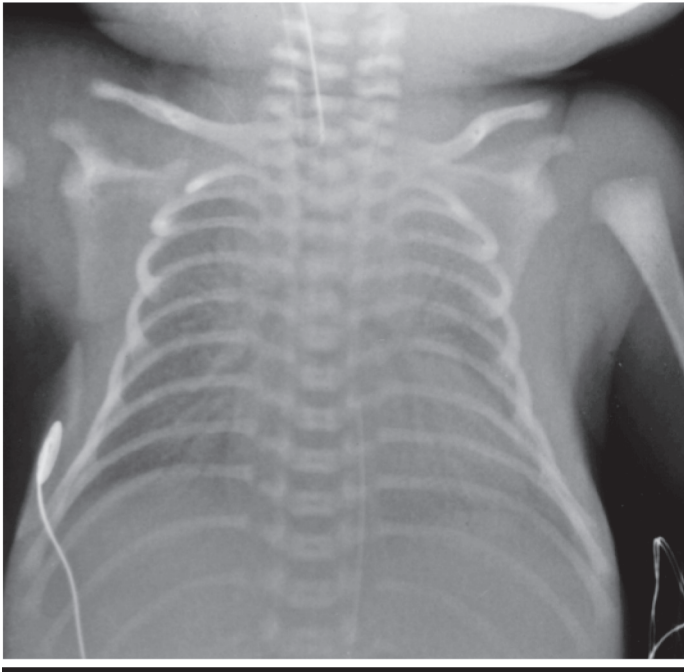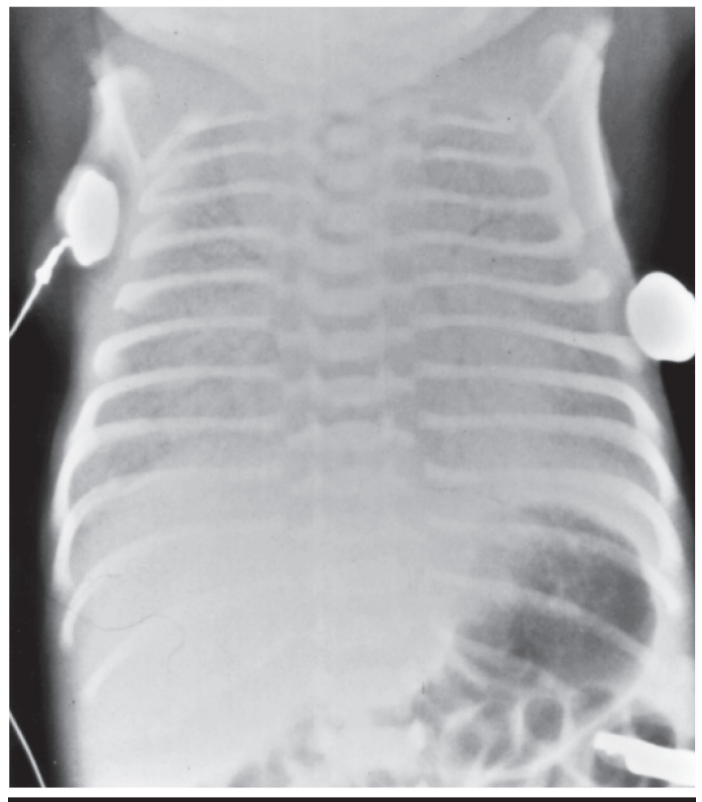

FIGURE 2A-8 ■ Diffuse opacification with loss of distinct heart borders.

Increased Lung Opacification

When diffuse opacification becomes apparent in the chest x-ray of the neonate with RDS, it is usually as a result of nonexpanded alveoli with little or no terminal airway aeration. Initially, the heart borders may be visible, but the x-ray may progress to complete loss of visualization of the heart borders or a "whiteout" (Figures 2A-7 and 2A-8).

Successive chest x-rays may gradually grow more opaque, preceded by a granular chest x-ray, but in some instances, the first x-ray may display this opaque appearance in the neonate with severe disease. Another cause of increasingly opaque lungs on chest x-ray may be pulmonary edema resulting from left-to-right shunting across the ductus arteriosus. Clinical evaluation for signs of a patent ductus arteriosus should be carried out when this chest x-ray picture is seen. Pulmonary edema may also occur secondary to "leaky capillaries," with increased capillary permeability leading to fluid leak into the alveolar spaces. As the alveoli fill with fluid, their appearance on the chest x-ray becomes more opaque. It has been suggested that the lung volumes of neonates with pulmonary edema will be greater than those of neonates with RDS because in edema the alveolar units are not collapsed but rather are filled with fluid. Expiratory films can also give the impression of increasing lung opacity, but recognition of a trachea deviated to the right, domed diaphragms, and a stable clinical picture allow for easy discrimination. Massive bilateral

pulmonary hemorrhage can also lead to sudden near or total lung opacity. Generally, this problem is rapidly recognized clinically (Figure 2A-9).
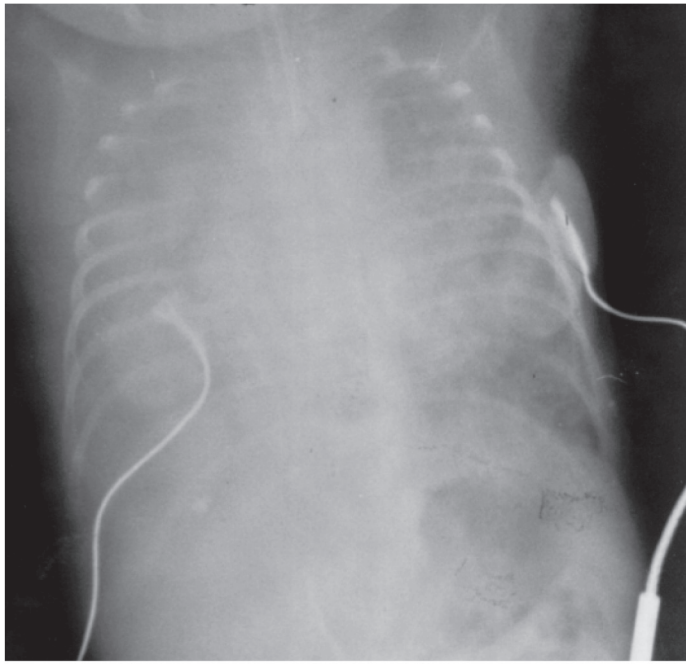
PROGRESSION OF CHANGES

Four gradations in the progression and severity of x-ray changes seen in RDS have been outlined.[2] The first, Grade 1, consists of a fine granularity with some air bronchograms visible. Grade 2 is characterized by a more apparent, distinct, and coarse granularity to the lung fields, with more extensive air bronchograms. Grade 3 is characterized by increasing opacity, with decreasing air bronchograms and granularity. Heart borders are still visible in Grade 3. In Grade 4, diffuse bilateral opacification is present, with lack of apparent heart borders and loss of air bronchograms—a "whiteout" on chest x-ray.

The use of exogenous surfactant will change the x-ray and clinical course of RDS. Following surfactant administration, improved lung expansion and clearing lung fields with only a mildly hazy background are seen in many cases. In others, normal pulmonary radiolucency may follow surfactant administration. A small percentage of neonates are nonresponders, and their clinical and x-ray course changes little after surfactant administration.

FIGURE 2A-9 ■ The lungs of this premature neonate with bilateral pulmonary hemorrhage appear bilaterally opaque, although the right is more opaque than the left.
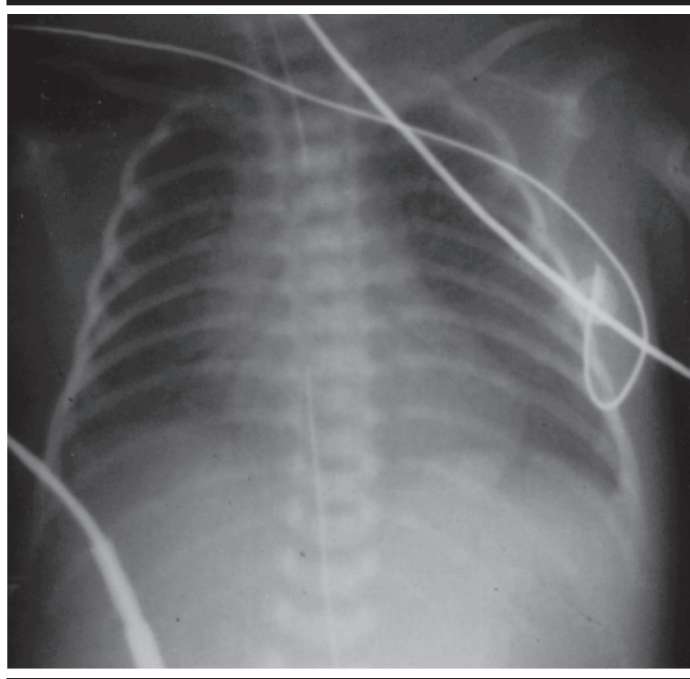
Marked clinical deterioration occurred before this film was taken, and large amounts of frank blood were suctioned from the endotracheal tube.

FIGURE 2A-10 ■ The mild, diffuse, bilateral haze characteristic of neonates in the recovery phase of RDS.

In the recovery phase of RDS, the x-ray appearance of the lungs presents as a mild, diffuse, bilateral haze (Figure 2A-10). In neonates whose course has been typical and who have not received surfactant, the recovery phase occurs between day 4 and 7 of life and is complete by day 10. The hazy appearance is thought to be due to the increased recruitment of mildly injured and edematous alveoli. The hazy appearance is lost over one to two weeks, and the lung fields return to their normal lucency.

An atypical x-ray appearance of the lungs in RDS has been described but is rarely seen. In some cases, the lower lobes show a more distinct pattern of change than the upper lobes. It is theorized that the upper lobes mature earlier than the lower lobes and therefore demonstrate less severity. This atypical appearance has been documented more commonly in larger premature neonates with milder disease. Positioning can also lead to apparent lobar differences in RDS. Prolonged supine positioning may lead to greater underaeration of the most dependent portion of the lung; the posterior lower lobes will appear more dense or opaque on x-ray. Prolonged positioning on one side leads to improved aeration of the elevated lung, and the x-ray may show increased density of the dependent lung. If, during administration, exogenous surfactant instillation is inadvertently greater in one lung than in the other, an asymmetrical picture may occur.

DIFFERENTIAL DIAGNOSIS

The differential diagnosis of the x-ray picture of respiratory distress syndrome must include pneumonia, Group B streptococcal being the most common. Because some alveoli contain inflammatory exudate, they will appear more opaque on x-ray than those that are air filled. This will give a pattern of reticulogranularity to the chest x-ray. If the alveoli extensively fill with exudate or fluid, the lungs may become more opaque. These similarities make it difficult to discriminate between the premature neonate with respiratory distress syndrome and the infant with pneumonia on the basis of the chest x-ray alone (Figure 2A-11). Other historical, clinical, and diagnostic information must be evaluated.

In some premature neonates, retained lung fluid may mimic RDS on chest x-ray when it presents with a diffuse, bilateral hazy or granular picture. Often there is an L:S ratio or lung profile indicating pulmonary maturity or treatment with maternal steroids that helps in attempting to determine the etiology of the respiratory distress. Lung expansion is frequently normal to increased due to fluid in the alveoli, and the clinical and blood gas picture is more consistent with retained lung fluid as a diagnosis.

X-ray studies contribute to a volume of information gathered during a period of rapid adjustment of the neonate to extrauterine life and to his particular disease process. Although

FIGURE 2A-11 ■ This chest x-ray shows a diffuse, bilateral reticulogranular pattern with air bronchograms and lack of clear definition of the heart borders.

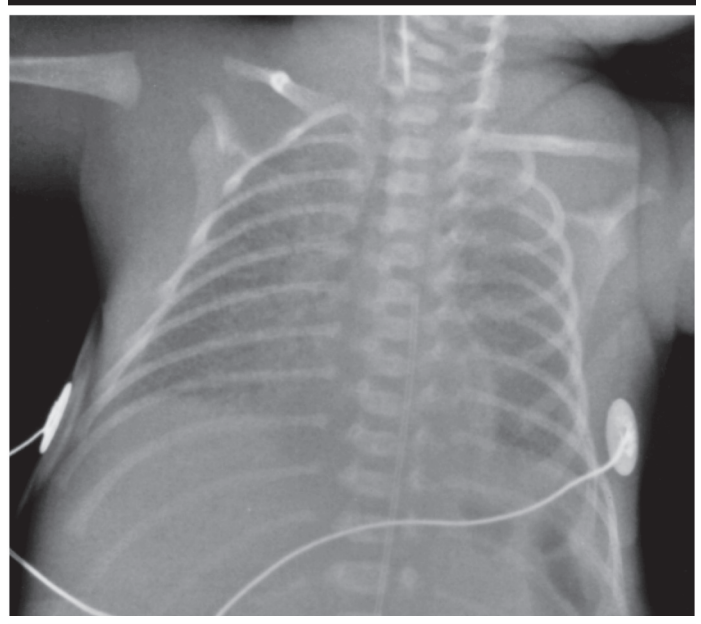**FIGURE 2A-12** ■ The first chest x-ray for a 33-week AGA neonate with respiratory distress.
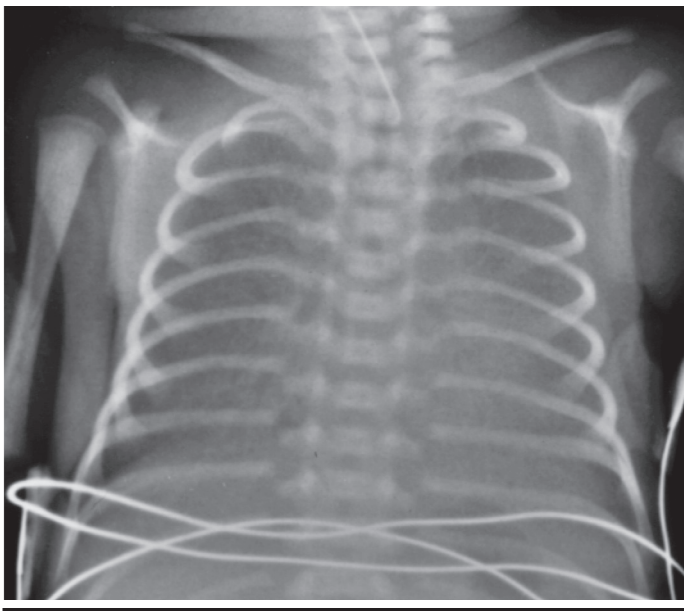
x-rays serve as a guide to the patient's diagnosis and care, the history, the clinical and diagnostic data gathered, and the response to treatment must all be considered in reaching a definitive diagnosis.

CASE PRESENTATION

A 33-week gestation, 1.8 kg AGA female was born by normal spontaneous vaginal delivery to a 20-year-old gravida 2, para 1 mother. The pregnancy was uncomplicated, and the mother had received prenatal care from the tenth week of pregnancy. Her history was positive for premature delivery of her first child at 32 weeks gestation. Spontaneous rupture of membranes occurred seven hours prior to delivery, and the fluid was clear. Maternal VDRL was negative, blood type was O positive, rubella status was immune. Delivery occurred three hours after admission to the hospital, and the neonate's Apgar scores were 6 and 7 at one and five minutes. Respiratory distress and the need for oxygen were present in the delivery room. Soon after admission to the NICU, the infant was intubated and placed on mechanical ventilation because of a blood gas showing respiratory acidosis and hypoxemia in 65 percent oxygen. Upon examination prior to intubation, tachypnea, marked retractions, and poor breath sounds were evident. A CBC and differential were obtained and revealed no abnormality. Oxygenation and ventilation improved following intubation and mechanical ventilation. Figure 2A-12 shows the first chest x-ray for this patient.

X-Ray Evaluation

Indication for the x-ray was respiratory distress in a premature neonate, first admission film.

Penetration appears normal and without overexposure or underexposure.

Rotation is present to the right.

The soft tissues of the neck, chest, and extremities are of normal thickness and without emphysema. Skin folds are present over the left neck and shoulder.

The bony framework is intact, with 12 ribs bilaterally and normal vertebrae.

The trachea shows a straight air column, consistent with an inspiratory film. The tracheal bifurcation can be seen at the fourth thoracic vertebra (T4). The endotracheal tube is high, above the first thoracic vertebrae. The right and left mainstem bronchi are visible.

The hilum appears of normal size; the thymus is not visible; and the heart is of normal configuration, location, and size.

The diaphragm is at T8 on the right and T9 on the left.

The pleura reach the edges of the bony thorax, and the costophrenic angles are visible but clearer on the right than on the left.

Gastric air is present on the left.

The intercostal spaces are normal in size.

Lung fields reveal a diffuse, bilateral reticulogranular pattern with some visible air bronchograms extending beyond the heart.

The endotracheal tube is above T1. An intravascular line is present at T6 on the left side of the vertebral column, and an abdominal film (not shown) confirms an umbilical artery line.

Impression: The history and clinical, laboratory, and x-ray data support the diagnosis of respiratory distress syndrome. The endotracheal tube requires repositioning. The umbilical artery line is in an acceptable position. Cultures have been obtained and antibiotics started, as is protocol for this unit.

Bronchopulmonary Dysplasia

Bronchopulmonary dysplasia (BPD) is a form of chronic lung disease most often resulting from surfactant deficiency disease (SDD) requiring positive pressure ventilation.[1] BPD is estimated to occur in 7,000–10,000 infants annually in the U.S. and is associated with significant adverse pulmonary sequelae in children.[2]

The term *bronchopulmonary dysplasia* was introduced by Northway, Rosen, and Porter in 1967 to describe the clinical, pathologic, and radiologic sequelae of neonates treated with greater than 70 percent oxygen therapy and positive pressure ventilation for 150 hours or more.[3] These neonates were premature and had severe RDS. In 1979, Tooley defined bronchopulmonary dysplasia as an abnormal chest x-ray at 30 days of age in neonates with a history of oxygen and ventilation requirements in the first week of life and one of the following: an arterial oxygen level of less than 60 torr in room air or an arterial carbon dioxide level of greater than 45 torr and oxygen dependence of greater than 21 percent.[4] More commonly today BPD is generally defined as chronic respiratory distress in an infant requiring persistent oxygen and who has an abnormal chest x-ray at one month of age.[2]

CLINICAL FINDINGS

Clinically, BPD is characterized by tachypnea, retractions, rales, hypoxemia in room air, compensated hypercarbia, chronic respiratory distress, poor weight gain, and difficulty in tolerating fluid loads. These infants are extremely fragile and may tolerate only small changes in their management regimens (that is, in the administration of oxygen, ventilation, and fluids). Mucus plugging is frequent in patients who require mechanical ventilation. Once BPD has developed, infants may require oxygen and ventilation for variable periods of time, and their course may be prolonged by such complications as sepsis and pneumonia. In its most severe form, BPD is characterized by end-stage respiratory failure, pulmonary hypertension, and cor pulmonale.

PATHOGENESIS

The pathogenesis of bronchopulmonary dysplasia is complex and not completely understood. Elements that seem to play a major role in the pathogenic scheme of the disease are a susceptible host (that is, a premature neonate and an immature or diseased lung) and early acute lung injury followed by abnormal healing.[5] Lung injury is related to oxygen toxicity and barotrauma and the resulting inflammatory reaction, capillary leak, abnormal lung repair, and airway obstruction.[6] Other factors that play a role in the pathogenesis are general and specific nutrient deficiencies that affect normal lung growth and repair and adequacy of the immunologic defenses. Infants who develop BPD progress from RDS or respiratory disease to chronic impairment in lung function once oxygen toxicity, barotrauma, and other contributory factors have produced cellular, airway, and interstitial changes. The initial abnormality or the severity of the lung disease and the complications often reflect the subsequent respiratory course.[7] Reinjury to the lung by infectious agents increases the severity of acute injury and subsequent lung damage. A possible contributory factor to the disease process is a genetic predisposition to increased airway reactivity. This has been postulated from the increased incidence of first-degree relatives affected with asthma or related disorders.[8]
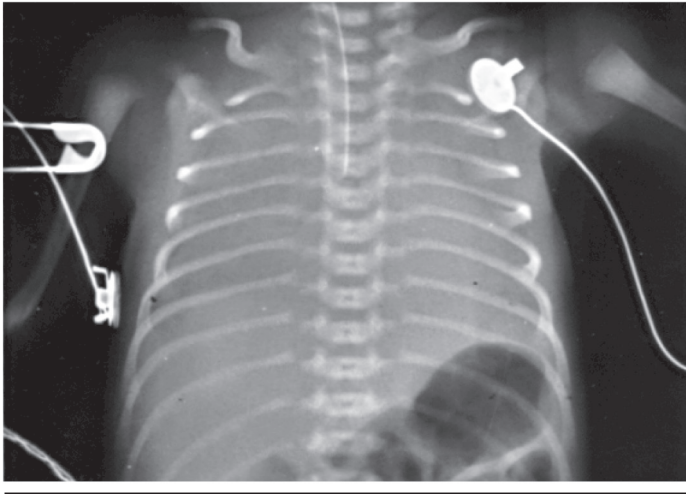
PATHOLOGY

The microscopic appearance of BPD was described through evaluation of the lung at autopsy. It is usually characteristic and follows the four stages outlined by Northway.[9,10] Stage 1 is seen in neonates who die in the first three days of life. Hyaline membranes, atelectasis, patchy loss of ciliated cells, and necrosis of bronchial mucosa are seen. Stage 2 occurs in neonates who die between day four and day ten. Evidence of necrosis and repair of the alveolar epithelium is present, with regeneration and proliferation of bronchiolar epithelium and membrane formation in the bronchioles. Stage 3 is seen in neonates dying between days 10 and 20. Examination of the lung during this stage reveals phagocytosis of membranes, bronchiolar metaplasia, and interstitial fibrosis. Stage 4 is characterized by an obliterative bronchiolitis, interstitial and peribronchial fibrosis, and bronchiolar metaplasia and narrowing.[8,11] The lungs are characterized grossly by areas of emphysema and atelectasis along with fibrosis and interstitial edema. Smooth muscle of the airways and vasculature often shows marked hypertrophy. These pathologic changes are also present in the lungs of neonates who survive with bronchopulmonary dysplasia, and they contribute to the abnormalities in lung function associated with the disease.

LUNG FUNCTION CHANGES

The functional changes in the lung follow the pathology. Increased airway resistance is the most common alteration of pulmonary function seen in neonates with BPD.[6,8] This, in addition to low compliance in the lung bed, leads to the marked increase in the work of breathing, hypoventilation, and carbon dioxide retention characteristic of the disease. The distribution of ventilation is abnormal, with some areas of the lung being ventilated but not perfused and other areas

FIGURE 2A-13 ■ Bilateral opacification in a six-day-old, 31-week gestational age neonate.

This infant's course was complicated by late decelerations on fetal monitoring and Apgar scores of 3 and 7 at one and five minutes. The early neonatal period was consistent with severe RDS, requiring a high concentration of oxygen and positive pressure ventilation. This x-ray is consistent with stage 2 disease as described by Northway. This neonate developed bronchopulmonary dysplasia. At the time the x-ray was taken, an echocardiogram was negative for evidence of a PDA.

FIGURE 2A-14 ■ X-ray of a 15-day-old, 29 week gestational age neonate whose prior films were consistent with RDS.

A PDA was diagnosed and treated on day 3 of life. This x-ray is consistent with Northway's description of stage 3 BPD. The neonate was oxygen dependent at discharge on day 65 of life.
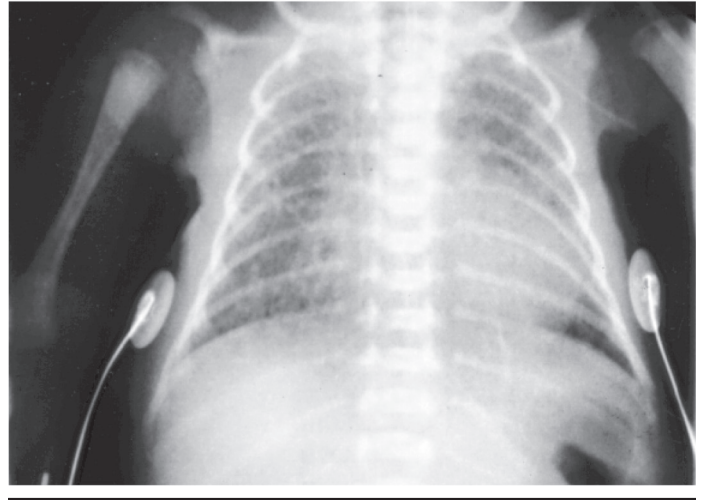

being perfused but not ventilated—leading to ventilation perfusion mismatching and suboptimal ventilation. The degree of airway damage is not uniform throughout the lung, and this determines the abnormal distribution of ventilation and the development of areas of overdistention alternating with areas of collapse. The small airways are thought to be the site of obstruction for the most part, but the large airways are also compromised in some patients and show increased collapsibility during expiration due to bronchomalacia. Increased lung volumes late in the course of the disease reflect air trapping by partial airway obstruction due to fibrosis or mucus plugging from abnormal mucociliary function. Lung compliance is consistently decreased. This decrease may reflect abnormal elastic properties of the damaged, fibrotic lung; an increase in interstitial fluid; or overdistention of portions of the lungs.[12,13]

RADIOLOGIC FINDINGS

Northway described the characteristic progression of the chest x-ray changes in BPD in 1967.[3] The patient population that survived oxygen therapy and positive pressure ventilation for RDS in the late 1960s and early 1970s differed from today's population. Neonates weighed more and were of greater gestational age. The type of ventilation available, ongoing monitoring, treatment of complications of prematurity, fluid and nutritional support, and knowledge of the disease process and its management were all at an early stage of development. Consequently, the typical progression of radiologic findings seen today in the majority of neonates has been modified and is milder.[7] The progression Northway described still occurs, however, in a minority of patients who have severe disease or whose course is complicated by pulmonary interstitial emphysema or pneumonia.[7,8]

Northway described four stages of radiologic change. Stage 1 consists of the radiologic findings of RDS and occurs during the first two to three days of life. Findings include atelectasis, reticulogranularity, and air bronchograms. During stage 2, which occurs between days four and ten, the findings consist of increased air bronchograms and cardiomegaly with progressive lung opacity. These findings may represent severe RDS with diffuse alveolar collapse leading to more apparent air bronchograms and subsequently to severe atelectasis and a "whiteout" on x-ray (Figure 2A-13). This stage is also indistinguishable from pulmonary edema caused by myocardial insufficiency, patent ductus arteriosus (PDA), or fluid overload.[7] It may also be present with pneumonia and pulmonary hemorrhage as exudate or blood fills the alveolar spaces. Stage 3 occurs between days ten and twenty and shows the appearance of small radiolucent areas alternating with irregular areas of increased density (Figure 2A-14). This stage is indistinguishable from pulmonary interstitial emphysema and if seen today does not necessarily follow pulmonary opacity. Stage 4 occurs after thirty days of life and presents with a picture of cystic-appearing lungs with hyperexpansion. These lungs exhibit hyperlucency in some areas and streaky infiltrates or densities in others (Figure 2A-15). Cardiomegaly is present in some cases of stage 4 disease.

Today, the radiologic stages 2 and 3 as described by Northway are less commonly seen.[13] Stage 1 may also be the x-ray picture of other lung diseases predisposing to the development of BPD, such as meconium aspiration. Stage 4 may be seen without the prior findings of stages 2 and 3. The progression of these stages is not necessary for diagnosis. The history of oxygen and ventilation, lung disease, chronic respiratory distress, and the need for oxygen or oxygen and ventilation in the neonate with an abnormal chest x-ray together allow the diagnosis to be determined.

Many neonates who develop BPD today have required oxygen and ventilation for milder RDS or respiratory disease than Northway described. Most neonates have a milder, modified respiratory course.[11,14] The initial chest x-ray is consistent with the etiology of the neonate's respiratory disease. The lungs may not become completely or markedly opaque at four to ten days, but instead take on a hazy appearance. After three to four weeks, the hazy opacification changes to a fine reticular pattern, often with hyperexpansion.[11]

Hyperexpansion in BPD is due to partial peripheral airway obstruction secondary to fibrosis and sometimes to mucus plugging of the bronchioles. The intercostal spaces are wide, and the diaphragms may be flat or concave as a consequence of air trapping. *Diffuse haziness* may represent prolonged healing and resolution of the inflammatory process caused by oxygen and barotrauma in combination with some capillary leakage and mild pulmonary edema from cellular changes.[7,14] In cases of normally expanded lungs with diffuse haziness or hypoexpanded lungs, an element of atelectasis may be present. *Reticular patterns* represent some hyperexpanded alveoli, related to partial airway obstruction, against a background of lung edema, fibrosis, or atelectasis. *The streaky strands or areas of density* seen with Northway's stage 4 disease represent fibrosis, scarring, or atelectasis. *Radiolucencies* seen in this stage are larger than those of stage 3 and represent air trapping with larger blebs or cysts at a damaged alveolar level. *Cardiomegaly,* when present in Northway's stage 2, may follow a PDA in the premature neonate or myocardial damage from asphyxia. Cardiomegaly in stage 4 disease usually represents cor pulmonale with increased right ventricular pressure and pulmonary artery pressure from hypertrophy of the lung vasculature.

The radiologic patterns of bronchopulmonary dysplasia gradually improve and normalize over time in some infants. In others, these findings may persist into childhood.

CASE PRESENTATION

A 30 week gestation, 1.2 kg, average-for-gestational-age male was delivered by cesarean section for fetal distress to a 35-year-old, gravida 5, para 4 mother. The pregnancy was complicated by premature labor five hours prior to delivery and by late decelerations on fetal monitoring. The mother had received no prenatal care. Her pregnancy history included two prior premature neonates, the first delivered at 34 weeks

FIGURE 2A-15 ■ This chest x-ray is consistent with stage 4 BPD as described by Northway.

This neonate was born at 33 weeks gestation. His course was complicated by Group B beta-hemolytic streptococcal sepsis and pneumonia and pulmonary hypertension. He required high pressures and oxygen during the first two weeks of life and developed pulmonary interstitial emphysema. He subsequently died of respiratory failure.
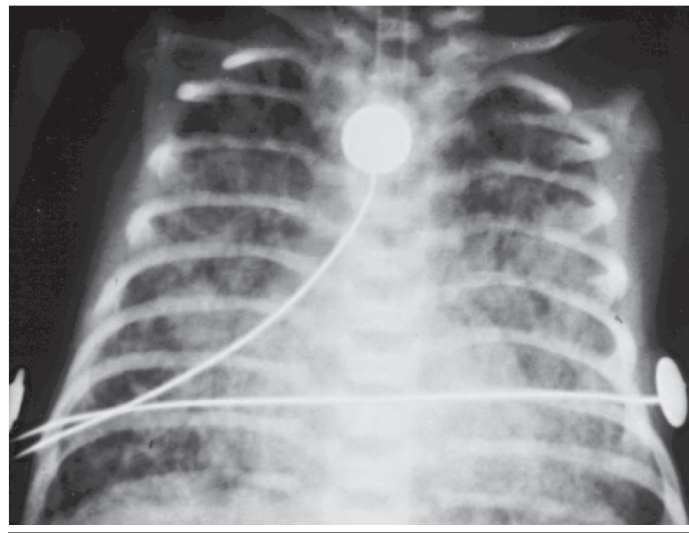

gestation and the second at 26 weeks gestation. The mother's VDRL was negative, and her blood type was B positive.

The neonate required intubation and ventilation in the delivery room for respiratory depression. His Apgar scores were 4 and 7 at one and five minutes. Surfactant was administered in the delivery room, and the neonate was transferred to the NICU and placed on intermittent mandatory ventilation with a fractional inspired oxygen concentration (FiO_2) of 60 percent, a peak inspiratory pressure (PIP) of 28 cm, a positive end-expiratory pressure (PEEP) of 4 cm, and a rate of 40 breaths per minute. Lung compliance was poor, and blood gases revealed hypoxemia and respiratory acidosis. The chest x-ray was consistent with RDS. A sepsis evaluation was performed and antibiotics were begun. Despite receiving three doses of surfactant, the neonate required high oxygen concentrations and positive pressure ventilation. His course was complicated by a PDA, present at 48 hours of life, that was treated with indomethacin. Despite aggressive management, the neonate required prolonged mechanical ventilation. By day of life (DOL) 12, he had been weaned to an FiO_2 of 0.38, a PIP of 26 cm, a PEEP of 3 cm, and a ventilator rate of 24 per minute. The chest x-rays revealed haziness bilaterally with mild hyperexpansion.

Corticosteroid therapy was initiated on DOL 13 with subsequent weaning from ventilation. On DOL 18, lethargy and increasing oxygen need as well as a requirement for ventilation occurred. A sepsis evaluation was undertaken. Blood and tracheal aspirate cultures were found to be positive for *Candida*

FIGURE 2A-16 ■ Diffuse haziness bilaterally in a 35-day-old neonate whose course included RDS and PDA treated with indomethacin.

Mild hyperexpansion is also present. The central line was subsequently withdrawn to the right atrial–superior vena caval junction.
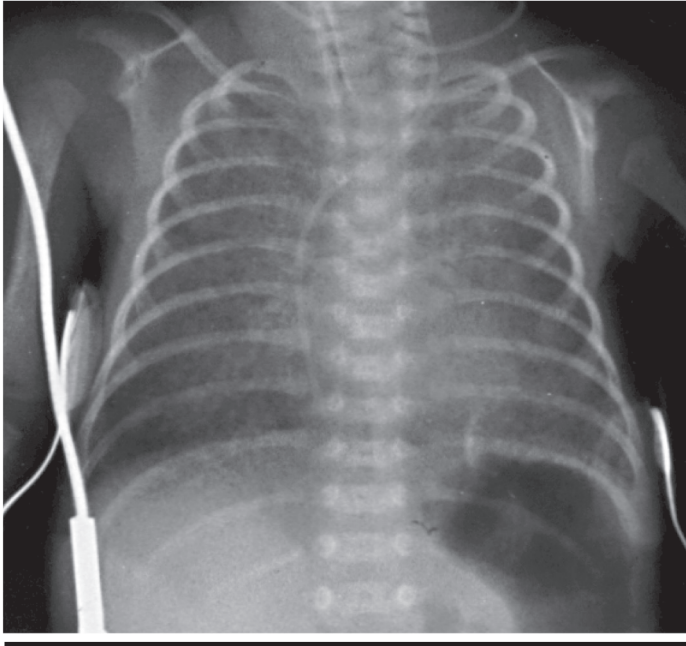
albicans, and treatment was initiated. Corticosteroids were discontinued. Increased oxygen and ventilator support were required for 4 to 5 days, following which time the neonate was able to be weaned back to baseline settings. Figure 2A-16 is the chest x-ray at DOL 35. Ventilatory settings were as follows: FiO_2, 0.30; PIP, 20 cm; PEEP, 2 cm; and ventilator rate, 18 breaths per minute. Blood gases revealed compensated hypercarbia. This patient was subsequently extubated on DOL 40 and required oxygen at discharge on DOL 60.

X-Ray Evaluation

The chest x-ray shown in Figure 2A-16 was obtained on DOL 35 for assessment of the placement of a percutaneously placed central line and for a follow-up evaluation of the lungs.

Penetration appears normal and without overexposure or underexposure.

Rotation is present, slightly to the right.

The soft tissues are of normal thickness and without emphysema.

The bony framework is intact, with 12 ribs visible bilaterally and normal clavicles and vertebrae.

The trachea shows a straight air column consistent with an inspiratory film. The endotracheal tube is located at the second thoracic vertebra (T2). The carina and the right and left main bronchi are difficult to appreciate.

The hilar areas bilaterally show diffuse haziness. The thymus is not visible.

The heart is of normal configuration, location, and size. A central line is present in the right atrium.

The diaphragms are at the tenth vertebral level. They are mildly domed in appearance. Mild hyperexpansion is present.

The pleura reach the edges of the bony thorax, and the costophrenic angles are clear bilaterally.

The intercostal spaces are normal to slightly increased in width.

The lung fields reveal a diffuse, bilateral, hazy appearance, which is less marked at the lateral or outer one-third of the lungs bilaterally.

The endotracheal tube is at T2.

Gastric air is present on the left.

Impression: The history, clinical findings, oxygen and ventilation requirements, and chest x-ray are consistent with bronchopulmonary dysplasia. The central line was subsequently withdrawn to the right atrial–superior vena caval junction.

Pneumothorax in the Neonate: Assessment and Diagnosis

Pneumothorax occurs more often in the neonatal period than at any other time of life.[15] It can happen spontaneously, secondary to mechanical ventilation, as a complication following certain procedures, or as a result of pneumonia or aspiration.[16] The frequency of spontaneous pneumothorax is approximately 1 percent of all live births.[15] Horbar and colleagues reported data on 118,448 very low birth weight newborns (410–1,500 g) followed through the Vermont Oxford Network from 1991 to 1999. They documented an increasing risk for pneumothorax with time. Rates of pneumothorax for neonates with birth weights of 501–750 g were as high as 14 percent in 1999.[17] The case study related here summarizes the course of a neonate with a recurrent tension pneumothorax.

Most often pneumothorax occurs when there is a passage of air from ruptured alveoli into the mediastinum and then into the pleural space surrounding the lungs (Figure 2A-17). Air may also be introduced into the pleural space as a result of a puncture wound, most commonly found after thoracic surgery in the newborn. A pneumomediastinum occurs when the free air is confined to the mediastinal space. A pneumopericardium, air in the pericardial sac, usually occurs along with a pneumothorax, representing an extensive dissection of free air.

FIGURE 2A-17 ■ Diagram of air from ruptured alveoli entering pleural space surrounding the right lung.
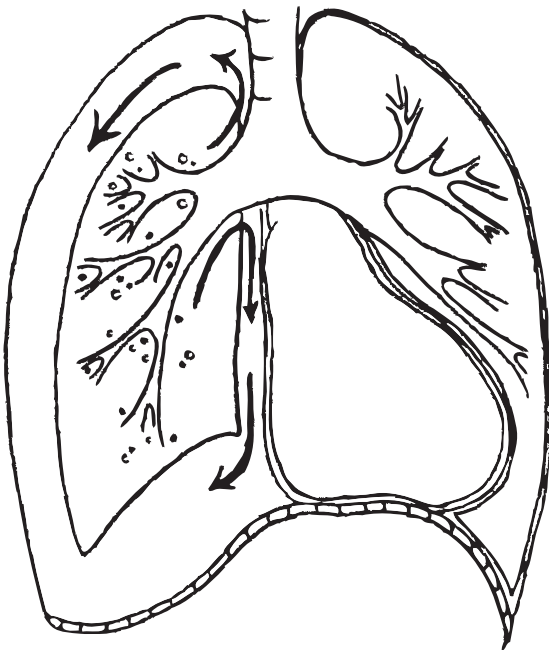
From: Korones SB. 1986. *High-Risk Newborn Infants: The Basis for Intensive Nursing Care,* 4th ed. St. Louis: Mosby, 252. Reprinted by permission.

TABLE 2A-1 ■ X-ray Findings: Pneumothorax

Increased lucency on the affected side

1. Decreased or absent pulmonary vascular markings
2. Overall increase in the size of the affected hemithorax
3. Widened intercostal spaces
4. Flattened diaphragm on the affected side
5. Sharp edge sign (The cardiac border and the diaphragm are seen in sharp contrast.)
6. With tension pneumothorax, mediastinal shift with deviation of the trachea and heart to the opposite side, decreased volume and increased opacity of the opposite lung
7. With bilateral pneumothoraces, narrow cardiac silhouette

From: Carey BE. 1999. Neonatal air leaks: Pneumothorax, pneumomediastinum, pulmonary interstitial emphysema, pneumopericardium. *Neonatal Network,* 18(8): 81. Reprinted by permission.

The pleural cavity is the potential space located between the parietal and visceral pleural membranes. When free air enters the pleural cavity, the normal subatmospheric (negative) pressure in the pleural space rises to approximately atmospheric pressure, and the pleural membranes separate.[18] This accumulation of air and pressure within the pleural space compresses the lung, impairing gas exchange. If the compression is severe enough and the air leak large enough, the lung, heart, and pulmonary vessels are compressed and may be shifted to one side, a condition referred to as a tension pneumothorax. This can result in significant cardiovascular compromise, hypotension, and hypoxemia.

Mechanical ventilation is a significant cause of pneumothorax in the newborn. Hooke's Law provides an explanation. When applied to the elastic properties of the lungs, Hooke's Law basically confirms that volume varies with pressure. Like a spring, the lungs expand to their elastic limit when pressure is applied. However, if the elastic limit is reached and the pressure continues to rise, the alveolus ruptures, allowing gas to enter the pleural space.[18]

SIGNS AND SYMPTOMS

Nonspecific and sometimes subtle signs of pneumothorax may include decreased breath sounds on the affected side, increased respiratory effort, cyanosis, grunting, nasal flaring, retractions, and agitation. Cyanosis, hypercapnea,

hypoxemia, chest asymmetry, apnea, and bradycardia can also occur. Signs of shock, such as hypotension and metabolic acidosis, may occur because of compression of the vena cava, with resultant decreased cardiac output.[15] A tension pneumothorax often has more specific signs and symptoms than a pneumothorax that is the result of other pathology. The practitioner should observe for sudden deterioration in the infant's condition, a change in the point of maximal impulse to the side of the shifted heart, severe dyspnea, and extreme cyanosis. A pneumomediastinum that occurs spontaneously in a normal term infant is often asymptomatic. In other neonates, it may be associated with mild to moderate respiratory distress, including tachypnea, cyanosis, and muffled heart sounds. A pneumopericardium causes significant and sudden clinical deterioration, including severe cyanosis, muffled or distant heart sounds, hypotension, and bradycardia.
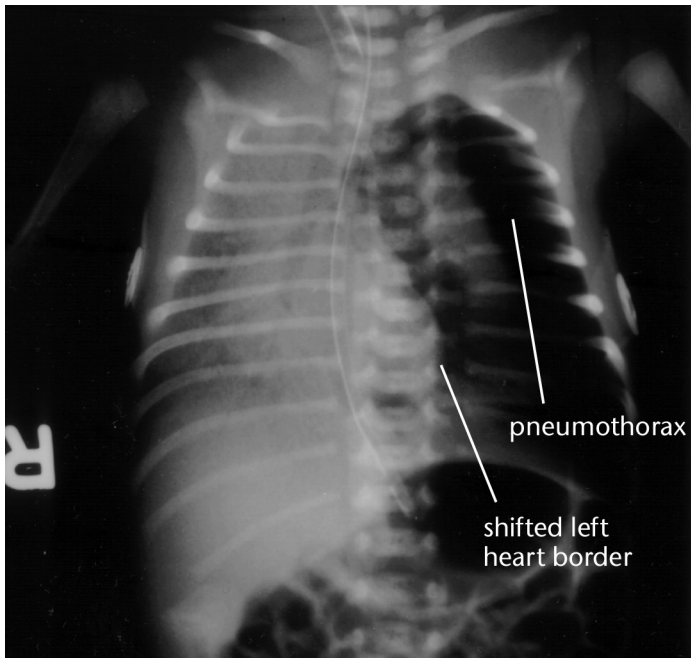
DIAGNOSIS

An anterior-posterior x-ray and a lateral x-ray are the most valuable tools to diagnose a pneumothorax (Table 2A-1). A pneumothorax may be subtle and be demonstrated by a mild increase in translucency on the affected side, particularly in the case of an anterior pneumothorax, or it can be dramatic, as demonstrated in Figure 2A-18. Figures 2A-19 and 2A-20 demonstrate pneumothoraces that are more subtle than the tension pneumothorax in Figure 2A-18. Free air allows a majority of the x-ray beam to pass through the chest, resulting in increased exposure of the film; therefore, free air appears dark on x-ray. Areas containing lung, heart, and fluid appear gray or white.

If an immediate diagnosis is needed, transillumination can be done. In this procedure, a fiberoptic probe attached to a flexible tube is placed on the chest wall while the nursery is darkened. If a pneumothorax is present, the chest wall overlying the area of free air appears bright. Solid tissue such as the lung does not transilluminate. A positive transillumination of the chest in combination with shifted or muffled heart

FIGURE 2A-18 ■ Thirty-week gestational age male infant with large left tension pneumothorax detected at 24 hours of age.

Note that the heart, tracheal air column, and esophagus (with the nasogastric tube) is shifted to the right side of the chest. The endotracheal tube is high with the tip at the level of the clavicles. The nasogastric tube is in the stomach.

pneumothorax

shifted left heart border

FIGURE 2A-19 ■ Right spontaneous pneumothorax demonstrated by areas of increased translucency along the right diaphragm, and the right rib border, and in the upper right chest.
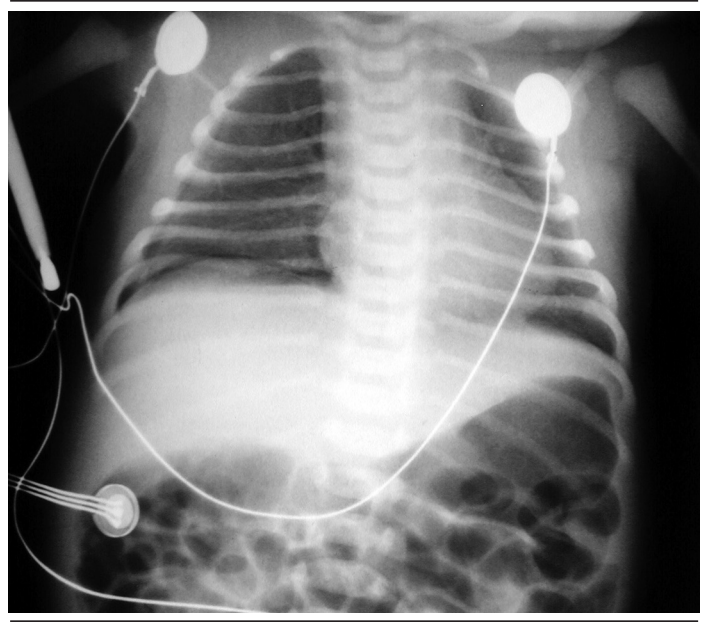

FIGURE 2A-20 ■ Thirty-three-week gestational age male infant with left pneumothorax secondary to mechanical ventilation for respiratory distress syndrome.

Note the large translucent area at the base of the left lung.

free air

sounds in a clinically compromised infant is justification for a needle aspiration procedure prior to obtaining an x-ray for confirmation.

The severity of pneumothoraces in the neonate may range from benign, spontaneous, and asymptomatic to causing significant respiratory and cardiovascular compromise. The neonatal nurse can assist in the diagnosis and prompt treatment of pneumothorax by identifying the neonate at risk for it, monitoring for signs and symptoms, and identifying radiographic features consistent with air leak syndromes.

CASE PRESENTATION

CD was a twin boy born to a 30-year-old, gravida 1, para 2, Caucasian mother at 30 1/7 weeks gestation. Maternal blood work was unremarkable. The mother received a course of betamethasone approximately two weeks before delivery. Her pregnancy was complicated by pregnancy-induced hypertension presenting at 26 weeks of gestation. CD and his brother were delivered by cesarean section because of worsening maternal preeclampsia. CD's Apgar scores were 7 at one minute, 9 at five minutes, and 9 at ten minutes. He was transported to the neonatal intensive care unit, where he was placed on nasal continuous positive airway pressure (CPAP) at 4 cm and at an FiO_2 of 0.4. CD's initial chest
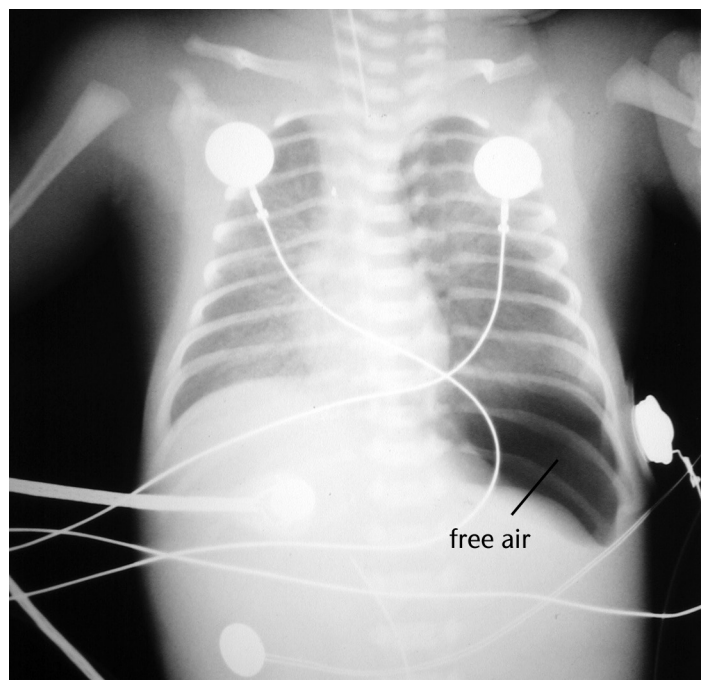
FIGURE 2A-21 ■ Thirty-week gestational age male infant's admission chest x-ray demonstrating bilateral interstitial infiltrates consistent with hyaline membrane disease.

FIGURE 2A-22 ■ Thirty-week gestational age male infant with left tension pneumothorax treated with insertion of an angiocatheter.

Caregivers aspirated 190 mL of air. The tip of the catheter appears crossing the midline. The mediastinum is still shifted to the right, as is evident by the position of the tracheal air column, nasogastric tube, and the right heart border.

endotracheal tube shifted to right
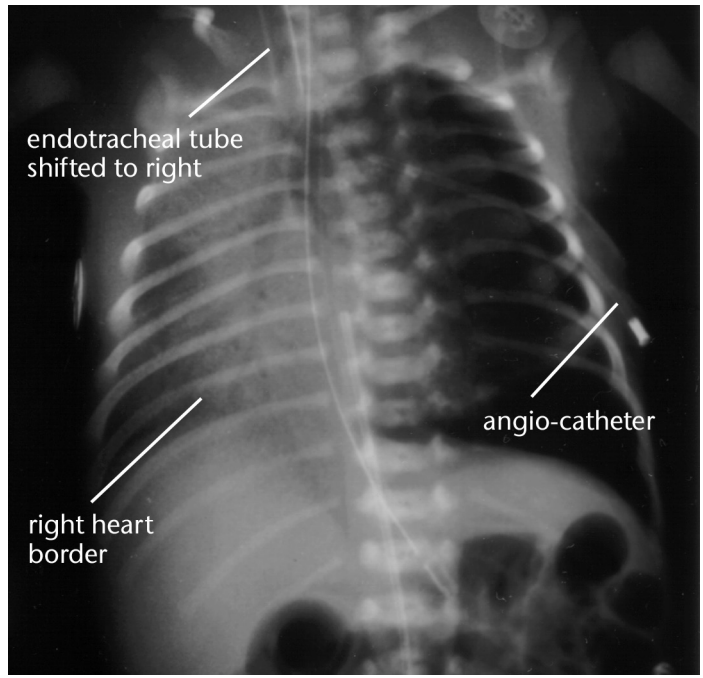
right heart border

angio-catheter

x-ray was consistent with hyaline membrane disease with interstitial infiltrates in both lungs (Figure 2A-21). There was no evidence of pneumothorax, and the cardiac silhouette was within normal limits. His initial arterial blood gas on 48 percent oxygen was pH 7.26, PCO_2 53 mmHg, PO_2 78 mmHg, HCO_3 24 mEq/liter, and base deficit of –4.3 mEq/liter. For the next 12 hours of life, CD remained on CPAP at 4 cm and 30–40 percent oxygen, had two stable blood gas levels, and had a respiratory rate of 60–75 breaths/minute with no significant episodes of apnea or bradycardia.

At approximately 24 hours of life, CD's respiratory rate suddenly increased to 80–90 breaths/minute, his color became dusky both centrally and peripherally, and he had a significant drop in oxygen saturation. CD required positive pressure ventilation and was intubated. A chest x-ray was obtained and showed a large left pneumothorax with a shift in the cardiac silhouette from the left to the right side of the chest (see Figure 2A-18). An arterial blood gas revealed a pH 7.18, PCO_2 50 mmHg, PO_2 263 mmHg, HCO_3 18 mEq/liter, and a base deficit of –10.3 mEq/liter. After the infant was given pain medication, the left chest was aspirated with a 20-gauge needle, and approximately 190 mL of air was obtained (Figure 2A-22). A 9 French chest tube was placed at the anterior fourth intercostal space and connected to an air evacuation source with 15 cm of H_2O; intermittent suction

was applied (Figure 2A-23). CD was given a dose of surfactant for hyaline membrane disease after he was intubated and again approximately 12 hours later. He remained on simultaneous intermittent mandatory ventilation (SIMV) until he was extubated on DOL 7, at which time the pneumothorax was completely resolved. CD was placed in an oxyhood at approximately 40 percent oxygen.

CD's neurologic exam was normal. A cranial ultrasound obtained on day 2 was within normal limits. CD received fentanyl for sedation and analgesia after intubation and during placement of the chest tube. He continued to receive fentanyl 1 mcg/kg/dose by slow IV push as needed every six to eight hours while the chest tube remained in place.

The infant had adequate urine output during the first week of life. Serum electrolyte levels assessed within that first week were within normal limits. CD was given small enteral feedings of breast milk beginning on DOL 3 and was receiving his maximum feedings of breast milk (160 mL/kg/day) by nasogastric tube by DOL 12. Phototherapy was initiated on DOL 3 for a total bilirubin level of 8.3 mg/dL (142 micromols/liter), and he remained on phototherapy for three days.

A complete blood count (CBC) with differential and a blood culture were obtained upon admission to the NICU. Blood for another CBC was drawn at 24 hours of life; both

FIGURE 2A-23 ■ Thirty-week gestational age male infant with resolving left tension pneumothorax with left chest tube in place.

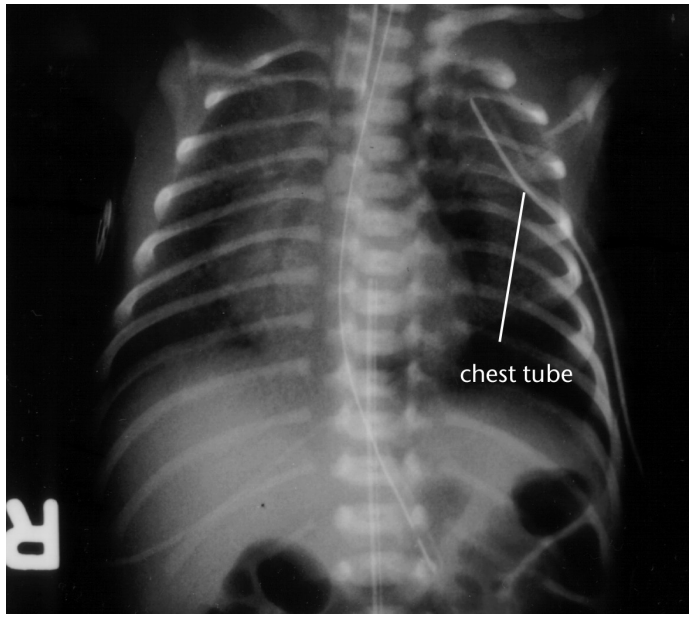Note that the heart has assumed a more central position within the thoracic cavity.

chest tube

FIGURE 2A-24 ■ Thirty-week gestational age male infant with reaccumulation of free air in the left pleural space when compared to Figure 2A-23.

The left chest tube is in place overlying an area of compressed lung. This occurred on day 8 of life.

samples had results within normal limits. A tracheal aspirate was obtained once the infant was intubated. Both the blood culture and the tracheal aspirate were negative for bacteria. On DOL 7, a routine CBC revealed an elevated ratio of immature to total neutrophils. Therapy with cefotaxime (Claforan) was initiated for seven days. Both peripheral and arterial blood cultures were obtained, with negative results.

The infant's initial hematocrit levels were 42 percent at 1 hour of life and 57 percent at 12 hours of life. On DOL 7, his hematocrit was 32 percent and 29 percent on DOL 8, for which CD was given 10 mL/kg of packed red blood cells. A post-transfusion hematocrit was 36 percent. On DOL 5, CD was diagnosed by echocardiogram with a moderately large patent ductus arteriosus. He received one course of indomethacin and required no further treatment.

On DOL 8, CD was reintubated because of mild respiratory distress, several significant drops in oxygen saturation levels, and bradycardia. The chest x-ray revealed a moderate recurrence of the left pneumothorax, and a new 9 French chest tube was placed at the same site (Figure 2A-24). By DOL 16, the pneumothorax had resolved and the chest tube was removed (Figure 2A-25). CD was extubated and weaned to a nasal cannula on DOL 13. On DOL 30, a chest x-ray revealed chronic lung disease with interstitial markings and atelectasis (Figure 2A-26). CD's oxygen requirements increased (nasal cannula at 80 percent with flow of 0.5 liter/minute), and he displayed a slight increase in his work

of breathing. Mild wheezing was noted upon auscultation. Administration of the inhaled bronchodilators budesonide (Pulmicort) and levalbuterol (Xopenex) every 12 hours was begun to ease his work of breathing. CD was also started on a ten day course of the diuretics spironolactone and chlorothiazide, which are used in combination to improve pulmonary function for patients with chronic lung disease.[19]

CD's persistent chronic lung disease and a slightly irregular stooling pattern prompted an evaluation for cystic fibrosis. The DNA probe found that the colon had one Leo delta F508 mutation, indicating that he was a cystic fibrosis carrier.[20] It was recommended that CD undergo sodium chloride testing in a month or two to locate any mutations undetected by this DNA probe study.

It was felt that CD's clinical symptoms could be attributed to reflux and possible aspiration. An upper gastrointestinal study done on DOL 56 demonstrated gastrointestinal reflux. A pediatric pulmonologist diagnosed CD with chronic pulmonary aspiration. This is caused by saliva or food entering the airways during swallowing, or it may occur as a result of gastroesophageal reflux.[21] Therapy with ranitidine and metoclopramide was begun. CD was also diagnosed with persistent feeding difficulty, contributing to both his lung disease and his need for oxygen.

FIGURE 2A-25 ■ Thirty-week gestational age male infant on day 16 with resolved pneumothorax and bilateral hazy infiltrates.

CD was discharged to home on DOL 77 on 1.0 FiO$_2$ at 0.2 liters/minute, spironolactone, ranitidine, metoclopramide, and daily multivitamins. Because of his increased work of breathing and fatigue with oral feeding attempts, CD's feeding plan at the time of discharge was to attempt oral feeding four times a day; the remaining feedings would be given by nasogastric feeding tube.

By the time CD reached four months of age, his oxygen was discontinued. He received the majority of his feedings through a feeding tube until approximately nine months of age. At this time, CD weighed approximately 17 pounds and began using a sippy cup containing thickened formula and was able to take all feedings orally. He has tolerated this well, consuming 3 to 6 ounces per feeding. CD's parents report that he is growing appropriately and has had no further need of a nasogastric tube. His parents felt that he was doing well developmentally, and they were scheduled to have developmental follow-up the next month.

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FIGURE 2A-26 ■ Thirty-week gestational age male infant on day 30 with chest x-ray demonstrating hazy, coarse infiltrates bilaterally consistent with chronic lung disease.

The nasogastric tube needs to be advanced into the stomach.

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