Neonatal Chest Imaging

Eric J. Crotty

Contents

Abstract

Neonatal lung disease is a common problem with potential for significant morbidity and mortality. Chest radiographs remain the most important imaging tool for investigation of these diseases. Many of these diseases can have a similar appearance on radiographs, but differentiation can be often be achieved by noting differentiating and sometimes subtle imaging findings, and taking into consideration pertinent clinical information such as the gestational age and perinatal history. As these patients are often critically ill, radiographs also need to be evaluated for adequate positioning of the support tubes and catheters. Many complications of these diseases, such as air leak related to mechanical ventilation, can also be assessed with radiographs. This chapter will describe and illustrate the imaging findings of diseases of the neonatal lung and complications of their management.

1 Introduction

The chest radiograph is the most frequent imaging study performed on neonates. This reflects respiratory distress being a very common sign in an ill neonate, especially in premature infants. A wide spectrum of medical and surgical disorders can present in the neonatal period with respiratory distress. This chapter will focus on the common pulmonary conditions, as the cardiac and surgical conditions will be discussed in other chapters.

2 Technique

Although the radiation dose from an individual chest radiograph is low, it is important that the ALARA principals are observed. While patients in the neonatal intensive care unit are ill, they often do not require a daily chest radiograph, and

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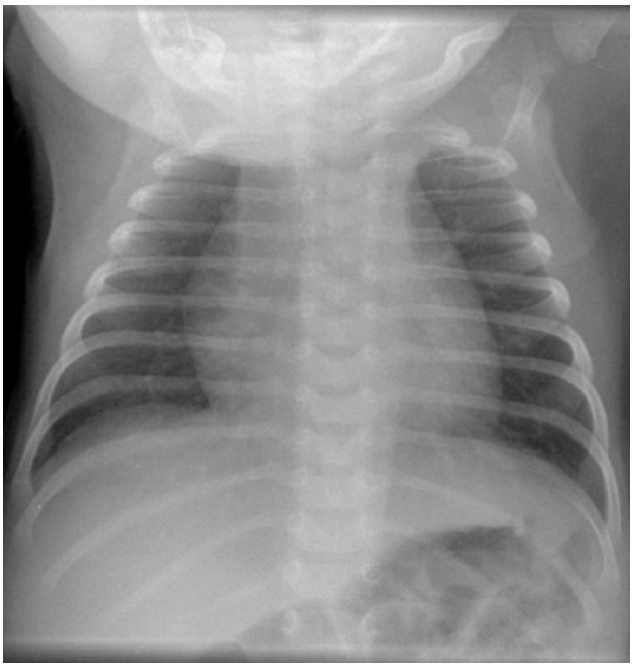

Fig. 1 Normal anteroposterior (AP) chest radiograph in a neonate. Symmetrically inflated lungs are seen with sharp costophrenic angles. The configuration of the cardiothymic silhouette is normal

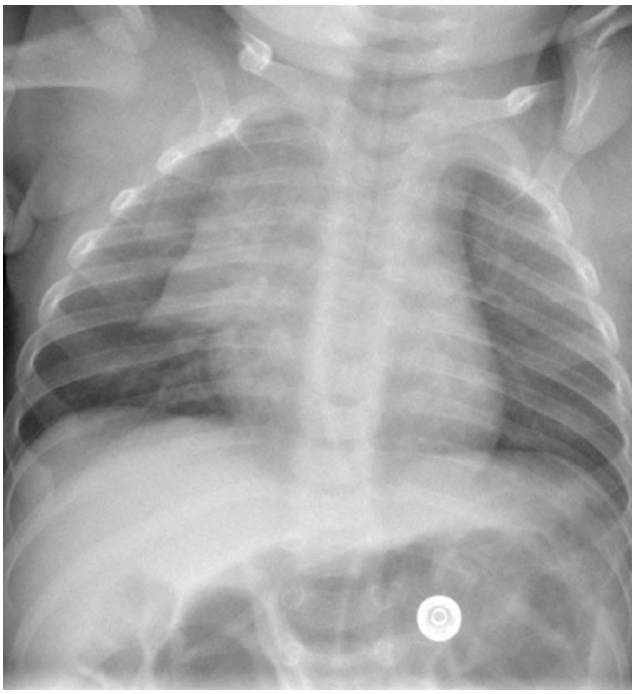

Fig. 2 Thymic wave sign. Undulating lateral border of the soft thymus from deformation by the overlying ribs. The thymus also projects like a sail away from the other mediastinal structures

judicious ordering of imaging is the best method to decrease exposure to ionizing radiation. When a chest radiograph is obtained, proper technique is important. Images are obtained anteroposterior (AP) with the patient in the supine position. Care should be taken to avoid rotation. Imaging is centered at the nipple line and should extend from the lung apices superiorly to L1/L2 level inferiorly. An AP view usually suffices for evaluation of the chest. Occasionally a cross-table lateral view or a lateral decubitus view can be helpful, most often in the evaluation for an anterior pneumothorax.

3 Systematic Approach

A systematic method of evaluating radiographs is recommended. The lungs should demonstrate symmetrical aeration and radiolucency. Patient rotation will lead to asymmetrically increased or decreased density and a unilateral hyperlucent lung can mimic a pneumothorax or a congenital overinflation lesion. Pulmonary vasculature should be inconspicuous in the periphery of the lungs but should be visible in the central two-thirds. The hemidiaphragms should be dome-shaped and the costophrenic angles should be sharp. The transverse cardiothoracic ratio can be up to 60 % in neonates (Fig. 1). The normal thymus can have a varied appearance and can mimic a mass or consolidation. Various signs can be used to identify a normal thymus. These include a wavy lateral border due to impression by the anterior ribs, a notch between the thymus and the heart, and a sail-like appearance of the thymus projecting off the mediastinum (Fig. 2). The thymus should be visible in a normal neonate. However, stress and illness can lead to rapid involution of the thymus. Confirmation of the presence of a thymus and differentiation of a thymus from a mass can usually be made by ultrasound, as a normal thymus has a typical sonographic appearance (Fig. 3) (Han et al. 2001).

Patients in the neonatal intensive care unit often have catheters and tubes and evaluation of this support apparatus is an important part of reviewing chest radiographs in these infants. Review should include not only the chest cavity, but also the osseous structures and the soft tissues of the chest wall. The upper abdomen should also be reviewed for comorbid conditions such as necrotizing enterocolitis, a common disease in patients with respiratory distress syndrome (RDS). The signs of this condition include pneumatosis intestinalis, portal venous gas, and free intraperitoneal air, all of which may be identified on a chest radiograph (Fig. 4). Abdominal heterotaxy with malposition of the stomach and liver can be accompanied by asplenia or polysplenia and is strongly associated with congenital heart disease. The osseous structures need to be evaluated for vertebral and rib abnormalities. The Vertebral anomalies, Anal atresia, Cardiac anomalies, Tracheoesophageal abnormalities, Renal anomalies, and Limb anomalies (VACTERL)

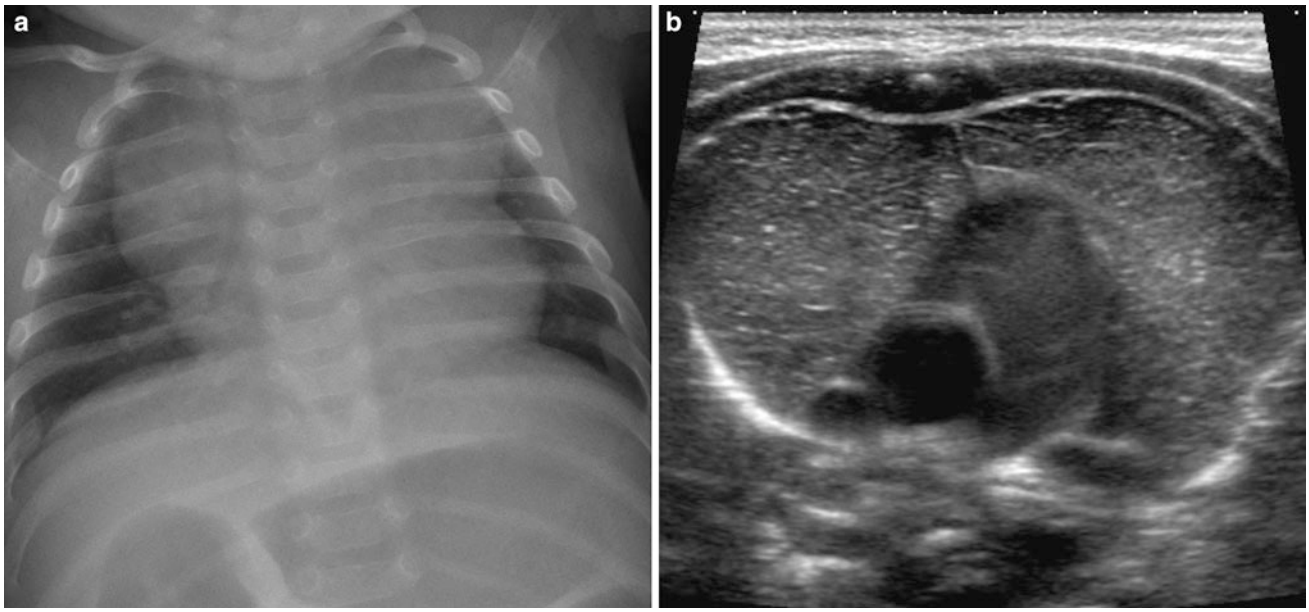

Fig. 3 Prominent thymus confirmed with ultrasound. **a** Neonate with a prominent lobulated mediastinal contour on a chest radiograph. **b** Ultrasound demonstrates a normal thymus with the typical appearance of echogenic lines and punctate foci on a hypoechoic stroma

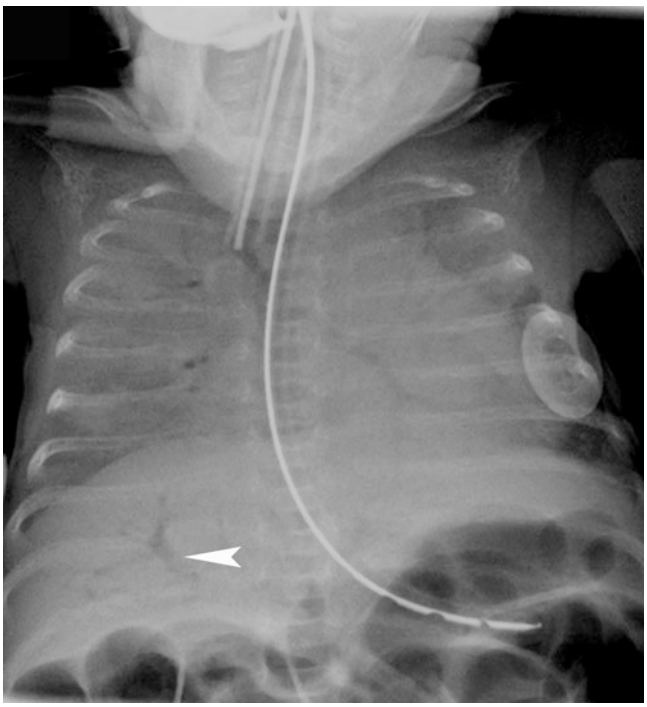

Fig. 4 Abdominal pathology on a chest radiograph. Chest radiograph in a 3 week old former 27 week gestation premature infant with necrotizing enterocolitis demonstrating branching lucent structures in the liver (*arrowhead*) consistent with portal venous gas

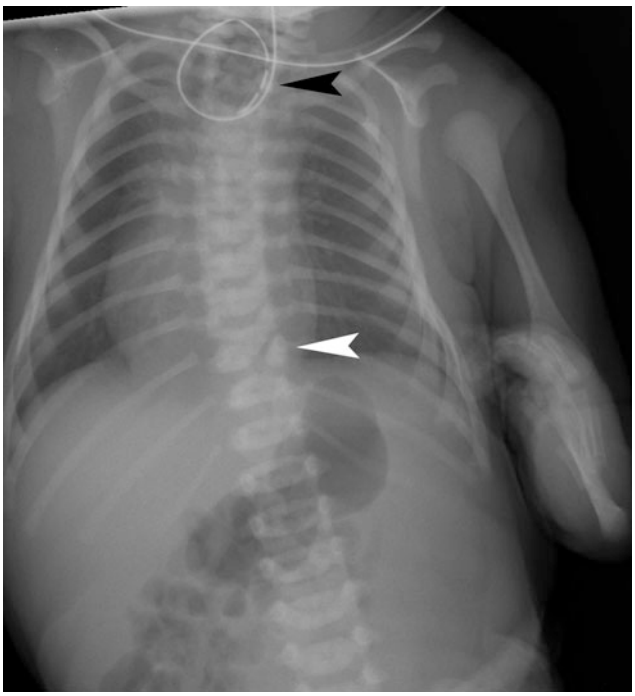

Fig. 5 VACTERL association. Notice the vertebral segmentation anomaly (*white arrowhead*). An enteric tube is coiled in the atretic proximal esophagus (*black arrowhead*) and there is gas in the bowel consistent with esophageal atresia with a tracheoesophageal fistula. The patient also has a deformity of the left upper extremity

association may be suggested by a dilated esophagus, absent bowel gas, and vertebral anomalies (Fig. 5). Rib anomalies can be associated with conditions with restrictive physiology such as asphyxiating thoracic dystrophy and thanatophoric dwarfism. In cases where the gestational age is unknown or where the provided history is limited, examination of the humeri may help, as the proximal humeral epiphysis is ossified in 80 % of term infants.

4 Medical Disease

4.1 Transient Tachypnea of the Newborn

Transient tachypnea of the newborn (TTN), also known as "wet lung," is a common cause of respiratory distress in infants who are either near-term, term, or postterm. It is secondary to retention of fetal fluid in the newborn's lung and occurs with an incidence of 5.9 % (Tutdibi et al. 2010).

The production of fetal lung fluid decreases as gestation approaches full term. The remaining fluid is cleared from the lungs during labor by active resorption of fluid from the air spaces through epithelial sodium channels. Hormones, including epinephrine, glucocorticoids, and thyroid hormones released during the stress of labor, as well as inhaled oxygen in the postnatal period trigger this resorptive process (Barker and Olver 2002). The removal of lung fluid is practically completed by 2 h of life (Aherne and Dawkins 1964). If the epithelial sodium transport mechanism is immature or the lungs are not exposed to the stress of labor, fluid resorption may be inadequate. The retained fluid in the interstitium leads to decreased compliance of the lungs. The majority of this fluid is removed from the interstitium via the pulmonary veins and lymphatics (Humphreys et al. 1967; Bland et al. 1982). Epinephrine has also been demonstrated to cause the release of surfactant (Lawson et al. 1978), which increases pulmonary compliance and decreases the effect of any retained fluid. Pressure transmitted to the lungs by compression of the chest wall during delivery with resultant clearance of fetal lung fluid via the tracheobronchial tree, the so-called "vaginal squeeze" contributes minimally to removal of this fluid.

Transient tachypnea of the newborn is seen more often in patients that are born by cesarean section, especially elective cesarean section without preceding labor. It is also seen more commonly in infants of mothers who have been sedated, in infants of diabetic mothers with poor glucose control and in infants of mothers with asthma, in large or small for gestational age infants, and in male infants (Schatz et al. 1991; Persson and Hanson 1998; Tutdibi et al. 2010). The severity of TTN also correlates with elective cesarean section and shorter duration of labor as well as lower gestational age (Tutdibi et al. 2010).

Infants with TTN present with signs of respiratory distress and they may require supplemental oxygen. More severe complications including pneumothorax, the need for positive pressure ventilation or extracorporeal membrane oxygenation, and death have been recorded (Ramachandrappa and Jain 2008). The condition is usually self-limiting, most patients recovering in 24–72 h, but occasionally patients need longer to become asymptomatic. The majority of patients with TTN recover fully without long-term morbidity, although some studies have shown an increased incidence of childhood asthma in these patients (Birnkrant et al. 2006).

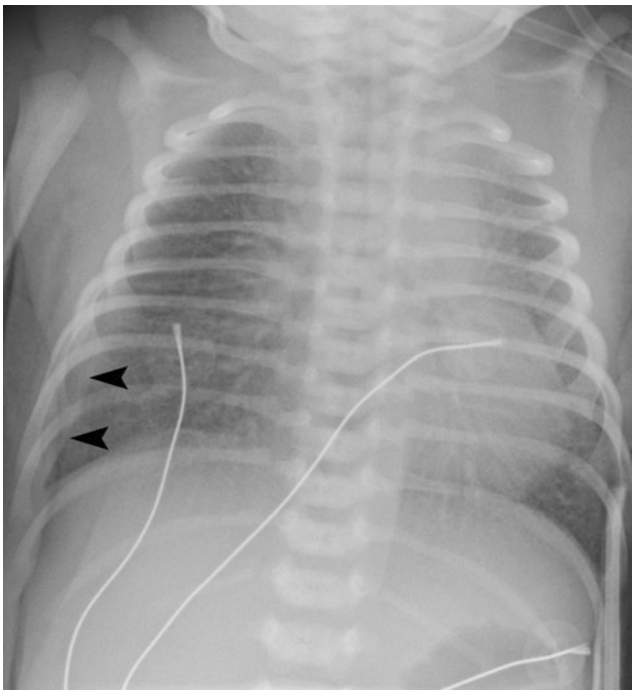

Fig. 6 Term infant with transient tachypnea of the newborn. The lungs are well inflated with prominent interstitial opacities radiating from the hila. There is a small right pleural effusion (*arrowheads*)

Transient tachypnea of the newborn is a clinical diagnosis and radiographs of the chest are primarily performed in these infants to exclude other causes of respiratory distress. On imaging, the lungs are well inflated. Symmetrically prominent interstitial opacities radiating from the hila are most commonly seen (Fig. 6). Diffuse fine granular opacities may be present bilaterally and can be confused with RDS if attention is not paid to the patient's gestational age and the degree of inflation. Small pleural effusions may be evident, another finding not seen in RDS (Fig. 7). A follow up radiograph is usually not indicated as the patients clinically improve, but if performed it demonstrates rapid clearance of the radiographic abnormalities (Swischuk 1970; Wesenberg et al. 1971).

4.2 Respiratory Distress Syndrome

Respiratory Distress Syndrome (RDS) is a disease of neonates resulting from surfactant deficiency. RDS is primarily a disease of premature infants born at less than 36 weeks of gestation, although it can rarely be seen in term infants and also in infants of diabetic mothers with poor glucose control. Other factors that increase the risk of developing RDS include intrapartum asphyxiation, multiple gestation births,

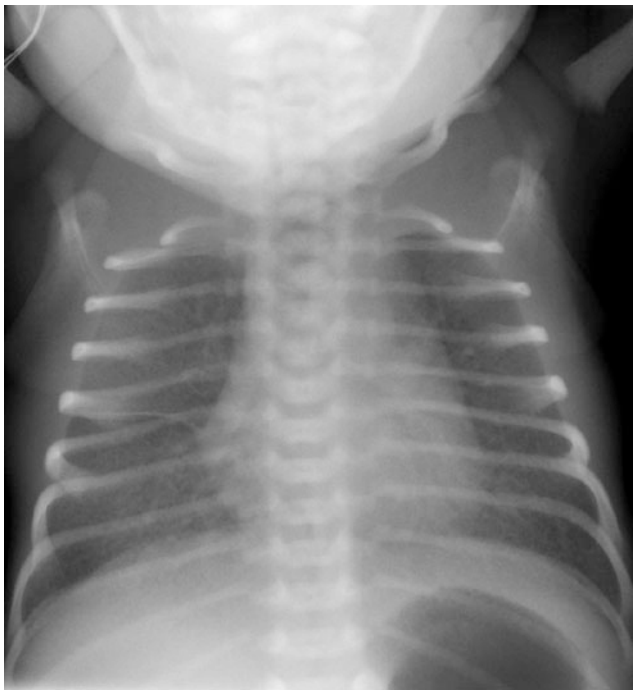

Fig. 7 Term infant with transient tachypnea of the newborn. The appearance could be confused with respiratory distress syndrome as there are fine granular opacities. However, the lungs are well inflated and there is a small amount of pleural fluid along the minor pulmonary fissure

sepsis, and maternal and fetal hemorrhage. Male and Caucasian infants have an increased incidence of RDS (Anadkat et al. 2012). The lower the gestational age, the greater the incidence of RDS; it occurs with an incidence of 93 % in infants less than 28 weeks gestation (Stoll et al. 2010), 10 % at 34 weeks, and 0.3 % at greater than 38 weeks gestation (Hibbard et al. 2010).

Alveoli begin to form during the later part of the canalicular stage of lung development, at about 24–28 weeks gestation (Agrons et al. 2005) and are lined by Type II pneumocytes which express surfactant, a complex lipoprotein, into the alveoli. Surfactant becomes activated when it combines with surface surfactant proteins which are also produced by Type II pneumocytes. This activated surfactant reduces surface tension within the alveoli, not only preventing them from collapsing but also allowing collapsed alveoli to expand with less applied force. In preterm infants, an insufficient amount of surfactant results in collapse of the alveoli and atelectasis with resultant development of hypoxia and acidosis. An inflammatory reaction ensues, often exacerbated by oxygen therapy and barotrauma from positive pressure ventilation. This inflammation results in damage to both the respiratory epithelium and capillary endothelium with loss of integrity of these structures. Interstitial edema ensues along with formation of a membrane along the terminal bronchioles and alveolar ducts (Stocker 1992). These hyaline membranes prevent gas exchange and result in ventilation–perfusion mismatching, leading to hypoxia and acidemia. Over time this can lead to arteriolar vasoconstriction and pulmonary hypertension.

Clinically, infants become symptomatic soon after birth and develop progressive worsening of symptoms over the first 48 h of life with signs of respiratory distress. The increased effort required for breathing leads to fatigue often necessitating support with positive pressure ventilation. The natural history for the majority of infants with uncomplicated RDS is gradual improvement as endogenous surfactant production is induced. Superimposed neonatal pneumonia, a patent ductus arteriosus, persistent pulmonary hypertension, and sepsis can all lead to prolongation of symptoms and a more complicated clinical course, including the development of an air leak. Long term, the infants are at risk of developing bronchopulmonary dysplasia.

The administration of steroids to the expectant mother for 12–36 h while in preterm labor has been shown to accelerate lung maturation in fetuses over 28 weeks gestation with decreased severity of RDS (Liggins and Howie 1972). A similar decrease in the severity of RDS has not been shown to occur in infants born between 24 and 28 weeks gestation following prenatal steroid administration to the mother (Garite et al. 1992). However, infants born at this gestation have been shown to have a reduced incidence of other diseases of prematurity following steroid administration, such as necrotizing enterocolitis, high-grade intracranial hemorrhage, and also decreased mortality (Crowley et al. 1990). A further reduction in the severity of RDS can be achieved by the administration of exogenous surfactant to the neonate via an endotracheal tube (Suresh and Soll 2005). Exogenous surfactant therapy results in decreased surface tension in the alveoli and subsequent lessening of respiratory symptoms as the work of breathing lessens. In addition, the infant does not require as high concentrations of therapeutic oxygen or as high positive airway pressures if they are being mechanically ventilated.

The classic description of RDS on radiographs is diffuse fine granularity bilaterally (Fig. 8), effacement of normal pulmonary vascularity, and central air bronchograms. Untreated lungs are low in volume due to the diffuse acinar collapse (Fig. 9), although this is less commonly seen now as patients are usually intubated, receive positive pressure ventilation and are administered surfactant prior to an initial radiograph. Occasionally this may be more severe with near complete whiteout of the lungs (Fig. 10). Following administration of surfactant and application of positive airway pressure, these appearances may change, with improved lung volumes and clearance of the diffuse granularity (Fig. 11). This improvement can be rapid and can result in complete clearance, partial and symmetric clearance, or patchy and asymmetric clearance (Dinger et al. 1997;

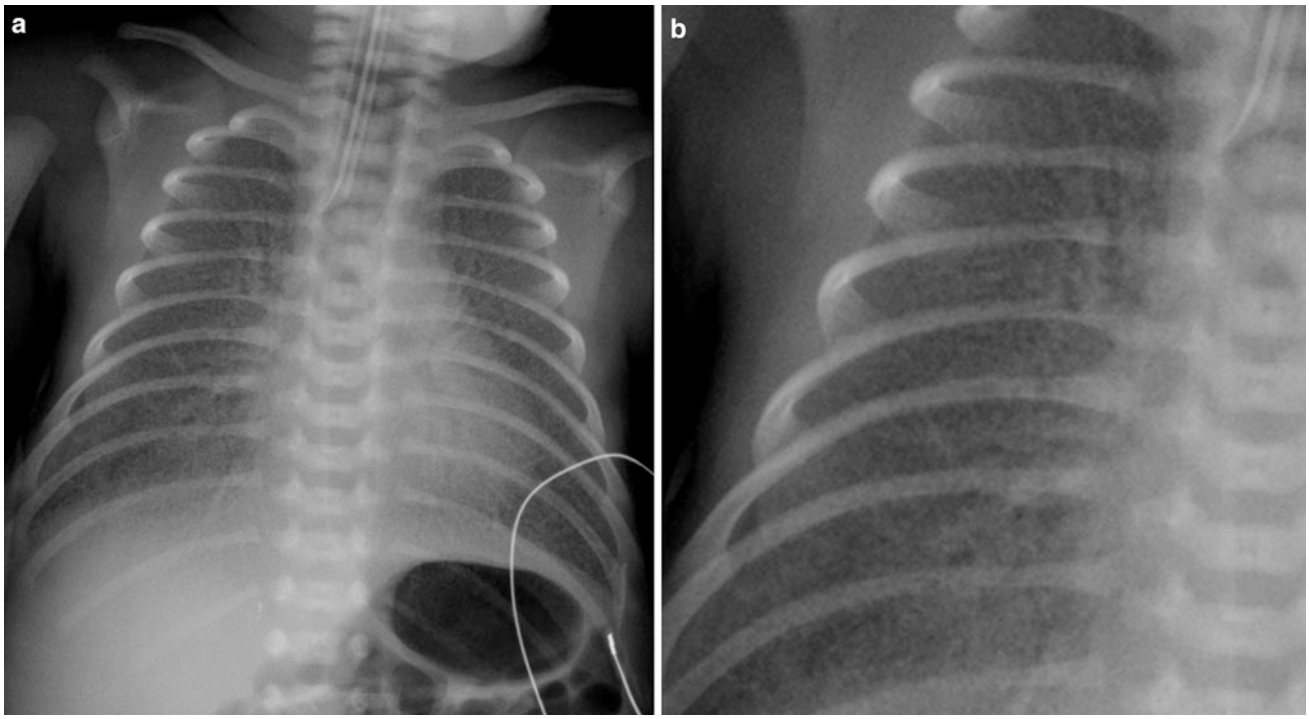

Fig. 8 Newborn with respiratory distress syndrome. **a** There are hazy opacities diffusely distributed bilaterally. **b** The granular nature of these opacities is well seen on the magnified image

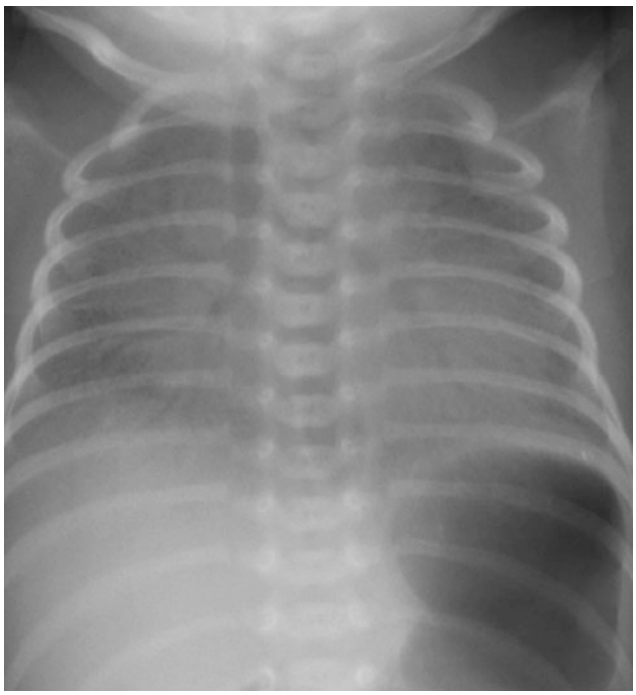

Fig. 9 Newborn with untreated respiratory distress syndrome. The lungs are low in volume with increased density bilaterally and subtle central air bronchograms

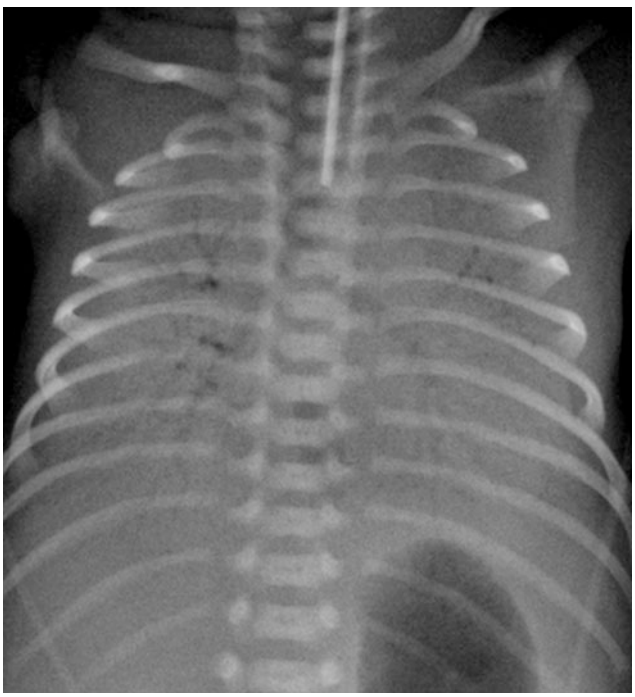

Fig. 10 Newborn with a "whiteout" appearance from respiratory distress syndrome. The lungs are densely opacified, obscuring the cardiac and diaphragmatic contours, and there are prominent air bronchograms bilaterally

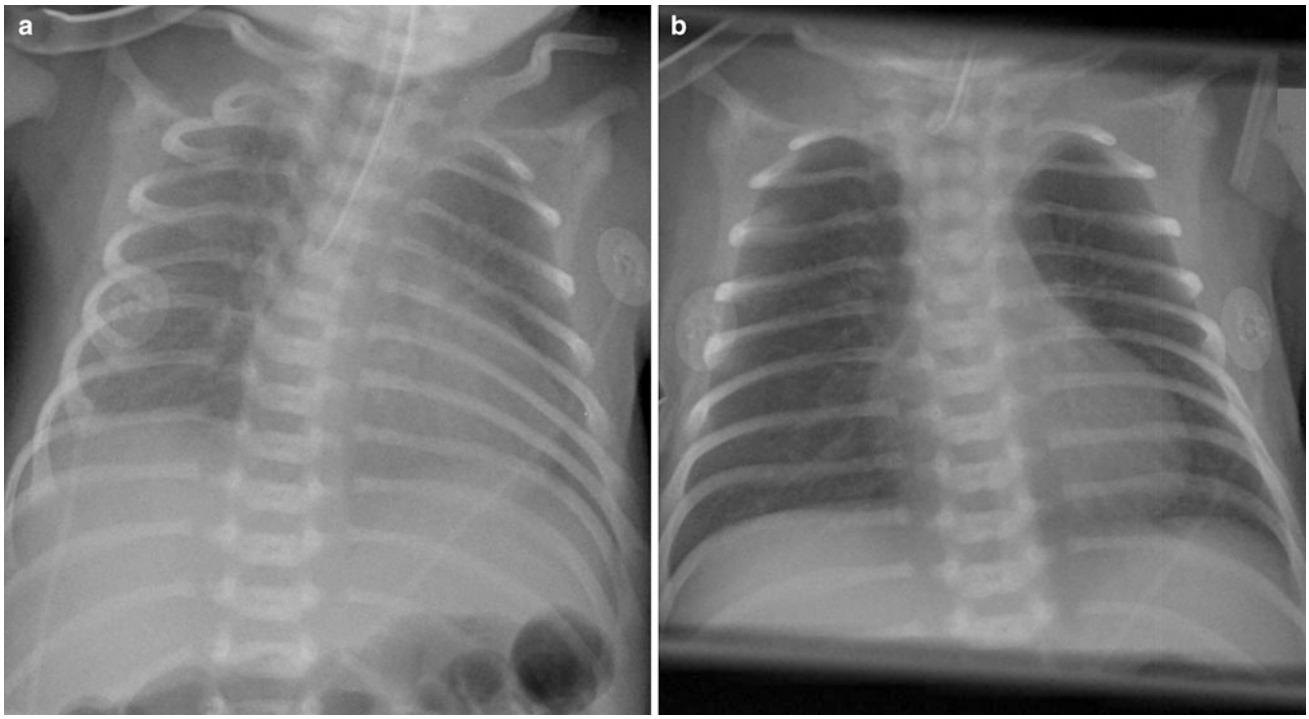

Fig. 11 Effect of surfactant administration. **a** Initial radiograph of a newborn with respiratory distress syndrome (RDS) taken following intubation. Fine granular opacities are present bilaterally. **b** Radiograph taken 12 h later demonstrates rapid clearing of these opacities following the administration of surfactant

Slama et al. 1999), which may reflect uneven distribution of the administered surfactant, insufficient surfactant administration, and regional differences in aeration (Slama et al. 1999) (Fig. 12). This uneven clearance can mimic other entities such as neonatal pneumonia. Over time, the radiographic appearance may reflect complications of RDS and prematurity such as an air leak phenomenon, superimposed infection, chronic lung disease related to the surfactant deficiency, i.e., bronchopulmonary dysplasia, persistent pulmonary hypertension, and edema. This edema can sometimes be severe and hemorrhagic and is secondary to a left-to-right shunt through a patent ductus arteriosus. This can occur rapidly as pulmonary arterial blood pressure decreases (van Houten et al. 1992). With treatment, localized hyperinflation can rapidly occur, mimicking air leaks (Cleveland 1995).

Very immature infants, less than 27 weeks gestation and weighing less than 1,000 g, may develop mild haziness bilaterally which clears with surfactant therapy. Subsequently, these infants may again develop mild diffuse haziness bilaterally, thought to reflect seepage of lung fluid into the interstitium through damaged arteriolar basement membranes, the so-called "leaky lung" (Swischuk et al. 1996). Because these infants are extremely immature their

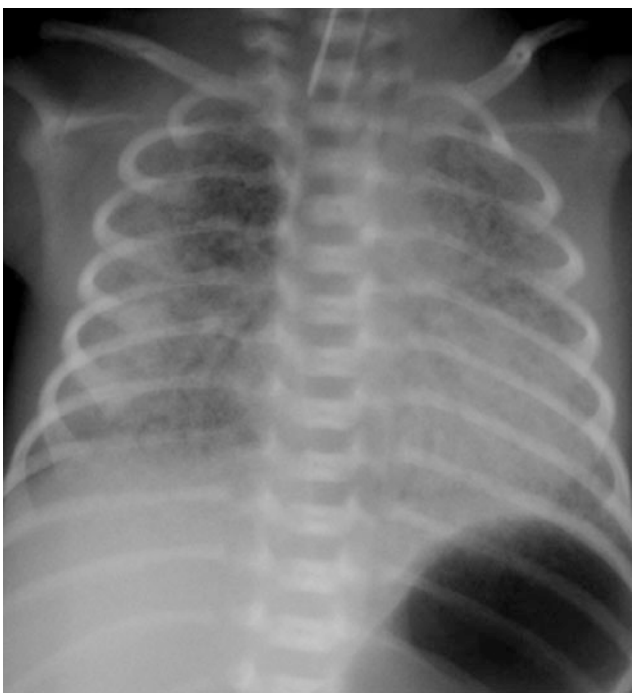

Fig. 12 Newborn premature infant with uneven aeration following the administration of surfactant. There is relative lucency in the right upper lobe and relatively increased density in both lung bases

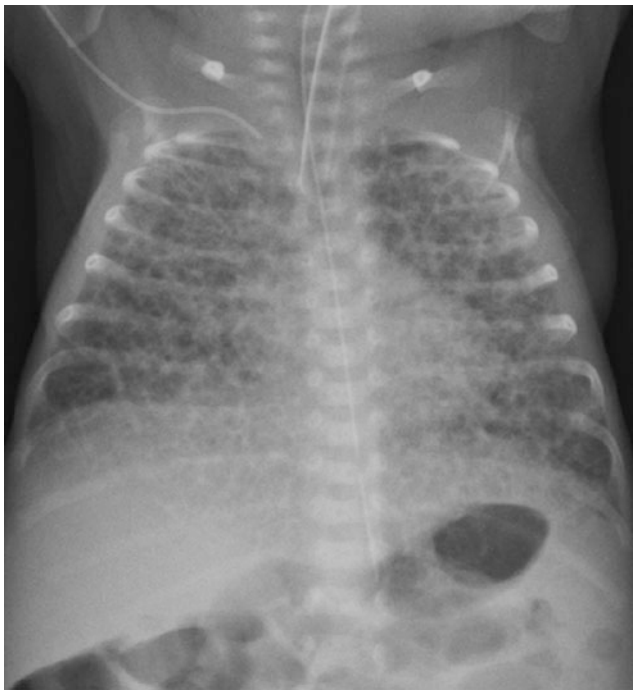

Fig. 13 Early development of chronic lung disease in a premature infant who is now 10 days of age. The lungs are hyperinflated and there are coarse reticular opacities bilaterally with intervening lucencies. These findings are typical of chronic lung disease

lungs are hypoplastic with a deficient number of alveoli and as a result they often require prolonged positive pressure ventilation and high oxygen concentrations. The resultant barotrauma can lead to the early development of coarse irregular reticular opacities bilaterally consistent with chronic lung disease (Cleveland 1995) (Fig. 13).

Respiratory Distress Syndrome was formerly known as Hyaline Membrane Disease, a term that is no longer favored as hyaline membranes are seen in other neonatal lung diseases and are not specific to RDS. It has been suggested that RDS is also a nonspecific descriptive term that could describe the clinical appearance of a number of respiratory illnesses and it has been proposed that the term Surfactant Deficiency Disease be used as this would more accurately reflect the underlying etiology (Swischuk and John 1996).

4.3 Bronchopulmonary Dysplasia

Bronchopulmonary dysplasia (BPD) is a chronic disorder of the lungs most commonly seen in low birth weight infants who were born prematurely. The pathogenesis of BPD is not completely understood but is complex and multifactorial in origin. Aside from prematurity, mechanical ventilation, and oxygen therapy, a number of other factors are known to contribute to the development of BPD including a patent ductus arteriosus or fluid overload, inflammation (alone or associated with infection), poor nutrition, and genetics (Bancalari et al. 2003). Infection may result from chorioamnionitis, may be acquired during delivery, or may be nosocomial.

Bronchopulmonary dysplasia was originally described as a disease of premature infants who were treated with oxygen and mechanical ventilation (Northway et al. 1967). The effects from the surfactant deficiency coupled with the ventilator-induced lung injury and the further damage from oxygen toxicity resulted in changes of alveolar septal fibrosis, alveolar cell hyperplasia, bronchiolar squamous metaplasia, and necrotizing bronchiolitis (Stocker 1986; Husain et al. 1998). This resulted in heterogeneous airway and parenchymal disease with hyperinflated but otherwise normal alveoli alternating with alveoli that are scarred to varying degrees along with smooth muscle hypertrophy and airway damage.

The patient population in this original description of BPD presented with severe RDS, had an average weight of 1,894 g and a gestational age of 33 weeks (Northway et al. 1967). Radiographically, this "old" BPD has four stages of development. Stage I (at 2–3 days) has changes of RDS with a diffuse granular pattern and central air bronchograms. Stage II (at 4–10 days) demonstrates almost complete opacification bilaterally. Stage III (10–20 days) shows small rounded lucencies with intervening areas of irregular opacification, while Stage IV (>1 month) has further enlargement of the lucent areas and thinning of the intervening linear opacities with hyperinflation of the lungs (Northway and Rosan 1968). These stages are less commonly seen today.

With modern therapy, a similar group of patients to that described in the initial description of BPD would have an excellent prognosis and would be unlikely to develop BPD. However, the incidence of BPD is not decreasing. This reflects significantly increased survival rates of neonates of less than 28 weeks gestation. Now the population that most commonly develops BPD has a gestational age of 22 to 28 weeks and weighs as little as 500 g. The lungs of a patient with this "new" BPD are at a more immature and simplified stage of development with fewer alveoli. Exposure to the extrauterine environment leads to a complete or partial arrest in acinar development (Husain et al. 1998). This extreme immaturity coupled with the frequent administration of prenatal maternal glucocorticoid therapy and postnatal extrinsic surfactant to the infant as well as less aggressive positive pressure ventilation and oxygen therapy, has resulted in a different histological and radiographic appearance and has also resulted in changing definitions of BPD. Currently the most widely accepted definition of BPD was issued in 2001 following a workshop held by the National Institute of Child Health and Human Development, the National Heart, Lung and Blood Institute, and the Office of Rare Diseases (Jobe and Bancalari 2001). This defines BPD as the need for supplemental oxygen for at

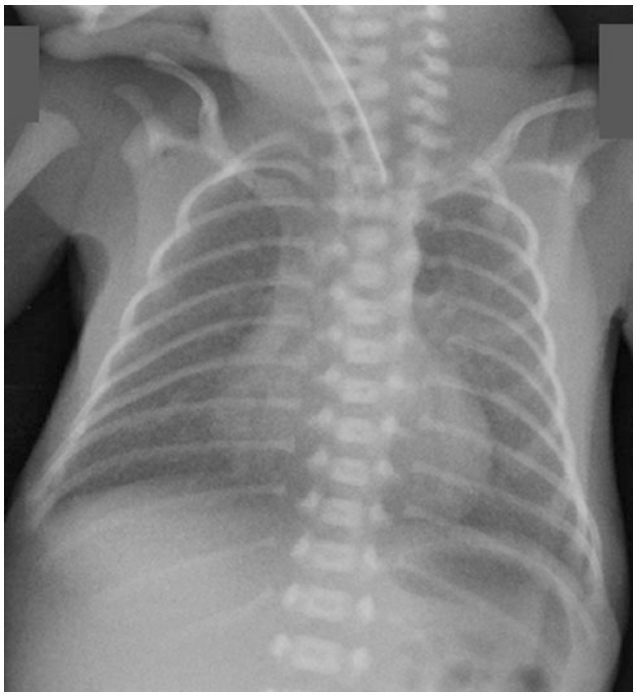

Fig. 14 Newborn 24 week gestation premature infant, first day of life. Mild hazy opacities are seen diffusely throughout both lungs

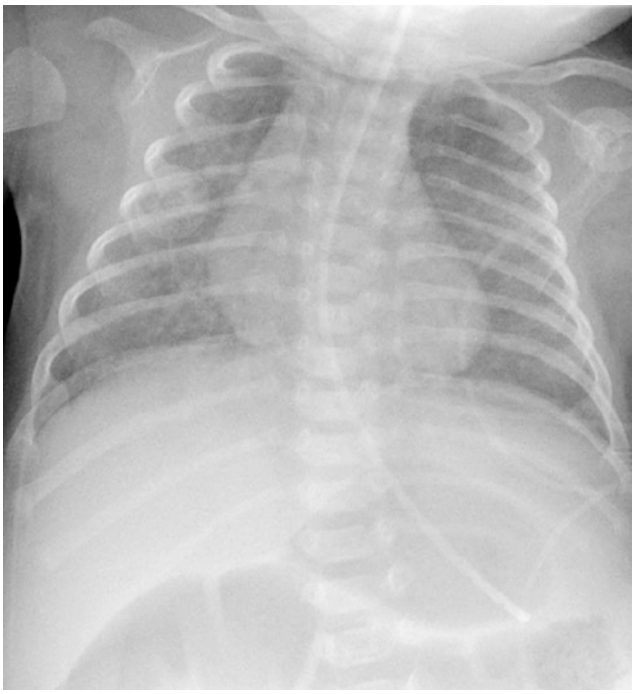

Fig. 15 Former 25 week gestation premature infant who is now 70 days old. Note the diffuse hazy opacification throughout both lungs. This is consistent with "new" bronchopulmonary dysplasia

least 28 days following birth and its severity is graded according to the extent of oxygen therapy and other respiratory support at 36 weeks postmenstrual age (gestational age at birth plus chronologic age) or at discharge, whichever comes first, if born at <32 weeks gestational age, or at 56 days postnatal age or at discharge, whichever comes first, if born at 32 or >weeks gestational age.

The histology of this "new" BPD in these extremely premature neonates demonstrates fewer but larger alveoli which have a more uniform caliber, with less interstitial inflammation and fibrosis. In these very immature neonates, chest radiographs initially may be clear or may demonstrate subtle diffuse hazy opacities bilaterally (Fig. 14). Over time, because they have fewer alveoli than normal, these neonates often require prolonged ventilator support and oxygen therapy. Although minimized, this support leads to chronic lung changes on chest radiographs. Most commonly this is a diffuse haziness bilaterally (Fig. 15). Less commonly they progress from this diffuse haziness to a more heterogeneous appearance with diffuse cystic lucencies and coarse reticular opacities bilaterally giving a "bubbly" appearance to the lungs similar in appearance to stages III and IV of the original radiographic description of BPD. This has been described as developing within a week of birth (Swischuk et al. 1996) but may also occur later as described in "old" BPD (Fig. 16) This appearance is seen when infants have a difficult post natal course that requires

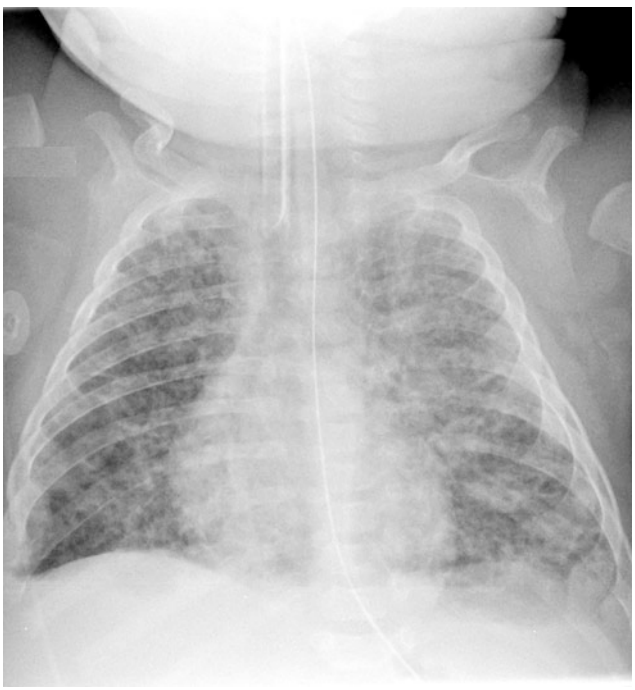

Fig. 16 Bronchopulmonary dysplasia in a 3-month-old former 24 week gestation infant. The lungs are hyperinflated. Coarse reticular opacities are present bilaterally with intervening small rounded lucencies giving a somewhat "bubbly" appearance to the lungs

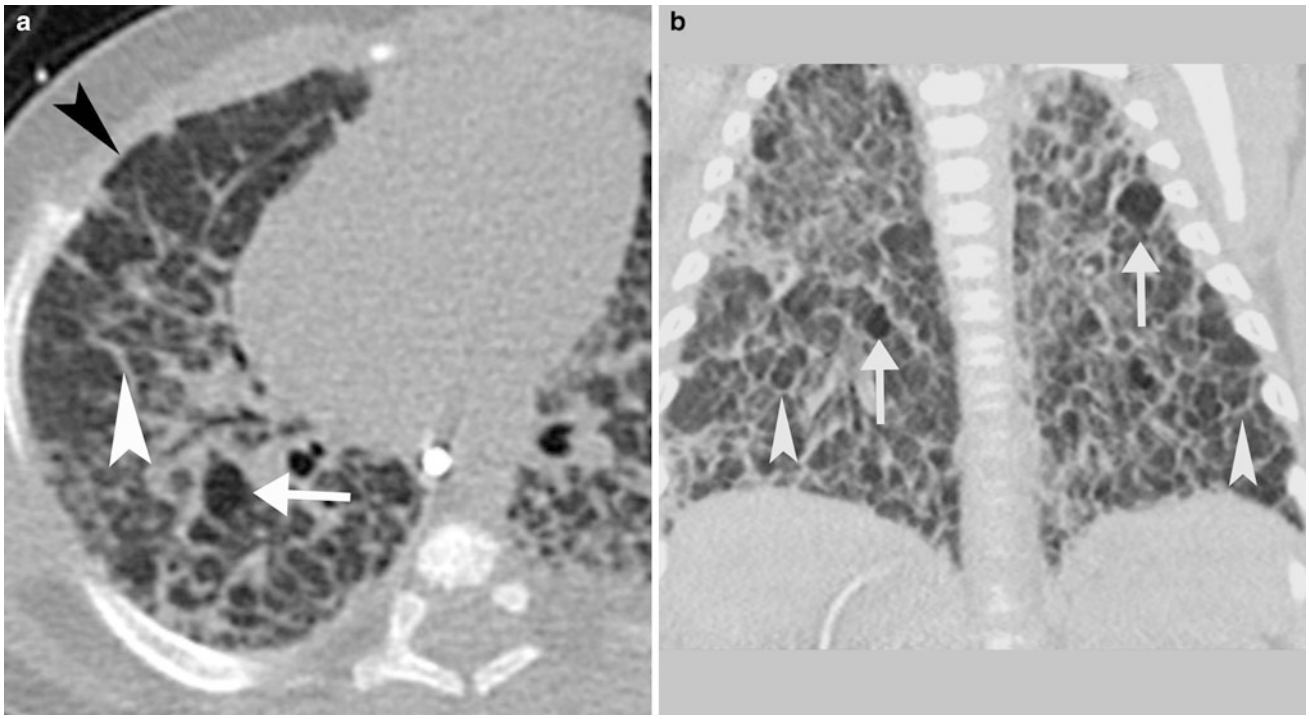

Fig. 17 CT in a 4-month-old former 24 week gestation infant with BPD. **a** and **b** There are thickened interlobular septa (*white arrowhead*) surrounding distended secondary pulmonary lobules, some of which are hyperlucent (*arrow*). Scattered subpleural cysts (*black arrowhead*) are also present

intubation and high pressure ventilation and high concentrations of supplemental oxygen.

CT is occasionally performed after the neonatal period in patients with BPD. These studies are sometimes requested in patients with ongoing respiratory difficulty in whom there is concern for a comorbid condition such as aspiration. If performed in infancy or early childhood, BPD will appear as hyperinflated lungs with distended secondary pulmonary lobules that are bounded by thickened interlobular septa (Fig. 17). Small subpleural cysts are frequently present. The distended secondary pulmonary lobules demonstrate air trapping on expiratory images. If imaged later in childhood, patients with longstanding BPD demonstrate overall increased lung volumes with mosaic attenuation and air trapping. There are linear and band-like opacities that represent areas of atelectasis and scarring. Subpleural triangular opacities that sometimes are associated with the linear opacities are thought to represent pseudo-fissuring (Oppenheim et al. 1994) (Fig. 18).

4.4 Meconium Aspiration Syndrome

Meconium aspiration syndrome (MAS) is defined as respiratory distress in an infant born through meconium-stained amniotic fluid with characteristic radiological changes and

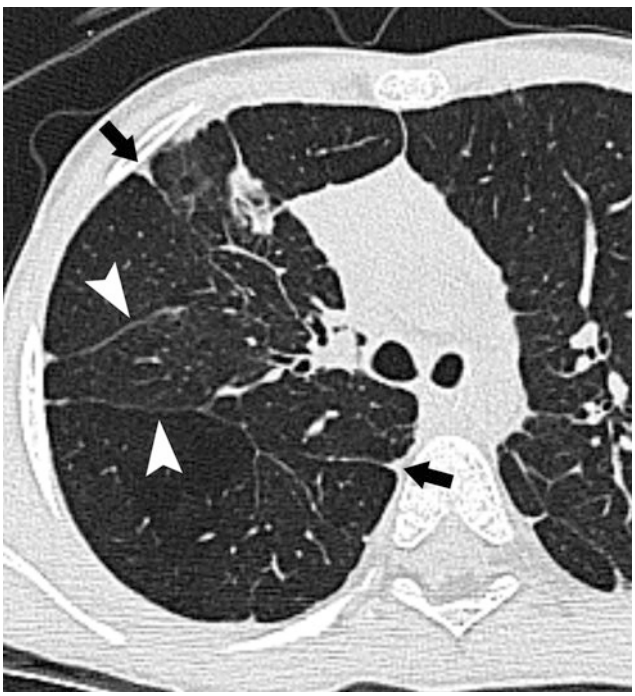

Fig. 18 CT in a 5-year-old former 24 week gestation premature infant. Axial CT images demonstrates multiple linear bands (*white arrowheads*), many extending to the pleural surface and many associated with triangular pleural-based opacities (*black arrowheads*). Subtle mosaic attenuation of the parenchyma is also present

whose symptoms cannot be otherwise explained (Wiswell et al. 1990). MAS occurs when meconium is aspirated into the lungs before or during labor and delivery. Staining of amniotic fluid is seen in 8–20 % of births, with MAS developing in approximately 20 % of these cases (Usta et al. 1995).

Meconium aspiration syndrome is a disease of term and especially of postterm neonates and of small for gestational age infants (Clausson et al. 1999). Passage of meconium in utero is rare before 37 weeks of gestation due to immaturity of the colon (Matthews and Warshaw 1979). Infants with MAS born after 40 weeks of gestation are more likely to require intubation than those born earlier (Dargaville et al. 2006). Factors predisposing to in utero passage of meconium include advanced maternal age, placental insufficiency, fetal distress, oligohydramnios, preeclampsia, and maternal drug use, particularly of cocaine (Swarnam et al. 2012).

Aspiration of meconium affects the lungs in a number of ways. If an airway is completely occluded, this can result in atelectasis. Partial occlusion of the airway may result in a ball-valve phenomenon with hyperinflation of the portion of the lung that is distal to the meconium plug. This can result in an air leak phenomenon if there is progressive overinflation. Although the primary constituent of meconium is water, it also contains many compounds such as pancreatic juices, bile, and gastrointestinal secretions that irritate the airways and alveoli, resulting in a chemical pneumonitis. Although the aspiration may be focal, the influx of inflammatory cells and chemical mediators in inflammation such as interleukins and tumor necrosis factors can induce a more widespread pneumonitis involving much of the lung (Cleary and Wiswell 1998). Surfactant lining the alveoli is deactivated by meconium which also may decrease the amount of surfactant produced (Dargaville et al. 2001; Janssen et al. 2006). This combination results in surfactant dysfunction, further promoting atelectasis and diminished aeration. The resultant hypoxia, hypercapnia, and respiratory acidosis lead to pulmonary arterial vasoconstriction. This may be compounded by the effects of preexisting chronic intrauterine hypoxia leading to thickening of the arteriolar walls. The increased resistance in the pulmonary vascular bed can result in persistent pulmonary hypertension of the newborn (PPHN), further worsening the degree of hypoxia and difficulty with ventilation.

Supplemental oxygen is the mainstay of therapy and may be all that is required (Singh et al. 2009) but more aggressive support is not unusual; intubation and mechanical ventilation is required in up to one-third of patients (Cleary and Wiswell 1998). In cases where adequate oxygenation cannot be achieved with mechanical ventilation, extracorporeal membrane oxygenation may be needed. Surfactant therapy, corticosteroids, and nitric oxide have been used as adjuvant therapies (Dargaville 2012).

Over the past decades, a reduction in the risk of MAS has been attributed to better obstetric practices, in particular, to avoidance of postmaturity and to expeditious delivery when fetal distress has been noted (Yoder et al. 2002). However, the mortality in patients with MAS remains considerable at 7 % (Dargaville et al. 2006), usually related to pulmonary hypertension and cerebral hypoxic ischemic injury. Approximately 10 % of patients intubated for MAS will develop a pneumothorax. This is an indicator of disease severity with a mortality rate of 42 % (Dargaville et al. 2006).

The most significant long-term morbidity in MAS is neurological injury. A diagnosis of MAS in the neonatal period confers a considerable risk of cerebral palsy (5–10 %) and global developmental delay (15 %) (Beligere and Rao 2008). Pulmonary sequelae are also seen. In the first year of life, up to half of infants will demonstrate respiratory symptoms with wheezing and coughing (Yuksel et al. 1993). Older children may exhibit evidence of airway obstruction, hyperinflation, and airway hyperreactivity, but appear to have normal aerobic capacity (Swaminathan et al. 1989).

On imaging a variety of appearances may be seen. The lungs are usually well inflated. Some cases may demonstrate symmetric fine reticular opacities bilaterally or may have more streaky opacities in the perihilar regions bilaterally, a radiographic appearance that can be difficult to differentiate from TTN (Fig. 19). In more severe cases, the lungs are hyperinflated with coarser linear and band-like opacities bilaterally reflecting atelectasis alternating with lucent areas corresponding to air trapping (Fig. 20). More ill-defined confluent opacities can be seen and relate to pneumonitis (Fig. 21). Findings may be symmetric but can be quite asymmetric. Small pleural effusions may be present (Gooding and Gregory 1971) (Fig. 22). Because of difficulty with ventilation and adequate oxygenation, air leaks are not uncommon and result in pneumothorax and/or pneumomediastinum in approximately 10 % of patients (Wiswell et al. 1990). Depending on the severity of the aspiration, the findings may resolve within 48 h or they may persist with more gradual improvement. However, the severity of the appearances on imaging does not always correlate with the clinical findings.

4.5 Neonatal Pneumonia

Neonatal pneumonia results from infection that can arise by a number of routes. Infection can be acquired in utero either transplacentally or via an ascending infection of amniotic fluid, in the perinatal period by inhalation of infected material during or immediately following birth, or in the neonatal period. Predisposing factors to neonatal pneumonia

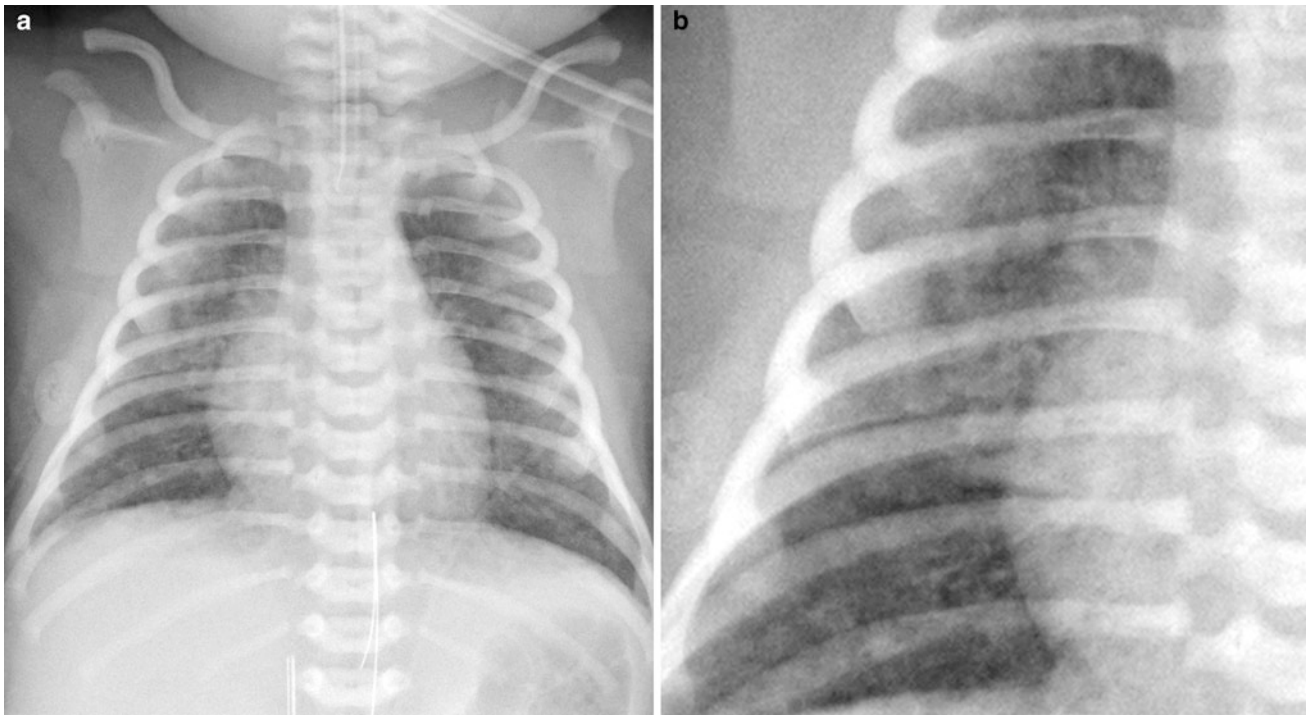

Fig. 19 Mild changes of meconium aspiration. **a** and **b** Mildly coarsened reticulonodular opacities are present bilaterally, most prominent in the right perihilar region. Without the history of meconium aspiration the appearance could be mistaken for transient tachypnea of the newborn or neonatal pneumonia

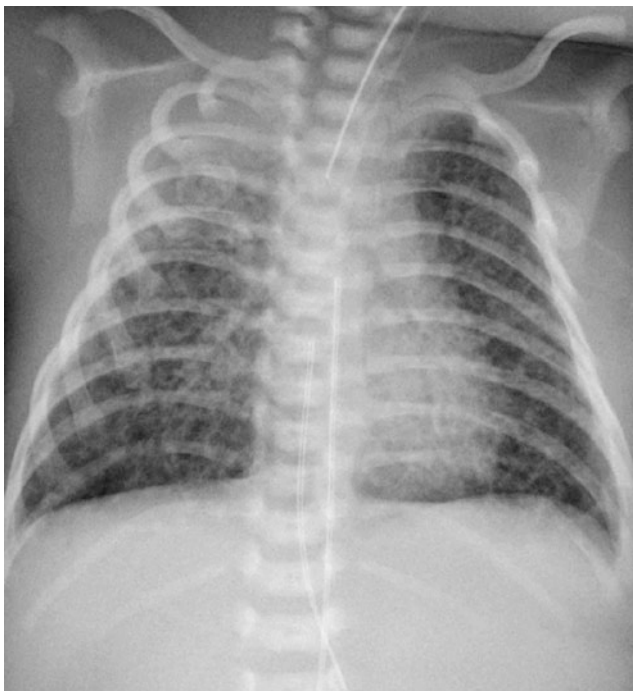

Fig. 20 Newborn term infant with meconium aspiration. The lungs are hyperinflated. Coarse reticulonodular opacities are present throughout both lungs with more confluent opacification in the right upper lobe

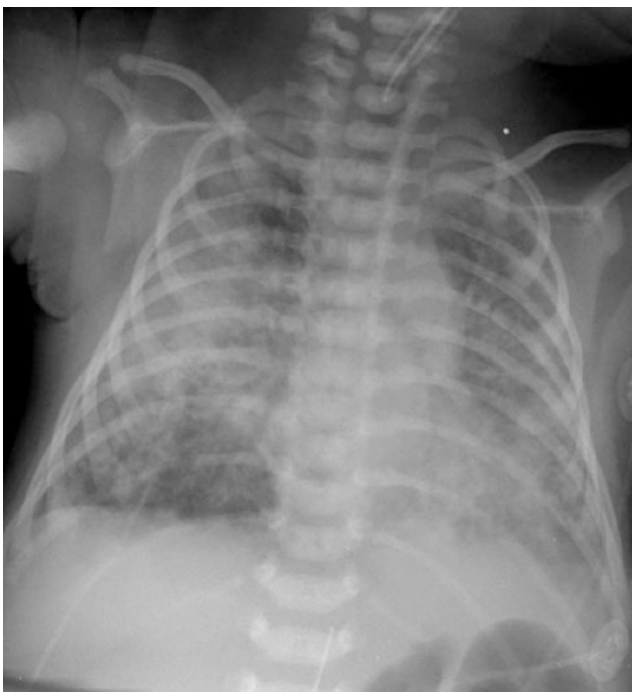

Fig. 21 Meconium aspiration with pneumonitis. The lungs are diffusely abnormal bilaterally with confluent opacities in the right mid lung and the left lower lobe. These confluent opacities are consistent with areas of pneumonitis and atelectasis

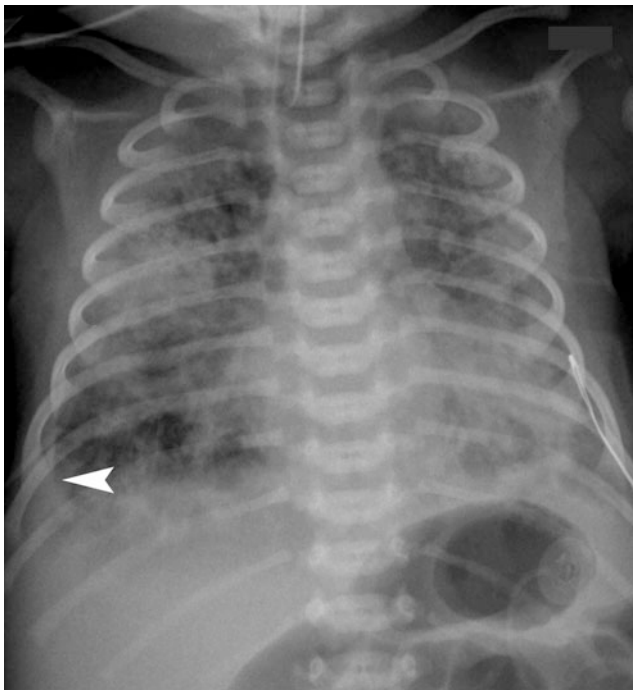

Fig. 22 Meconium aspiration with an effusion. Coarse reticular opacities are present bilaterally. More focal opacities are present in the peripheral left mid lung and in the left lower lobe with relative lucency at the right lung base suggesting air trapping. In addition, there is a small right pleural effusion (*arrowhead*)

include prolonged rupture of membranes, chorioamnionitis, maternal vaginal colonization, prematurity, and prolonged hospitalization.

In the developing world, neonatal infection accounts for significant morbidity and mortality. WHO figures estimates 800,000 neonatal deaths per year from respiratory infection in developing nations (Garenne et al. 1992). The estimated incidence in developed countries is less than 1 % in term infants and closer to 10 % in preterm and low birth weight infants (Dennehy 1987).

Neonatal pneumonia is termed as early onset if it manifests within the first 7 days of life, and the majority present within 48–72 h. Early onset pneumonia, especially when presenting in the immediate postnatal period, is often associated with generalized sepsis and a poorer prognosis. Pneumonia occurring beyond 7 days is considered late-onset, is usually not associated with sepsis, and generally has a better prognosis. Bacteria are the cause of most early and late-onset pneumonias.

The majority of early onset pneumonias in term and near-term neonates are caused by group B beta hemolytic streptococcus (GBS) , a common colonizer of the female genitourinary tract. The incidence of GBS pneumonia has decreased due to increased testing for GBS colonization of the mother's genitourinary tract and increased use of intrapartum antibiotics (Jeffery and Moses Lahra 1998). *Escherichia coli* is now the most common cause of pneumonia in very low birth weight infants (<1500 g) (Stoll et al. 2005). Numerous other bacteria can cause ascending infection and include *Hemophilus influenza,* other gram-negative bacilli, *Listeria monocytogenes, Enterococcus*, and *Staphylococcus*. In very low birth weight infants, *Ureaplasma urealyticum* is frequently recovered from endotracheal aspirates shortly after birth. It has been associated with the development of early onset of chronic lung disease and a poor prognosis (Kotecha et al. 2004).Viral and fungal organisms are rare causes of neonatal pneumonia. The most common viral pathogens include herpes simplex virus, respiratory syncytial virus, and adenovirus.

Most late-onset pneumonias are also caused by bacteria. These infections are usually nosocomial, especially in preterm infants, but can also be community-acquired following discharge. Organisms involved include *Pseudomonas aeruginosa*, *E. coli, Streptococcus pyogenes*, *Staphylococcus aureus*, and *Streptococcus pneumoniae*. Chlamydia trachomatis, an obligate intracellular parasite, causes a late-onset pneumonia that can manifest between 4 and 12 weeks of age (Hammerschlag 1994).

Early onset neonatal pneumonia can present with non-specific signs of infection, including temperature instability, apnea or tachypnea, tachycardia or bradycardia, hypoglycemia, abdominal distension, and listlessness. More specific signs of respiratory infection including grunting, retractions, and nasal flaring are variably present. Infected neonates may be gravely ill as septicemia is common in early onset pneumonia. In utero infection can result in the infant being still-born.

Chest radiographs in neonatal pneumonia are often non-specific as the appearance can overlap with other neonatal illnesses such as RDS, TTN, and meconium aspiration. The radiographic appearance can also vary depending on the responsible organism. As a consequence, the findings of neonatal pneumonia on imaging can be quite varied and radiographic diagnosis is difficult especially if not correlated with the clinical setting. Unlike pneumonia in older children, an isolated focal consolidation is rare in neonatal pneumonia (Haney et al. 1984). Most commonly, radiographs demonstrate bilateral ill-defined air-space opacities (Fig. 23) but these opacities can be diffuse and homogeneous (Haney et al. 1984). Multifocal coarse opacities may also be seen, similar to meconium aspiration (Fig. 24). A pattern very similar to RDS with diffuse granular opacities with central air bronchograms can be seen, usually with GBS infection (Ablow et al. 1976) (Fig. 25). However, small pleural effusions may be present which suggest infection rather than surfactant deficiency (Leonidas et al. 1977) (Fig. 26). In addition, the lungs are usually well inflated, rather than the low lung volumes seen in RDS (Ablow et al. 1976). Chlamydia trachomatis pneumonia may be preceded by conjunctivitis.

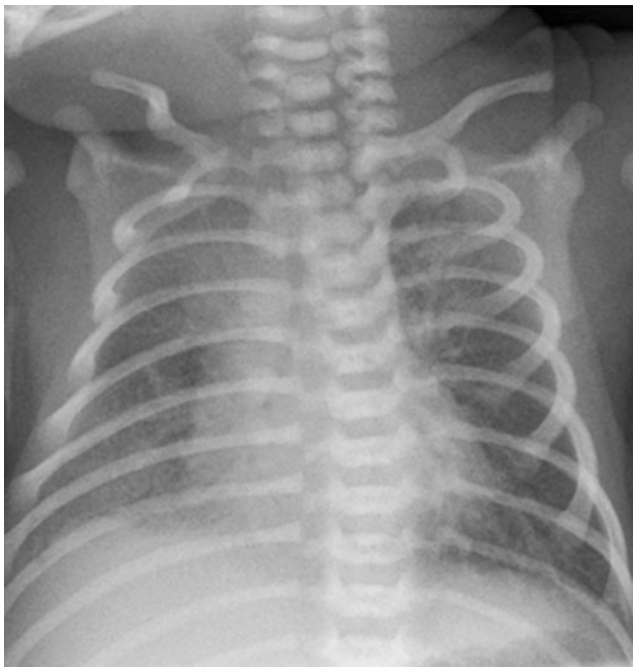

Fig. 23 Neonatal pneumonia. The patient was born at 39 weeks gestation. The lungs are well inflated and there are diffuse fine reticulonodular opacities bilaterally. More confluent opacities are seen in the bilateral upper and right lower lobes. Blood cultures grew group B streptococcus

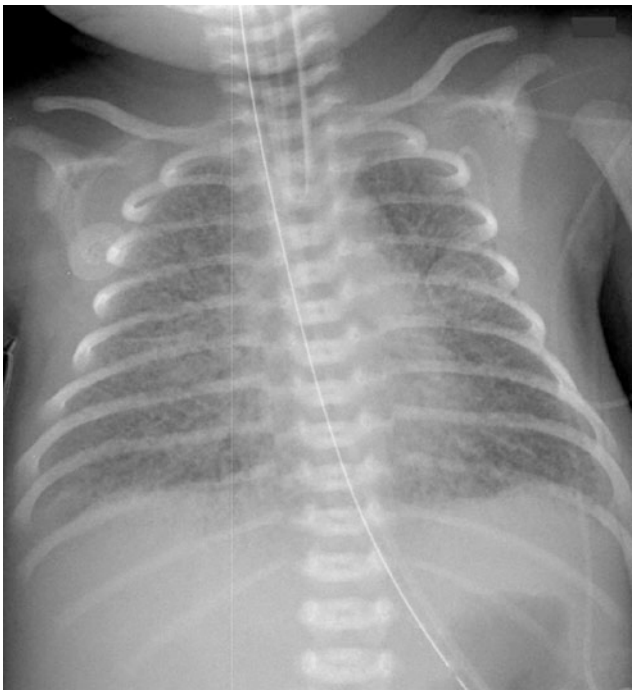

Fig. 25 Neonatal pneumonia appearing like respiratory distress syndrome. There are diffuse symmetrical fine reticular and granular opacities bilaterally, findings that can be seen with respiratory distress syndrome. However, the patient was a term infant and grew group B streptococcus from blood cultures

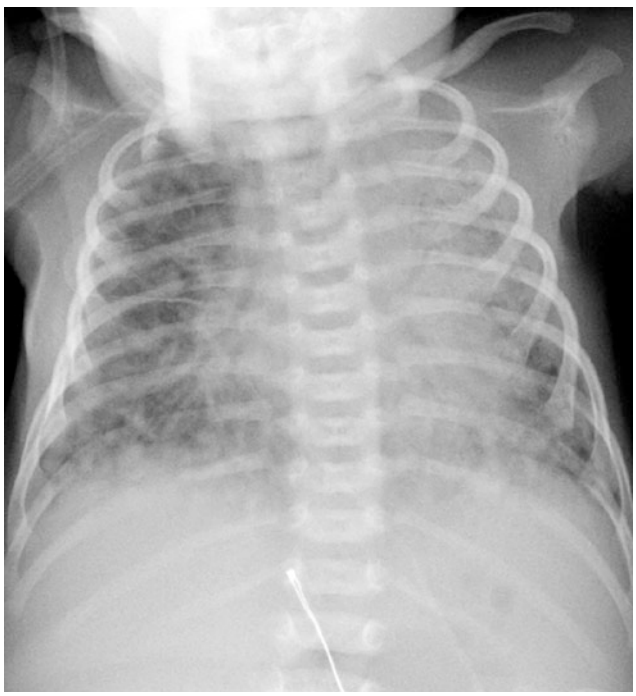

Fig. 24 Neonatal pneumonia appearing like meconium aspiration. Bilateral coarse reticular and nodular opacities are present diffusely, most confluent in the left upper lobe. Washings from a bronchoalveolar lavage isolated herpes simplex virus

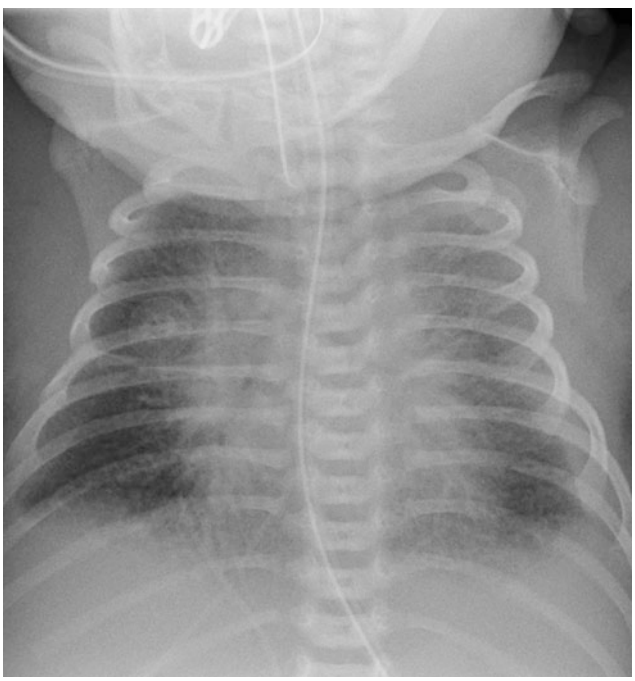

Fig. 26 Neonatal pneumonia and effusions. Fine reticular and granular opacities are present bilaterally which suggest respiratory distress syndrome. However, there are bilateral pleural effusions which make neonatal pneumonia more likely. Cerebrospinal fluid cultures grew group B streptococcus

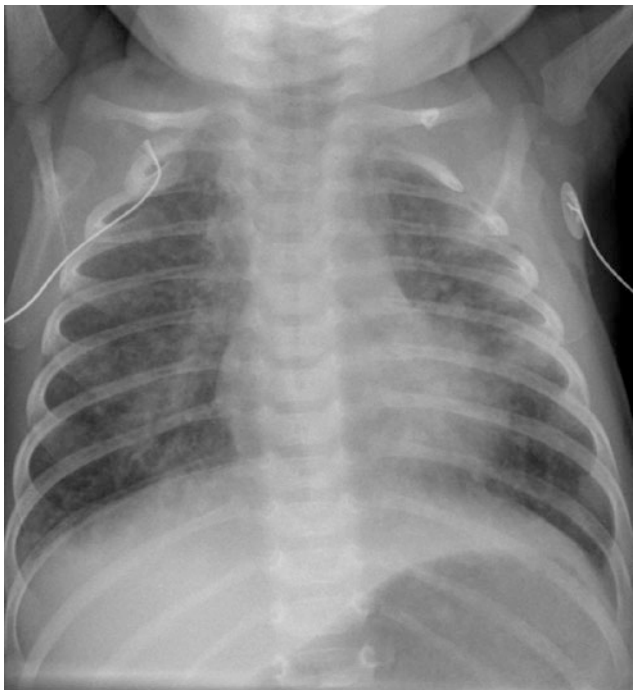

Fig. 27 Eight week old term female with chlamydia pneumonia. The lungs are hyperinflated and there are coarse reticular opacities bilaterally with more focal opacities in the lingula

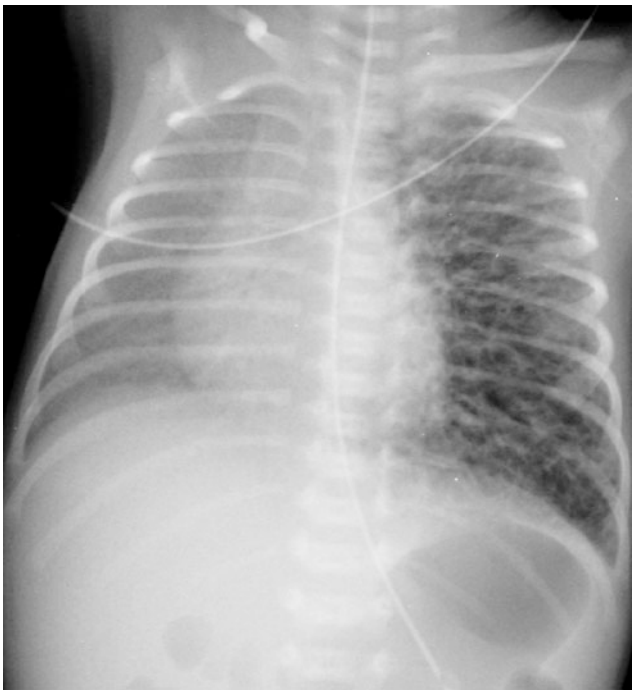

Fig. 28 Pulmonary interstitial emphysema in a patient on CPAP. Lucencies are seen throughout the left lung with intervening coarse reticular opacities. The patient was on continuous positive airway pressure for respiratory distress syndrome and had never been intubated

Radiographs demonstrate hyperinflation with bilateral ill-defined opacities, especially in the perihilar regions (Hammerschlag 1994) (Fig. 27).

5 Air Leak Phenomenon

Pulmonary air leaks occur when air escapes from the lung into surrounding structures or compartments. Airway overdistension results in rupture of the alveoli and passage of air into the perivascular and peribronchial spaces, resulting in pulmonary interstitial emphysema (PIE) . Alternatively, it can track peripherally to the pleural surface and rupture into the pleural space to create a pneumothorax or it can track centrally and enter the mediastinum to create a pneumomediastinum. Rarely, the air will track into the pericardial space to form a pneumopericardium, track inferiorly into the abdomen to form a pneumoperitoneum, or enter one of the pulmonary veins and create an air embolus which can be rapidly fatal. An air leak most often occurs as a result of intubation and mechanical ventilation. However, it can also occur in patients who only have had continuous positive airway pressure (CPAP) applied (Fig. 28). Air leaks are most often associated with RDS, meconium aspiration syndrome, and conditions that cause pulmonary hypoplasia.

5.1 Pulmonary Interstitial Emphysema

Pulmonary interstitial emphysema can compress the airways resulting in poorly compliant lungs that are difficult to ventilate as they will not inflate and deflate with respiration. The increased pressure in the interstitium can also compress pulmonary veins resulting in impaired venous return and diminished cardiac output (Plenat et al. 1978).

Radiographically, PIE is seen as tubular lucencies extending towards the mediastinum and small cystic lucencies (Fig. 29). PIE can be unilateral or bilateral, focal or diffuse. Diffuse unilateral PIE can result in mediastinal shift into the collateral hemithorax. Occasionally the small cystic lucencies may coalesce into a larger focal intra-parenchymal lucency termed a pneumatocele (Fig. 30). Usually PIE resolves over time, but it can persist and form a cystic mass that may result in mass effect and respiratory compromise and mimic a congenital pulmonary airway malformation (Donnelly et al. 2003). Without clinical history and comparing to prior imaging, diffuse PIE may be difficult to differentiate from bronchopulmonary dysplasia.

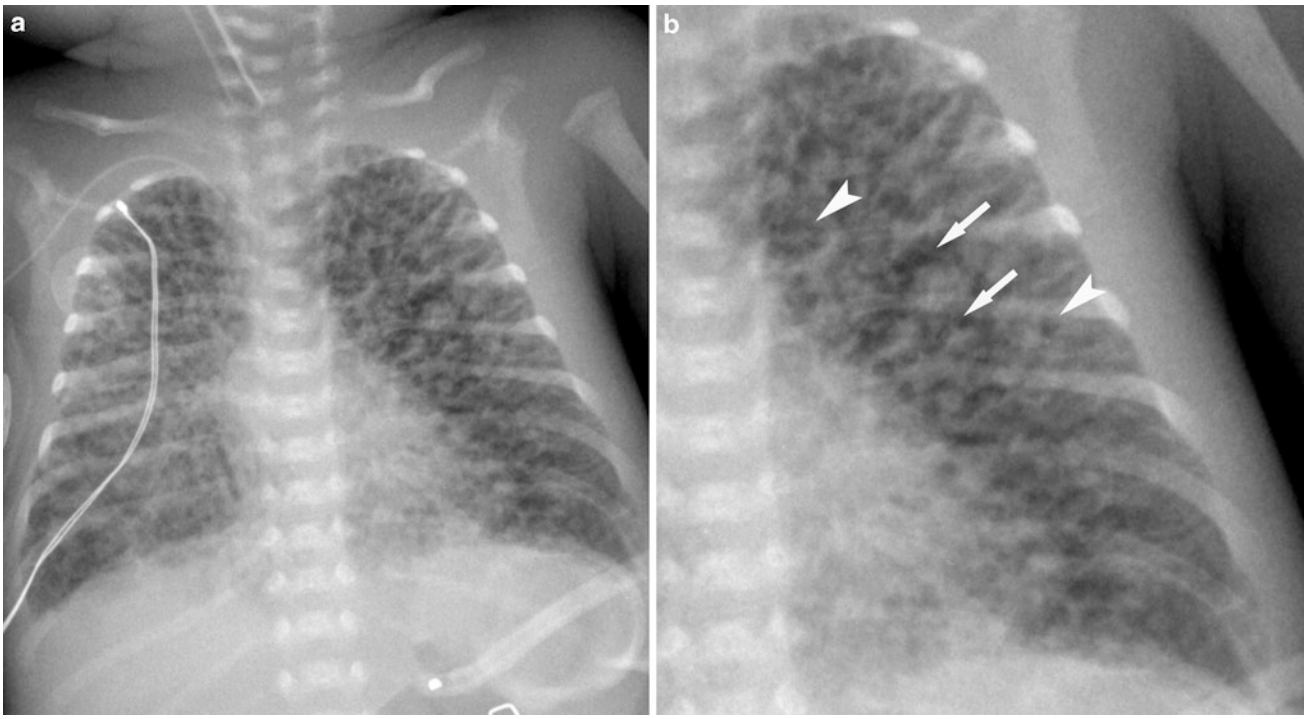

Fig. 29 Diffuse bilateral pulmonary interstitial emphysema. **a** There are mixed lucencies and streaky opacities diffusely throughout both lungs. **b** On the magnified view, tubular lucencies are seen radiating from the hilum (*arrows*) as well as scattered cystic lucencies (*arrowheads*)

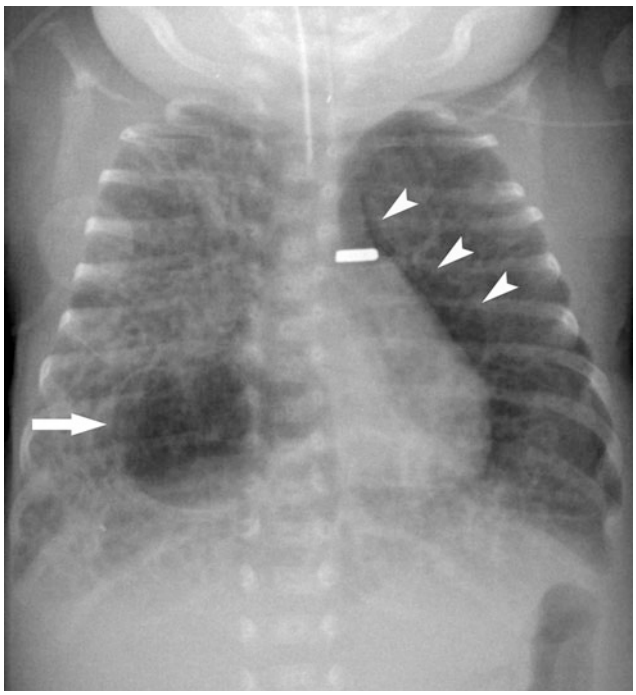

Fig. 30 Pulmonary interstitial emphysema and a pneumatocele. There is PIE and a rounded lucency in the right lung base consistent with a pneumatocele (*arrow*). There is also a subtle left pneumothorax indicated by overall mild decreased attenuation of the left hemithorax as well as a lucency adjacent to the left heart border (*arrowheads*)

5.2 Pneumothorax

When the air leak results in air entering the pleural space, a pneumothorax is formed. The lung collapses toward the hilum and a sharp interface is seen between the collapsed lung and the air in the pleural space. If air enters the pleural space under positive pressure and cannot exit, a tension pneumothorax may develop. This results in deviation of the mediastinum to the contralateral side and flattening or inversion of the ipsilateral hemidiaphragm (Fig. 31). This is a potentially life threatening emergency as systemic venous return may be obstructed by the increased intrathoracic pressure. Obstruction to venous return may result in a narrow appearance of the heart (Fig. 32). Fortunately, large tension pneumothoraces are easily identified. Less easily appreciated are smaller pneumothoraces. This is especially true in neonates in the intensive care setting as these images are obtained with the patient in the supine position. This results in pleural air preferentially collecting anteriorly and medially and an air-pleural interface may not be appreciable at the periphery of the lung (Moskowitz and Griscom 1976). On radiographs, a subtle lucency either focally or diffusely may overlie the lung. Often this lucency is anteromedially positioned and results in sharp margination of the heart, other mediastinal structures or the hemidiaphragm (Fig. 30).

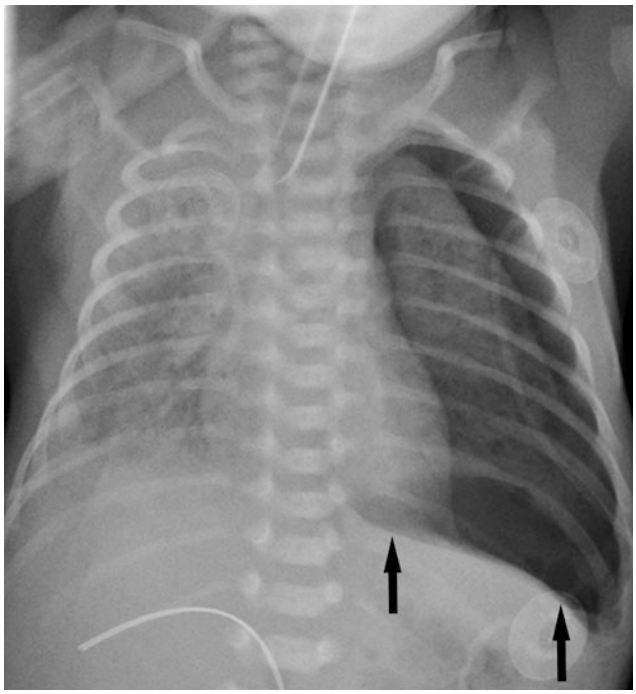

Fig. 31 Respiratory distress syndrome complicated by a tension pneumothorax. The left hemidiaphragm is flattened (*arrows*) and the mediastinal structures are displaced into the right hemithorax

Occasionally, the ipsilateral costophrenic angle may be asymmetrically prominent and well-defined, the "deep sulcus sign" (Fig. 33). Confirmation of the presence or absence of a pneumothorax may be obtained by performing a cross-table lateral or lateral decubitus view.

Occasionally skin folds can mimic the appearance of a pneumothorax. On closer examination, they can usually be correctly identified as the folds often extend beyond the edge of the thoracic cavity and usually do not follow the expected contour of the lung edge (Fig. 34).

Spontaneous pneumothoraces that are not associated with pulmonary disease usually occur in the immediate postnatal period. These are seen in 1 % of neonates with approximately 10 % of these infants being symptomatic (Greenough et al. 1992).

5.3 Pneumomediastinum

If interstitial air tracks centrally, it can enter the mediastinum and form a pneumomediastinum. An isolated pneumomediastinum is usually not a clinical problem. Radiographs demonstrate a lucent line sharply marginating the mediastinal structures. In neonates the prominent thymus can be outlined and occasionally elevated, giving a characteristic appearance that has been termed the "angel wing" sign"(Fig. 35). This is usually easily identified, but if the lobes of the thymus are markedly displaced then they can simulate upper lobe opacification (Fig. 36). Another sign of a pneumomediastinum is the "continuous diaphragm" signthat is seen when air is interposed between the diaphragm and the inferior surface of the heart. Mediastinal air, if extensive, can track superiorly into the neck or inferiorly into the peritoneal cavity (Fig. 37).

5.4 Pneumopericardium

Air tracking medially can enter the pericardial sac. A small amount of air in the pericardial sac is very difficult to distinguish from pneumomediastinum. A large pneumopericardium is more easily differentiated from a pneumomediastinum as the air is confined to the pericardial sac, creating a focal lucency around the heart which does not extend beyond the confines of the pericardium (Fig. 38). The pericardium itself may be visualized as a thin stripe separate from the surface of the heart. A large pneumopericardium can result in a pericardial tamponade and decreased cardiac output. Very rarely, pulmonary interstitial air can enter the pulmonary veins and result in an air embolus that is often fatal.

6 Lines and Tubes

When evaluating a chest radiograph, it is important to closely study the position of the support apparatus. Many patients in neonatal care units have umbilical venous and arterial catheters (UVC and UAC, respectively), endotracheal tubes (ETT), and gastric tubes, and malpositioning of these devices can lead to complications with resultant prolonged hospital stay, long-term morbidity, and even death. It can be easy to overlook the position of these devices, especially when they overlap or when there are confounding distractions like external wires and leads.

A correctly placed umbilical venous catheter follows the single anteriorly positioned umbilical vein that courses cephalad from the umbilicus into the liver along the free edge of the falciform ligament, usually at or slightly to the right of midline. Within the liver, the umbilical vein intersects with the left branch of the portal vein before continuing cranially as the ductus venosus to the middle or left hepatic vein, ultimately draining into the inferior vena cava (IVC) and right atrium. Optimal positioning of the tip of a UVC is below the right atrium within the suprahepatic IVC, between the T9 and T12 vertebral body levels (Fig. 39). A UVC can take an abnormal course prior to reaching its optimal position in the IVC or it can be advanced beyond the IVC. Abnormal positions prior to reaching the IVC include within the right or left branches of the portal vein (Fig. 40), the main portal vein, the superior mesenteric vein

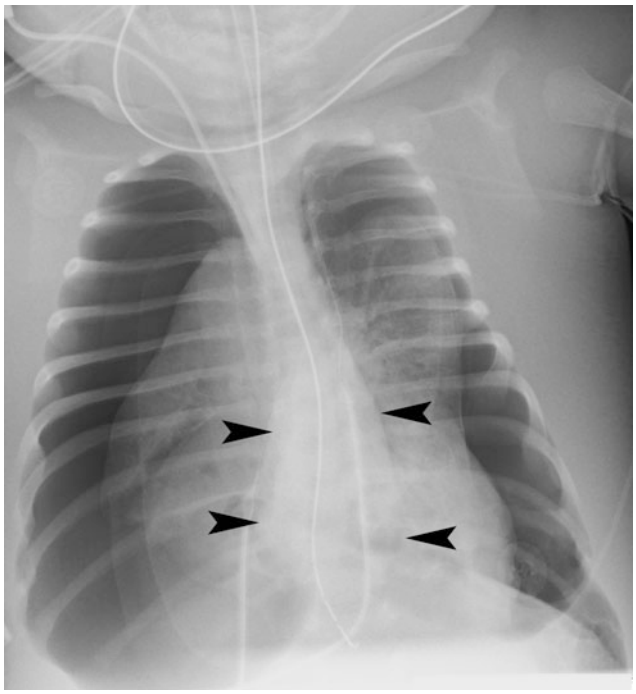

Fig. 32 Bilateral tension pneumothoraces with impaired venous return. Both hemidiaphragms are inverted and the heart has a narrow configuration (*arrowheads*) related to diminished central venous return

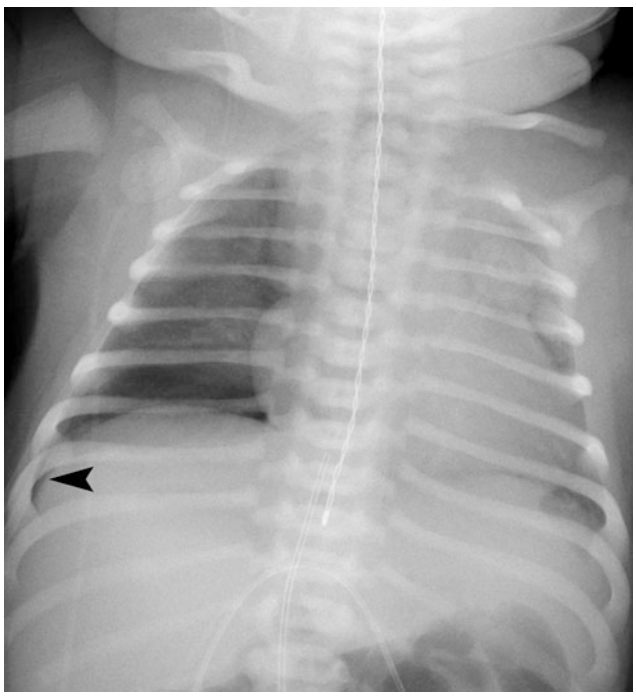

Fig. 33 Deep sulcus sign. Notice the asymmetric lucency of the right hemithorax, the lucent margination of the right side of the mediastinum and right hemidiaphragm, and the deeper than usual appearance of the right costophrenic sulcus (*arrowhead*)

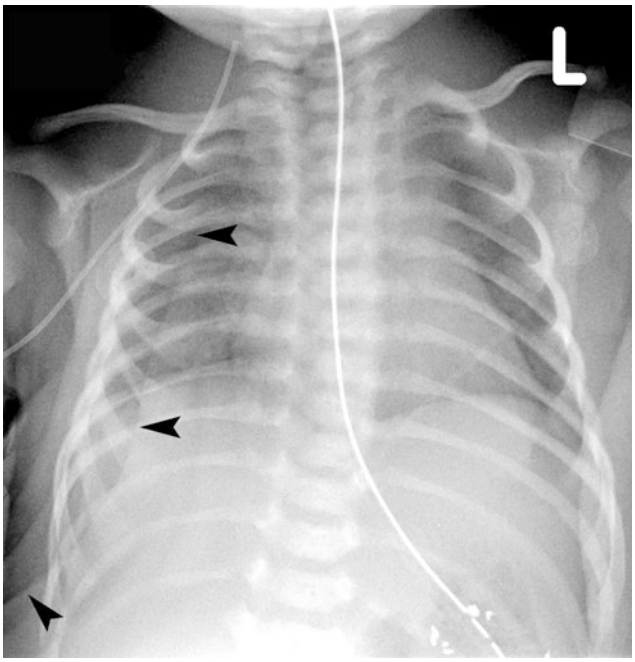

Fig. 34 Skin folds mimicking a pneumothorax. Relative lucency is seen in the periphery of the right hemithorax, raising the concern for a pneumothorax. However, the "edge" of the air-soft tissue interface can be followed beyond the ribs and into the chest wall (*arrowheads*), consistent with a skin fold. On closer inspection, multiple skin folds are visible along the right chest wall

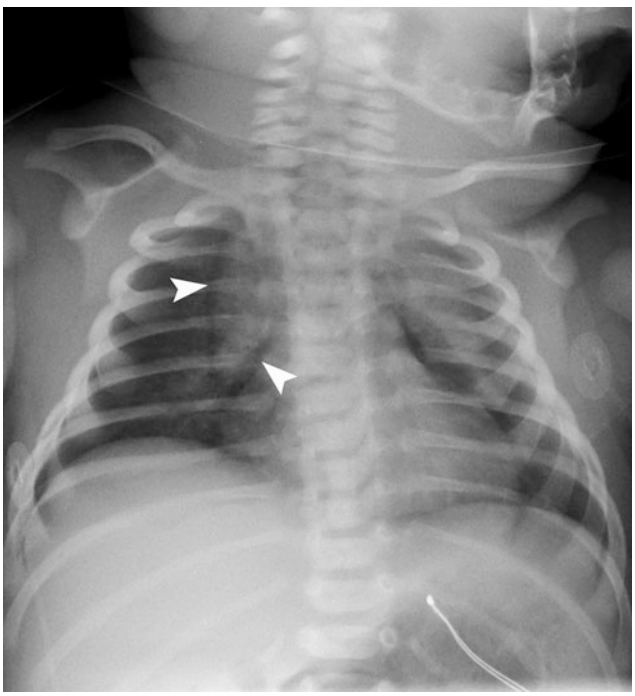

Fig. 35 Pneumomediastinum and angel wing sign. There is a lucent band outlining the right side of the superior mediastinum and extending under the right lobe of the thymus, slightly elevating it from the heart (*arrowheads*). A slightly more exaggerated appearance is seen on the left side. The elevated thymic lobes have the configuration of "angels' wings"

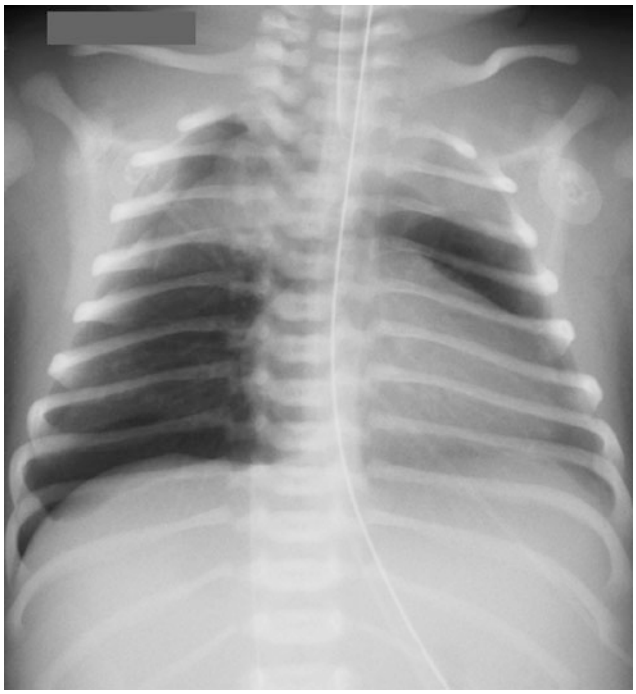

Fig. 36 Lobes of thymus simulating upper lobe opacification. The lobes of the thymus are lifted superiorly away from the heart and could be mistaken for upper lobe opacities. The apical position of the left thymic lobe could also be mistaken for a loculated pleural effusion

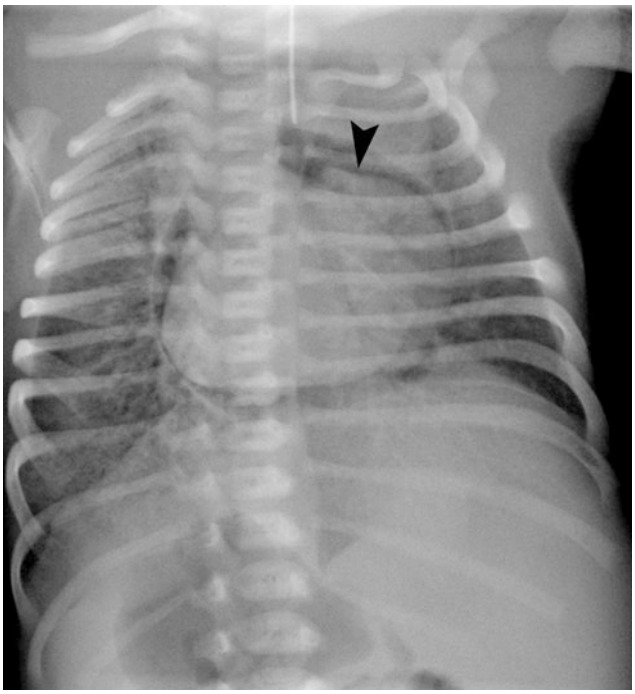

Fig. 38 Pneumopericardium. Interstitial air has tracked centrally and entered the pericardial sac, surrounding the heart. Note the air outlining the left atrial appendage (*arrowhead*)

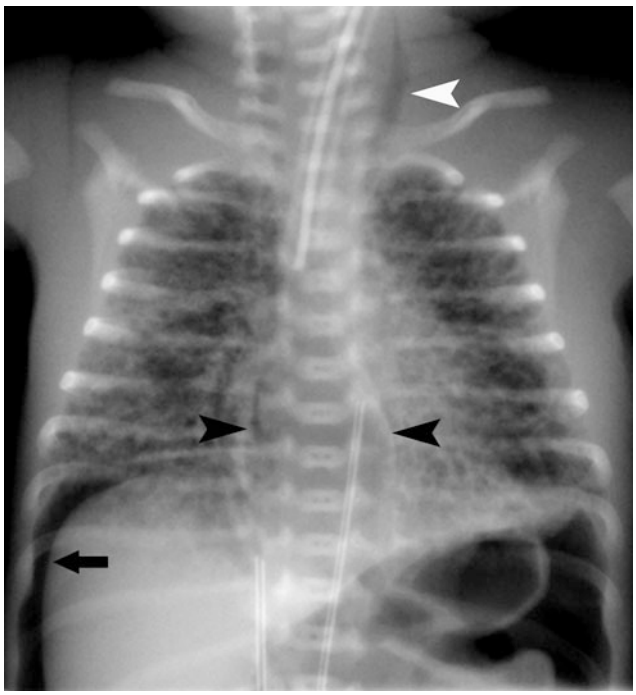

Fig. 37 Newborn premature infant with pneumoperitoneum secondary to a pneumomediastinum. Air has collected centrally in the mediastinum (*black arrowheads*) and has extended inferiorly into the abdomen (*black arrow*) and into the neck (*white arrowhead*)

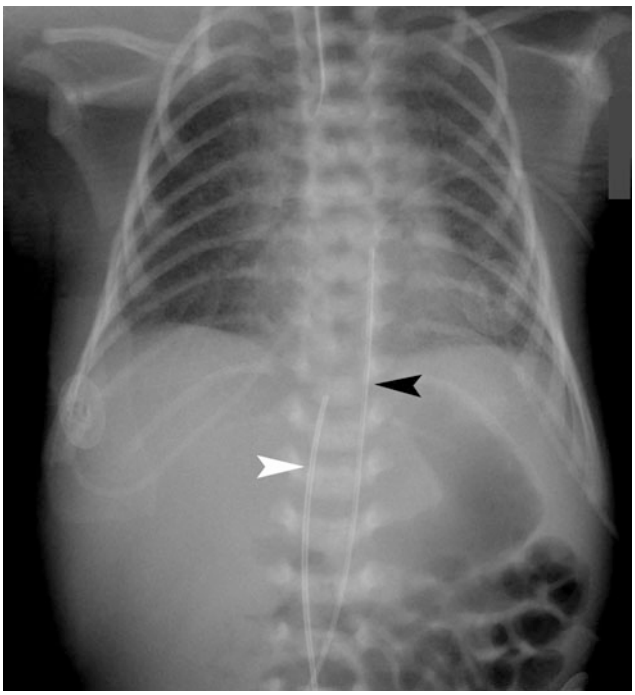

Fig. 39 Appropriate positioning of umbilical arterial and venous catheters. The tip of the UAC (*black arrowhead*) is at the level of the T7 vertebral body and the tip of the UVC (*white arrowhead*) is at the level of the suprahepatic IVC

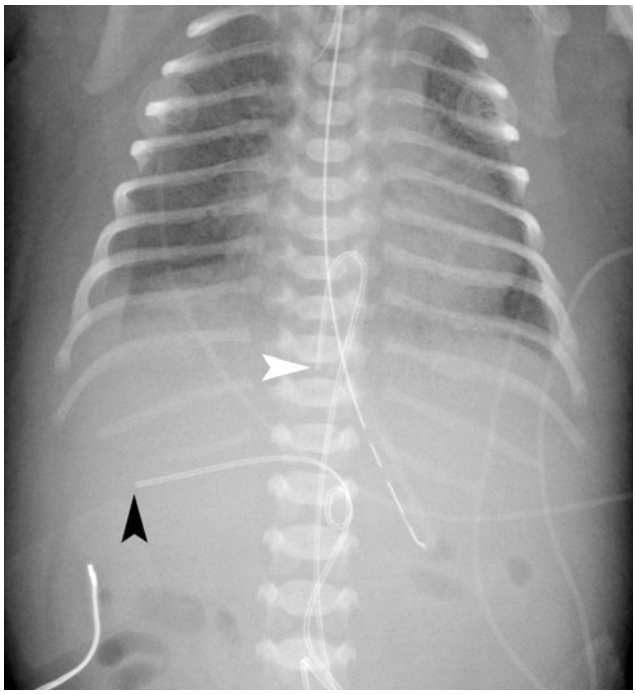

Fig. 40 Abnormal position of umbilical arterial and venous catheters. The UAC loops back on itself within the aorta (*white arrowhead*). Having looped in the umbilical recess, the UVC courses into the right portal vein (*black arrowhead*)

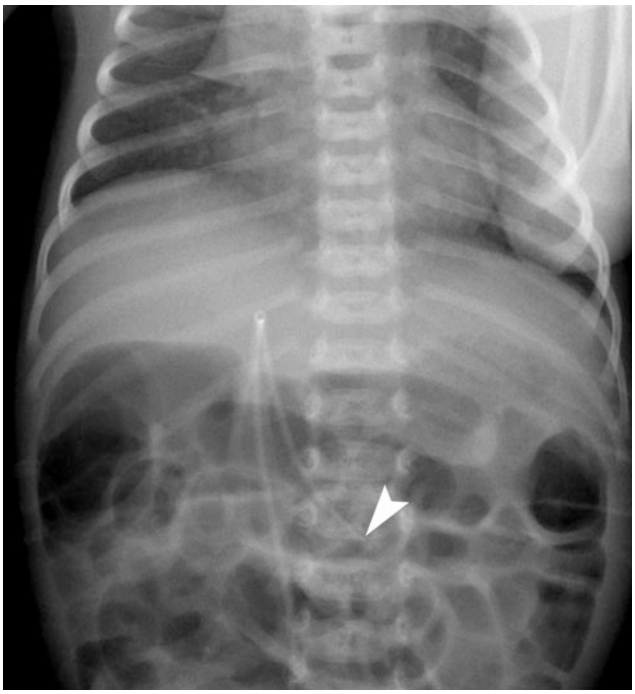

Fig. 41 Abnormal position of an umbilical venous catheter. The catheter courses inferiorly along the main portal vein to terminate in the superior mesenteric vein (*arrowhead*)

(Fig. 41), or the splenic vein. There is increased likelihood of the UVC being abnormally positioned if it loops in the liver (Fig. 40). This looping often occurs in the umbilical recess , a dilated segment of the umbilical vein situated immediately prior to the junction with the left portal vein. Abnormal positioning of a UVC in a portal vein may cause damage to the liver from the infused fluids. The UVC can also perforate the hepatic venous structures and terminate in the liver parenchyma.

If the UVC is advanced too far then it may terminate in the right atrium or, progress through the foramen ovale into the left atrium and from there into the left upper pulmonary vein (Fig. 42). Rarely, it may pass through the tricuspid valve into the right ventricle (Fig. 43) and from there it may enter the pulmonary arterial system. Alternatively, it may traverse the right atrium and enter the central veins above the heart (Fig. 44).

A correctly placed UAC follows one of the paired umbilical arteries which course caudad and posteriorly from the umbilicus to the internal iliac arteries. The UAC passes into the internal iliac artery, then the common iliac artery and aorta. Favored positioning of the tip of the UAC is between the T6 and T10 levels, proximal to the origin of the aortic branches that supply the abdominal organs (Fig. 39).

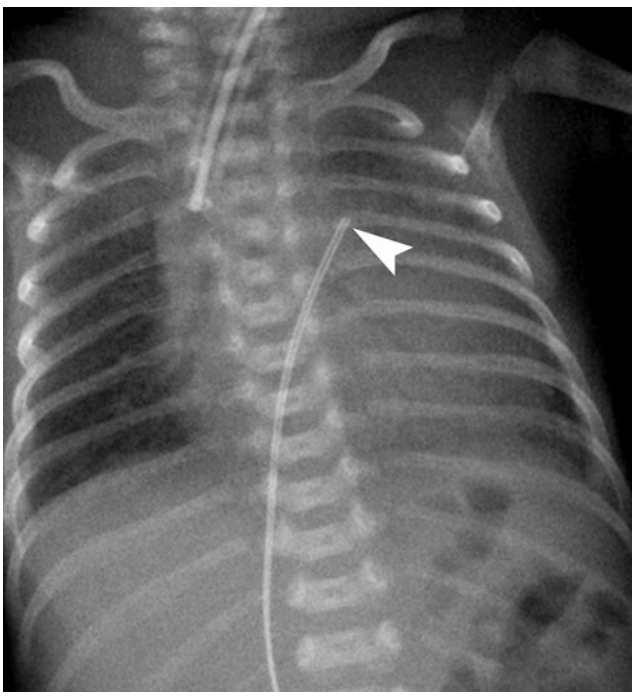

Fig. 42 Umbilical venous catheter in the left upper pulmonary vein. The UVC has crossed through a patent foramen ovale into the left atrium and then into the left upper pulmonary vein (*arrowhead*)

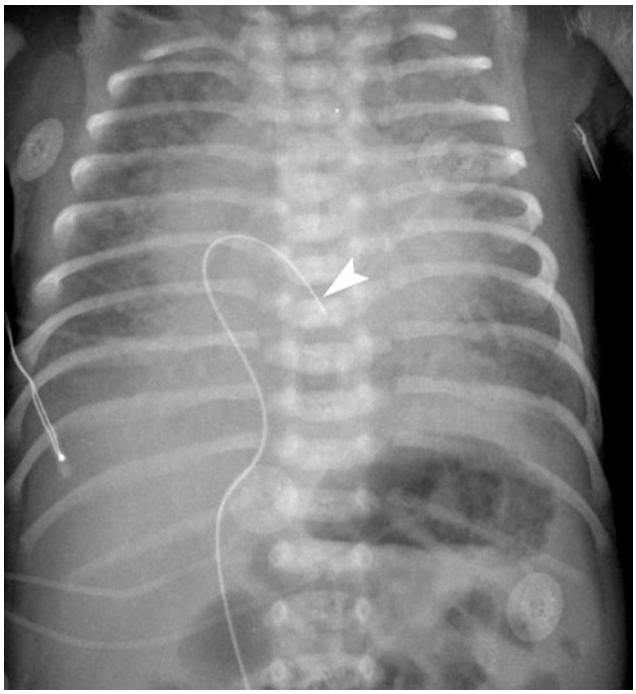

Fig. 43 Umbilical venous catheter in the right ventricle. The UVC has looped in the right atrium and courses through the tricuspid valve, terminating in the right ventricle (*arrowhead*)

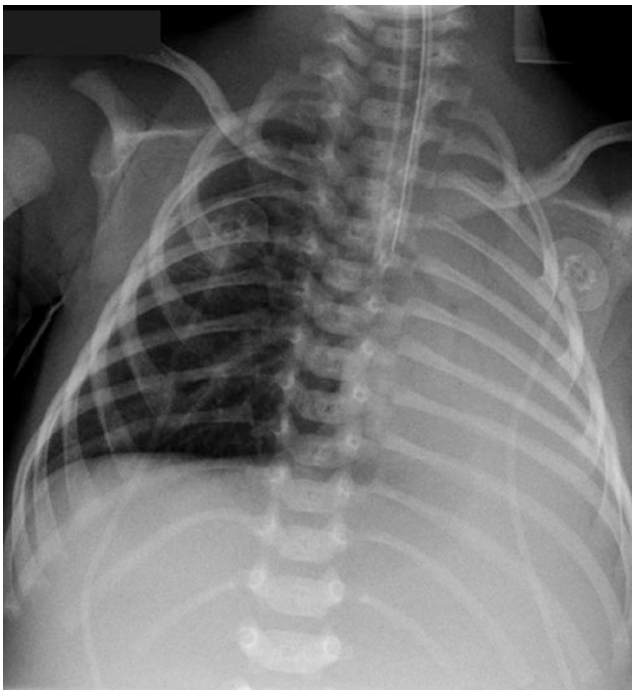

Fig. 45 Endotracheal tube in the right mainstem bronchus. The endotracheal tube has been advanced beyond the carina into the right mainstem bronchus, resulting in collapse of the left lung

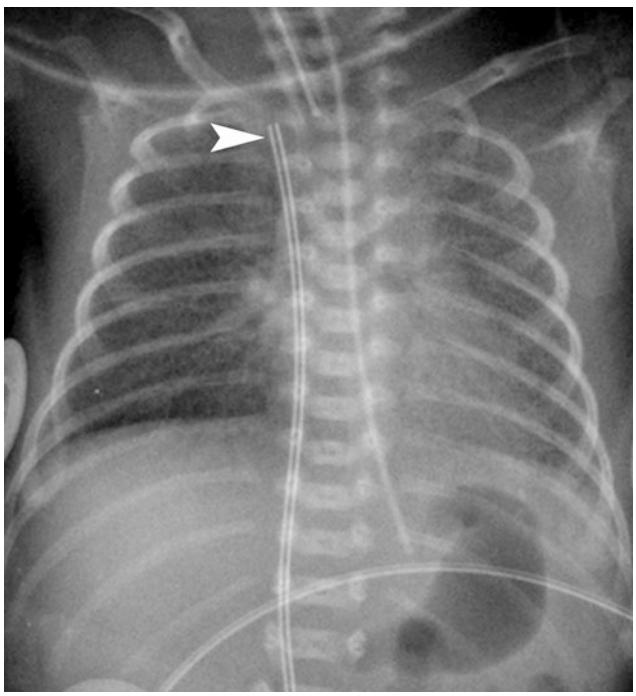

Fig. 44 Umbilical venous catheter above the heart. The catheter has been advanced through the right atrium and terminates in the right brachiocephalic vein (*arrowhead*)

If this position cannot be obtained, then the catheter tip may be positioned below the origin of these branches between the L3 and L5 vertebral body levels. The high position is preferred because it is associated with a lower incidence of complications, such as thrombosis (Mokrohisky et al. 1978). Abnormal positioning of the UAC includes looping in the aorta (Fig. 40) or positioning in the ipsilateral or contralateral common iliac, external iliac, or femoral artery, or within a branch of the abdominal aorta.

Endotracheal tubes should be positioned in the intrathoracic trachea above the carina. Positioning too high in the trachea increases the risk of accidental extubation. A low position of the ETT may cause collapse of the contralateral lung (Kuhns and Poznanski 1971) (Fig. 45) or overinflation of the ipsilateral lung with a resultant increased risk of an air leak (Thibeault et al. 1973). Unintended intubation of the esophagus can be recognized by gaseous distension of the esophagus, stomach, and bowel with volume loss of the lungs (Fig. 46).

Nasogastric and orogastric tubes should follow the course of the esophagus and terminate in the stomach. Occasionally, they may terminate in the esophagus or be ectopically positioned in the tracheobronchial tree (Fig. 47). If these tubes are used to administer nutrition, then positioning in the

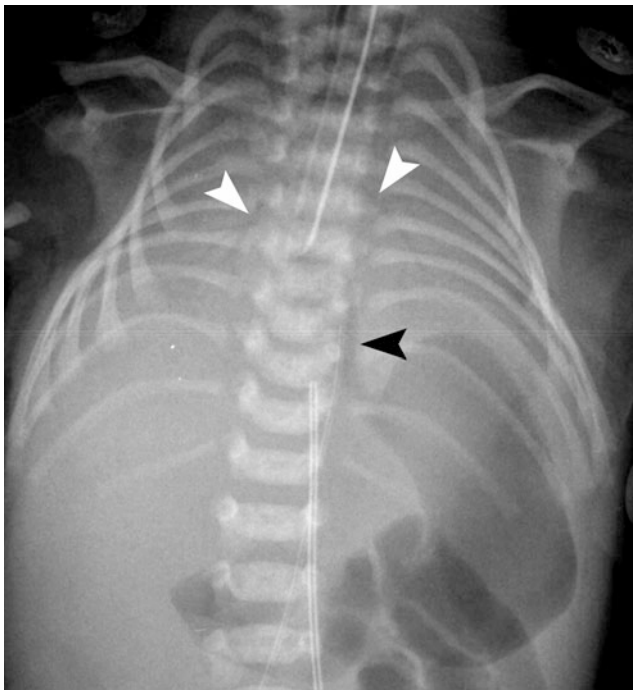

Fig. 46 Esophageal intubation. The tip of the endotracheal tube is not in the trachea or either mainstem bronchus (*white arrowheads*). Air is visible in the distal esophagus (*black arrowhead*), and the stomach and proximal small bowel are distended with air

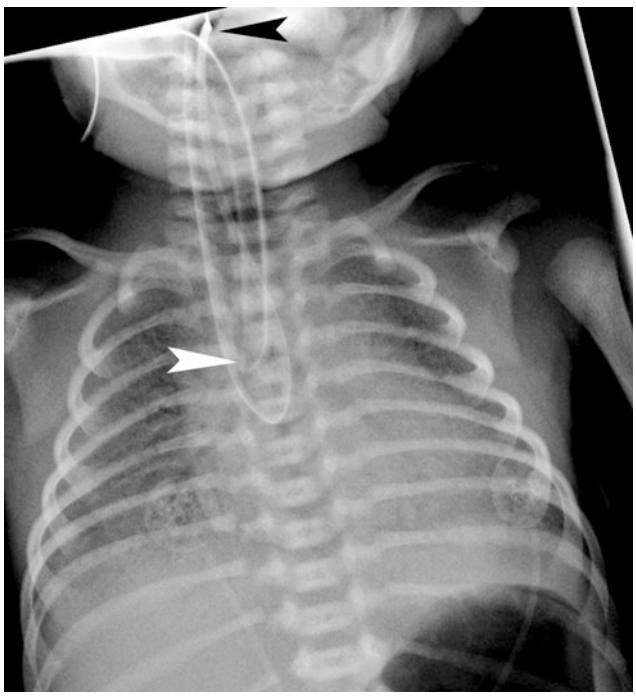

Fig. 47 Abnormal position of an enteric tube. A nasogastric tube is looped in the esophagus with the tip in the oropharynx (*black arrowhead*) while the tip of an endotracheal tube is in the right mainstem bronchus (*white arrowhead*)

tracheobronchial tree or esophagus may lead to aspiration and chemical pneumonitis. Esophageal perforation can occur, usually at the level of the piriform sinuses, especially in premature infants (Sapin et al. 2000).

7 Summary

Imaging of neonatal lung disease continues to play an important role in the care of ill infants. Although the radiographic appearances of many of the conditions can overlap, the clinical history including gestational age, maternal history, and birth history combined with the radiographic findings most often allow the radiologist to correctly diagnose the patient's illness. Attention to the support apparatus as well as extra-pulmonary findings is an important part of image interpretation.

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