Causes and management of pulmonary air leak in newborns

CP Hafis Ibrahim
Karthik Ganesan
Gurdeep Mann
NJ Shaw

Abstract
Pulmonary air leaks are usually complications of mechanical ventilation, although they can occur spontaneously. The reported incidence varies from 1% in term infants to 20% in preterm infants. The incidence has decreased in recent years. Ventilatory manoeuvres which increase mean airway pressure are associated with increased air leaks. Use of higher ventilatory rates, shorter inspiratory times and surfactant are known to reduce the incidence. Pulmonary interstitial emphysema presents as a slow deterioration of the infant during ventilation. Pneumothorax is usually associated with sudden deterioration. The diagnosis of a tension pneumothorax is clinical and emergency management should not be delayed for a confirmatory X-ray. A ventilatory strategy allowing for permissive hypercapnia with lowest possible pressures, shorter inspiratory times and higher ventilatory rates may aid in the management of pulmonary air leaks. High frequency ventilation may help when conventional ventilation fails. Sedation and paralysis may be helpful when the infant fails to synchronize with the ventilator. Pulmonary air leaks are associated with increased mortality and morbidity and a higher incidence of intraventricular haemorrhages.

Keywords air leak; infant; neonate; pneumothorax; pulmonary interstitial emphysema

Introduction
Pulmonary air leak is a well recognized complication of mechanical ventilation, causing significant morbidity and occasionally mortality. The overall incidence of air leaks in term infants is about 1%, although only about 10% of these are symptomatic.

The incidence in preterm infants is higher. The incidence of pneumothorax from 1990 to 2002 was 13% in babies weighing less than 750 g and 2% in babies weighing 1251–1500 g in a large North American study.¹ The incidence of pneumothorax at Liverpool Women’s Hospital in mechanically ventilated babies was approximately 2% in the years 2005 and 2006.

Definition
Pulmonary air leak refers to accumulation of air outside the pulmonary space. Pulmonary interstitial emphysema (PIE) and pneumothorax are most common, followed by pneumomediastinum and pneumopericardium.

Pathophysiology
Air leak is caused by alveolar overinflation which causes the alveoli to rupture. Poor compliance of the lungs may contribute to this as it results in unequal ventilation and some alveoli becoming over distended and some remaining collapsed. This is further accentuated by a reduced number of pores of Kohn in preterm neonates (which normally allow redistribution of air between well and poorly ventilated alveoli). The overinflated alveoli may rupture and free air can escape into the interstitial spaces of the lung, causing PIE. This is worsened in the preterm lung by the increased interstitial water, resulting in air being trapped in the interstitium.²

Air from the ruptured alveoli can also dissect along the perivascular spaces toward the hilum to reach the root of the lung. This can subsequently rupture into the pleural space leading to pneumothorax, into the mediastinum resulting in pneumomediastinum, or into the pericardium leading to pneumopericardium.

Aetiology
Spontaneous pneumothoraces can occur soon after birth due to the high pressures generated by the baby taking their first breaths or at resuscitation. Familial spontaneous pneumothoraces are rare.³

Lung diseases such as respiratory distress syndrome (RDS), meconium aspiration syndrome, congenital bullous lesions and pulmonary hypoplasia: these can all result in uneven lung compliance leading to alveolar overdistension and rupture.

Direct injury can result from suctioning through the endotracheal tube (ETT), use of introducers through the ETT for their placement or central venous catheter placement.

Mechanical respiratory support can be associated with air leak when using a prolonged inspiratory time,⁴ a high mean airway pressure (MAP)⁵ or poor patient synchronization with the ventilator (where infants actively expire during the inspiratory phase of mechanical ventilation).⁵ Continuous positive airway pressure (CPAP) may also be associated with an increased risk of air leak.⁶

Prevention
Surfactant administration has been shown to significantly reduce the incidence of pneumothorax (OR 0.35; 95% CI 0.26–0.49).⁸
Optimizing the respiratory support offered to mechanically ventilated babies can reduce the risk of air leak syndromes. Strategies include using the minimum necessary peak inspiratory and end expiratory pressure and inspiratory time to achieve adequate oxygenation and ventilation, and employing faster ventilator rates to prevent the baby breathing out of phase with the ventilator. The following is a summary of the current evidence regarding which ventilator strategies can reduce the risk of pneumothorax.

- A meta-analysis of three randomized controlled trials (RCTs) comparing high rate positive pressure ventilation (rate more than 60/min) with conventional mechanical ventilation at lower rates showed a decrease in air leak in the high rate group (RR 0.69; 95% CI 0.51–0.93).9
- A meta-analysis of five RCTs evaluating a long versus a short inspiratory time (Ti) using conventional mechanical ventilation in neonates with RDS showed that a long Ti (more than 0.5 s) was associated with an increased risk of pneumothorax (RR 1.56; 95% CI 1.24–1.97).10 However, all these studies were done in the pre-surfactant era and prior to the introduction of antenatal steroids.
- Elective high frequency oscillatory ventilation has not been shown to be effective in reducing air leaks. Compared to conventional ventilation, it showed a significant increase in air leaks in the high frequency group (RR 1.23; 95% CI 1.06–1.44).11
- Meta-analysis of six trials of patient-triggered ventilation (PTV) has not shown that PTV reduces the incidence of air leaks when compared to conventional ventilation (RR 1.03; 95% CI 0.8–1.34).9
- Retrospective studies have shown that maximal peak inspiratory pressures during the 24 h before diagnosis, number of suction procedures during the previous 8 h before diagnosis and ETT displacements have been associated with an increased incidence of air leaks.12,13
- Providing ‘routine’ paralysis to abolish the baby’s respiration does not prevent pneumothorax when compared to synchronous ventilation.14 Hence, synchronizing the baby’s ventilation by increasing the respiratory rate up to 60–80/min can prevent the need for paralysis. If the baby’s oxygenation does not improve and if obvious respiratory effort continues in spite of high rates, paralysis may be beneficial.15

Pulmonary interstitial emphysema (Figure 1)

Incidence
The incidence of PIE in the pre-surfactant era in mechanically ventilated babies under 1500 g was approximately 20%.16 It is likely that this complication now occurs much less frequently, although there are no recent population-based studies to support this.

Pathophysiology
PIE occurs more commonly in neonates with RDS and less frequently in neonates with meconium aspiration syndrome and sepsis.16 PIE causes air trapping in the interstitial spaces of the lung. This compromises the blood flow in the lungs, leading to ventilation perfusion mismatch and then hypercapnia and hypoxia.

Presentation
PIE often presents with a slow, progressive deterioration of the blood gases with the need for increasing ventilatory support.

Rarely, the neonate has a sudden deterioration with profound respiratory acidosis and hypoxaemia.

Diagnosis
Transillumination of the chest in diffuse PIE reveals hyperlucency, similar to pneumothorax. The diagnosis is confirmed on a chest radiograph (CXR) which reveals hyperinflation and small cysts, either localized or diffuse. There are linear radioluencies which are variable in length and do not branch. In extreme cases, large bullae may appear which may mimic congenital lobar emphysema or cystic adenomatoid malformation.

Pneumothorax (Figure 2)

Pathophysiology
Pneumothorax occurs when air leaks between the visceral and parietal pleural surface. Pneumothorax may develop spontaneously in non-ventilated neonates. It occurs at delivery when high opening pressure is needed to open up the alveoli, either by the baby taking breaths or at resuscitation. In the ventilated neonate it may occur after alveolar over-inflation secondary to using high initial ventilatory pressures or to failure to wean pressures once compliance is achieved (e.g. after surfactant administration).

Presentation
Neonates with spontaneous pneumothorax are usually asymptomatic or have mild signs of tachypnoea with an oxygen requirement. Occasionally, severe respiratory distress (grunting, nasal flaring and intercostal retractions) may occur. In the ventilated neonate, pneumothorax may result in a rapid clinical deterioration, resulting in cyanosis, hypotension, hypoxaemia, hypercapnia and respiratory acidosis. There may be decreased breath sounds on the affected side with heart sounds shifted to the opposite side, asynchronous chest movement and abdominal distension due to displacement of the diaphragm. With a rightsided pneumothorax, the liver can be displaced downwards.

Diagnosis
A high index of suspicion is needed to diagnose pneumothorax. Transillumination (whilst awaiting the CXR) with a
A fibre-optic light source placed on the neonate’s chest will illuminate the affected hemithorax. CXR remains the gold standard for diagnosing pneumothorax and should be performed unless the neonate’s condition needs emergency intervention. CXR appearances vary depending on the severity of the pneumothorax. A small pneumothorax is recognized by a difference in translucency between the two sides. CXR of a large pneumothorax or one under tension will display the following:

- air in the pleural cavity (the area appears hyperlucent with absent pulmonary markings)
- collapse of the affected lung
- displacement of the mediastinum and heart shadow to opposite side
- bulging intercostal spaces
- downward displacement of the diaphragm on the affected side.

Often, in ventilated babies, anteroposterior films of the chest may not show the classic radiographic appearance if free air is situated anteriorly. In such cases, a lateral decubitus X-ray film with the affected side up will show free air.

**Pneumomediastinum (Figure 3)**

**Incidence**
Pneumomediastinum in the pre-surfactant era has been reported to occur in up to 3% of ventilated babies, although anecdotally, now, the incidence seems to be much less.

**Pathophysiology**
Pneumomediastinum is preceded by PIE in most instances, when after alveolar rupture, air traverses the fascial planes and passes into the mediastinum.

**Pneumopericardium (Figure 4)**

**Incidence**
The incidence of pneumopericardium in extremely low birth weight ventilated neonates in the pre-surfactant era has been reported as being approximately 2%, although in current practice it is seen much less often.

**Pathophysiology**
Pneumopericardium occurs secondary to passage of air from the pleural space or mediastinum into the pericardial sac through a defect located at the reflection near the ostia of the pulmonary veins.

**Presentation**
Isolated pneumomediastinum may not be clinically apparent. Clinical signs range from mild respiratory distress to other features associated with more severe coexisting air leak syndromes (pneumothorax or PIE). Physical signs include tachypnoea, muffled heart sounds and an increase in anteroposterior diameter of the chest.

**Diagnosis**
CXR shows a halo around the heart border, excluding the diaphragmatic surface of the heart, or a lateral view may show a retrosternal translucency. The mediastinal air can elevate the thymus away from the pericardium, resulting in a ‘spinnaker sail’ appearance.

**Diagnosis**
CXR is confirmatory. There is air completely surrounding the heart, including the inferior diaphragmatic surface of the heart,
outlining the base of the great vessels and contained within the pericardium. The presence of air inferior to the diaphragmatic surface of the heart differentiates this condition from a pneumomediastinum. In severe cases, the transverse diameter of the heart can be reduced.\(^2\)

**Situations where the diagnosis may not be clear-cut**

Congenital lobar emphysema causes hyperinflation of one lobe of the lung (usually the left upper). Compensatory hyperinflation with atelectasis on the contralateral side mimics a pneumothorax. Cystic adenomatoid malformation, usually diagnosed antenatally, may mimic PIE radiologically if the cysts are small but is usually confined to one lobe and is usually unilateral.

**Management**

**Pneumothorax**

Asymptomatic pneumothoraces can usually be managed conservatively with close observation for any clinical deterioration.\(^2\) Mildly symptomatic pneumothoraces in term infants can be managed by increasing the inspired concentration of oxygen to near 100%, which helps in the resorption of air from the pleural spaces by nitrogen washout. This strategy should be avoided in preterm infants because of the risk of oxygen toxicity, mainly retinopathy of prematurity.

**Emergency management** of a pneumothorax is warranted if the baby has severe impairment of gas exchange and cardiovascular compromise. This is usually caused by a tension pneumothorax. Management is by needle thoracocentesis and this should not be delayed pending a CXR. This is carried out using a butterfly needle and sterile container with sterile water as an underwater seal. The skin surface should be cleaned with an antiseptic and a 21–25 gauge butterfly needle should be inserted perpendicular to the skin in the second intercostal space on the affected side and in the midclavicular line just above the lower rib.\(^17\) After insertion into the skin, the needle and skin should be shifted laterally before piercing the deeper muscle and pleura so as to avoid making a direct tract. The extension tubing of the butterfly needle is placed in the container of water below the level of the needle end. Drainage of air can be detected by bubbling in the water. Alternatively, a 50 ml syringe attached to the end of the butterfly needle with a three-way tap in between can be used. The air can be emptied from the syringe with the tap closed to the lung and opened to the air.\(^17\) The needle should be inserted with caution and the advancement stopped as soon as air is aspirated. Aspirating all the air with the needle risks further iatrogenic lung injury should the needle come into contact with lung tissue. Once the baby is stabilized with needle aspiration, a chest drain should be inserted.

**Chest drain insertion:** a chest drain should be inserted as the primary treatment for a significant pneumothorax that is not under tension, or following needle drainage for a tension pneumothorax. All units caring for sick infants should have essential equipment prepared for a chest drain insertion (Figure 5). The largest possible chest drain that can pass through an intercostal space should be used. The sizes of chest drains used in newborns range usually from 8F for the extremely preterm to 14F in larger babies.\(^3\) If using a drain with a trocar, it is advisable to remove the trocar prior to insertion because of the risk of injury to the lungs and deeper structures. The side of insertion should be re-checked prior to insertion and the baby positioned with the affected side elevated to approximately 45° from horizontal, with a support under the shoulder blade, and the ipsilateral arm positioned above the head. The chest drain should be placed in the fifth or sixth intercostal space in the mid or anterior axillary line. Rarely, it may have to be inserted more anteriorly in the second intercostal space for anterior pneumothoraces which have proved difficult to drain with the lateral approach. A wide area of skin around the insertion site should be cleansed with antiseptic. If time permits, the skin and subcutaneous tissue should be injected with 1% lignocaine. If the infant is ventilated, a bolus...
dose of opioid may be used. A 1–2 cm incision parallel to the ribs should be made above the lower rib in the space, avoiding the breast tissue. The subcutaneous tissue and muscle should be bluntly dissected with forceps. The pleura may be nicked with the tip of the scalpel or with a clamp. The tip of the chest drain should be inserted with artery forceps through the opening for 2–3 cm pointing anteriorly. The distal end of the chest drain should then be connected to a flutter (Heimlich) valve or underwater seal with an appropriate extension. Though some authors do not recommend Heimlich valves except for transport, on our unit we have found them to work satisfactorily in most settings. The chest drain should be secured in place with sutures on one or either side of the tube to snugly close the wound. The site then should be covered with gauze and dressed with transparent dressings. Although not always necessary, it may be useful to apply low pressure suction (5–10 cm H2O) to either the Heimlich valve or underwater seal to help lung re-expansion. The drain position should then be checked with a CXR. Once a chest drain is inserted, it is prudent to leave it for 72–96 h or at least 24 h after there is no air leak (confirmed by lack of fluttering of the Heimlich valve or bubbling of the underwater seal together with clinical and radiological expansion of the affected lung). It should then be clamped for 24 h and removed, provided that there is no re-accumulation of pleural air. The complications of chest drain insertion include haemorrhage, infection, damage to breast tissue and damage to deeper structures including the diaphragm, phrenic nerve, pericardium and thoracic duct.

Air leaks, including bronchopleural fistulae, which persist more than a few days after adequate placement of chest drains may need to be treated surgically. Alternatively, some success has been reported with conservative management, including instillation of fibrin glue or selective bronchial intubation of the contralateral side.2,18

**Pulmonary interstitial emphysema**

PIE may be global in both lungs or localized to single lobes of the lung. It can occur in isolation or may be associated with pneumothoraces, pneumomediastinum, pneumopericardium and pneumoperitoneum. Isolated PIE without extrapulmonary air leak can be managed conservatively by modifying ventilator management. When using conventional ventilation, the pressures should be kept at the minimum compatible with acceptable blood gases (pH more than 7.25, PaO2 45–52 mm Hg) with a degree of permissive hypercapnia. Higher ventilatory rates up to 100–120/min that ensure a short inspiratory time may be beneficial. If conventional ventilation fails, high frequency oscillation may improve gas transfer. In unilateral PIE, ventilating the baby with the affected lung in a dependent position or selectively intubating the contralateral bronchus may facilitate resolution.2,17 If an infant fails to improve with these ventilatory strategies, a pneumothorax may have to be created to release the interstitial air with lung scarification using a 21 gauge needle through the chest wall or by rupture of the blebs at thoracotomy. Fortunately, these interventions are very rarely required and should be performed only by experienced personnel.

**Pneumomediastinum**

Pneumomediastinum often occurs in conjunction with a pneumothorax and draining the latter usually adequately treats the pneumomediastinum. A pneumomediastinum occurring in isolation is difficult to drain because of multiple loculations and management should focus on the underlying condition. Multiple needle drainage and tube placements are theoretically possible but have never been used by the authors. Giving a term infant 100% oxygen may aid resolution but this strategy should be avoided in preterm infants at risk of retinopathy of prematurity.

**Pneumopericardium**

A pneumopericardium very rarely occurs in isolation. It is usually associated with other significant air leaks in preterm infants with severe lung disease requiring ventilatory support. A pneumopericardium which does not cause cardiovascular compromise can be treated conservatively. If cardiovascular compromise is present, a pericardial tap via a sub-xiphoid route, maintaining continuous cardiorespiratory monitoring, should be performed only by an experienced practitioner. Surgical placement of a catheter may be required if air re-accumulates.

**Pneumoperitoneum**

A pneumoperitoneum may rarely be associated with an intrathoracic air leak due to air tracking down through the diaphragmatic foraminae. It usually resolves with adequate management of the lung pathology and intrathoracic air leaks. If the accumulation of air in the peritoneal cavity causes respiratory embarrassment, it may need needle drainage or placement of a catheter.

**General management of babies with air leak**

The general principles of management of an ill, ventilated infant apply. A minimum touch policy should be used. No randomized trials of sedation in ventilated infants have been shown to alter any long-term outcomes. However, it seems prudent to sedate and give adequate analgesia using opioids to babies receiving mechanical ventilation who have an air leak. Although a meta-analysis has shown a trend towards reduced air leaks in babies receiving neuromuscular paralysis, the indication for its use after an air leak has occurred is unclear. Fluid balance, nutrition and cardiovascular support should be managed appropriately. It seems logical to adopt a ventilatory strategy aimed at achieving acceptable gas exchange with the least amount of mean airway pressure possible to prevent further barotrauma and volutrauma leading to worsening of the air leak.

**Prognosis**

Pulmonary air leaks in newborn babies are associated with increased mortality and morbidity. In a prospective cohort study in infants born weighing less than 1500 g there was a 13-fold increase in the composite outcome of death or bronchopulmonary dysplasia if a pneumothorax occurred in the first 24 h. Air leaks are also associated with an increased risk of intraventricular haemorrhage.

Practice points

- Pulmonary air leaks are caused by alveolar overdistension and ventilatory strategies which reduce mean airway pressure and improve synchrony (lower peak inflation pressure and positive end-expiratory pressure, shorter inspiratory times and higher ventilatory rates) can reduce the risk of occurrence
- Surfactant use in preterm infants with RDS significantly reduces the incidence of air leaks
- There is no evidence that sedation and paralysis prevent air leaks, but these may be used if an infant fails to synchronize with the ventilator despite maximum possible optimization of ventilation
- Asymptomatic air leaks can be managed with close clinical observation
- PIE usually presents with slow deterioration of a ventilated infant, whereas pneumothoraces present with acute deterioration
- Tension pneumothoraces should be diagnosed clinically and managed as an emergency using needle thoracocentesis
- Pulmonary air leaks are associated with increased morbidity, including intraventricular haemorrhages, and mortality