Systemic Air Embolism Secondary to Respiratory Therapy in the Neonate: Six Cases Including One Survivor

MARVIN S. KOGUTT[1]

Systemic air embolism has been described as a complication of respiratory therapy using positive pressure ventilation. This is usually a dire, if not fatal occurrence. The incidence of this severe complication will likely increase with the advent of more vigorous and aggressive respiratory therapy of the respiratory distress syndrome in neonates. It is important for both the clinician and the radiologist to be aware of this entity, its etiology, and its probable increasing frequency. This paper reports six cases of systemic air embolism, including one patient who revealed no clinical symptomatology, and in whom the diagnosis was made by radiographic findings only. This is the largest series yet reported and includes, to my knowledge, the first reported neonate to survive this complication.

Respiratory therapy using positive pressure ventilation has become commonplace in the treatment of the respiratory distress syndrome in neonates. The advent of this more aggressive therapeutic approach has brought about an increased infant survival rate from the primary disease; however, complications resulting from air entering the extrapulmonary spaces have become more frequent. Pneumomediastinum, pneumothorax, and pulmonary interstitial emphysema are rather frequent complications. Their spectrum may range from the mild and self-limited to the massive and fatal. The entrance of air into the intravascular space resulting in systemic air embolism is a catastrophic complication of positive pressure ventilation.

Six cases of systemic air embolism are presented, the largest series reported to date. In one case, the diagnosis was not suspected and was only noted radiographically after the episode. To my knowledge, this is the first reported patient to survive this usually fatal complication in neonates.

Case Reports

Case 1

G. B., a 1,190 g white female, was born after a 27 week gestational period. The infant had respiratory distress and required oxygen from birth. During the next several hours, the respiratory distress progressed and the infant was placed on a Bourne's ventilator. The peak pressure was 90 cm of water and the end-expiratory pressure was 10 cm of water. Severe cyanosis was noted 2 hr later and auscultation of the chest revealed "crunching" on respiration. Air was noted in the anterior chamber of the eye. Chest radiography revealed pulmonary interstitial emphysema and systemic vascular air embolism (fig. 1). The infant expired shortly thereafter. Autopsy revealed moderate pulmonary atelectasis with hyaline membrane formation and intraalveolar hemorrhage. No evidence of pulmonary venous fistulae or intravascular air was demonstrated.

Case 2

G. C., a 1,500 g white female, was born via cesarean section because of maternal bleeding at 30 weeks of gestation. The infant had no spontaneous respirations and required mechanical ventilation via endotracheal tube. Initial chest radiography revealed the pattern of hyaline membrane disease. A right pneumothorax occurred and was reduced by means of a pleural catheter. The infant remained stable until 26 hr of age, when she became markedly cyanotic and exhibited signs of vascular collapse. Chest radiography revealed systemic air embolism with marked amounts of air within the cardiac chambers and systemic vasculature (fig. 2). Attempts at resuscitation were unsuccessful and the infant expired. Pathologic findings revealed intracranial hemorrhage, severe hyaline membrane disease, and moderate pulmonary interstitial emphysema. No air was noted within the vascular system.

Case 3

B. D., a 880 g white male, was the product of a 25 week gestation requiring cesarean section for prolonged rupture of membranes. The infant required immediate intubation and was placed on the Bourne's ventilator which required end-expiratory pressures of 40 cm of water. At 10 hr of age, the infant underwent marked deterioration, and chest radiography revealed severe interstitial emphysema, subcutaneous emphysema, and systemic vascular air embolism (fig. 3). The patient expired at 11 hr of age. No autopsy was performed.

Case 4

L. K., a 1,300 g white male, was born after 28 weeks of gestation. The infant experienced respiratory distress shortly after birth. An endotracheal tube was inserted and the patient was placed on a Bird ventilator with the peak pressure at 30 cm of water with an end-expiratory pressure of 7 cm of water. One day after birth, chest radiography demonstrated a small left pneumothorax and a left pleural catheter was inserted. Over the next 3 hr, the infant required increased respirator pressures and exhibited increased cyanosis. An attempt to withdraw blood from the left radial artery produced large amounts of air within the syringe. Repeat chest radiography revealed a large pneumopericardium and intravascular air (fig. 4). The infant expired shortly thereafter. Autopsy revealed areas of variable atelectasis in both lungs with focal hemorrhage and findings of hyaline membrane disease. No evidence of bronchovenous fistulae was demonstrated.

Case 5

R. N., a 1,860 g white male, was the second twin born after 34 weeks of gestation. He exhibited grunting and cyanosis at birth, requiring intubation and mechanical ventilation. Initial radiog-

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[1] Departments of Radiology and Pediatrics, Ochsner Medical Institutions, 1516 Jefferson Highway, New Orleans, Louisiana 70121.

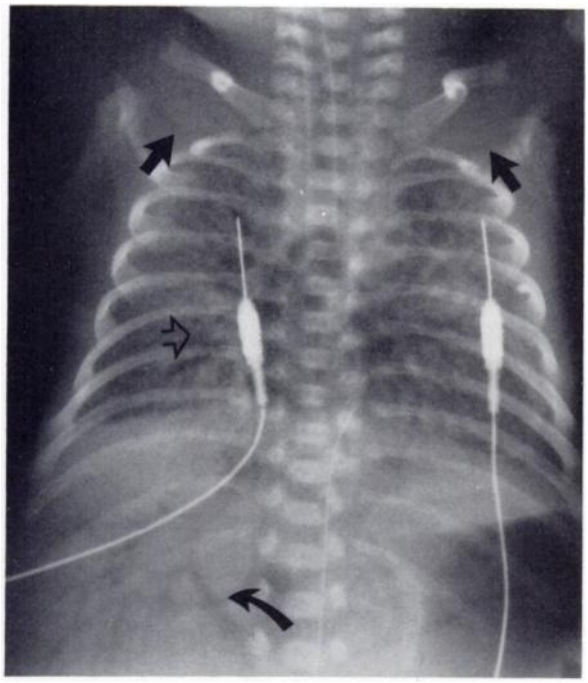

Fig. 1.—Case 1. Chest film showing air within hepatic veins (*curved arrow*) and peripheral arteries (*solid arrows*). Note marked pulmonary interstitial emphysema (*open arrow*).

raphy revealed the pattern of hyaline membrane disease. Ventilator peak pressure was 28 cm of water with an end-expiratory pressure of 6 cm of water. The infant remained stable until 18 hr of age, when he exhibited marked decrease in heart rate, increased cyanosis, and findings of decreased peripheral perfusion. Chest radiography revealed systemic vascular air embolism with air within the cardiac chambers, great vessels, and peripheral vasculature (fig. 5). Resuscitation attempts were unsuccessful and the infant expired. No autopsy was performed.

Case 6

B. H., a 1,100 g black male, was born via cesarean section after spontaneous rupture of the membranes after a 31 week gestational period. The infant showed symptoms of respiratory distress which did not respond to oxygen, and he was placed on a respirator via an endotracheal tube with a peak pressure of 20 cm of water and an end-expiratory pressure of 6 cm of water. Chest radiography revealed a small pneumomediastinum and a small collection of extrapulmonary air at the right lung base (fig. 6*A*). The patient remained stable, and chest radiography the next morning for "routine follow-up of pneumomediastinum" showed a collection of extrapulmonary air in the left hemithorax, pulmonary interstitial emphysema, and intravascular air within the left jugular and right brachial/axillary veins (fig. 6*B*). No intravenous fluids were being given during this time, and no acute symptoms or changes in condition were noted prior to or during the time the chest film was exposed. The infant was removed from the ventilator and continued to do well. Sequential chest radiography demonstrated no evidence of intravascular or extrapulmonary air. The infant was subsequently discharged with no evidence of pulmonary or neurologic sequelae.

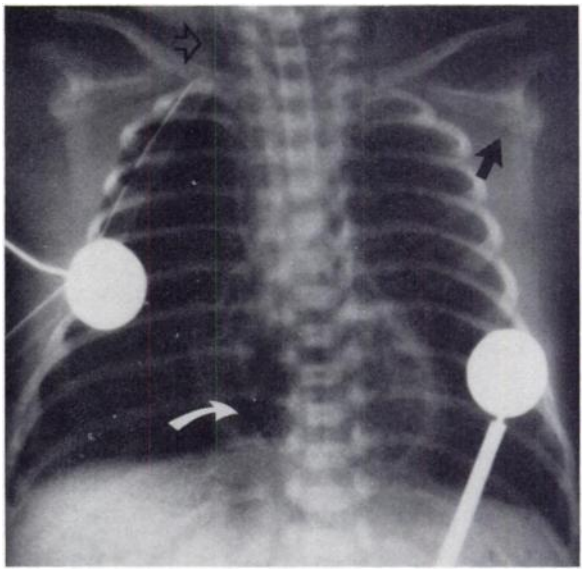

Fig. 2.—Case 2. Chest film prior to death showing air in heart (*white arrow*), axillary arteries (*solid arrow*), and jugular veins (*open arrow*).

Discussion

The use of positive pressure ventilation in the treatment of the respiratory distress syndrome of infancy has become an important therapeutic method in increasing the survival of these patients. However, the more aggressive use of respiratory therapy has itself resulted in a different and sometimes severe spectrum of complications. The high end-expiratory pressures often required to maintain adequate systemic oxygenation may result in air escaping into the extraalveolar spaces. The underlying abnormality has been demonstrated to result from alveolar rupture with dissection of air through the pulmonary parenchyma causing pulmonary interstitial emphysema [1–3]. The air may then dissect through the various tissue planes and along the perivascular sheaths to enter any of the extrapulmonary spaces. This may result in pneumomediastinum, pneumothorax, pneumoperitoneum, subcutaneous emphysema, pneumopericardium, or systemic vascular air embolism [4, 5].

The occurrence of systemic vascular air embolism secondary to positive pressure ventilation is a well recognized entity [3, 6–10]. Although the exact mechanism of this phenomenon is unproven, several theories have been proposed. The entrance of air into the vascular space most likely results from either the formation of alveolocapillary or bronchovenous fistulae after alveolar rupture [11–13]. This phenomenon has been demonstrated to occur when the intraalveolar pressure exceeds that of the left atrial/pulmonary venous pressure, causing reversal of the normal alveolar/vascular pressure gradient [11, 12]. When this occurs, escape of air from the alveoli into the vascular space is possible. Air then travels through the pulmonary veins directly to the left cardiac chambers and then into the systemic arterial circulation. It has been noted that air is virtually always

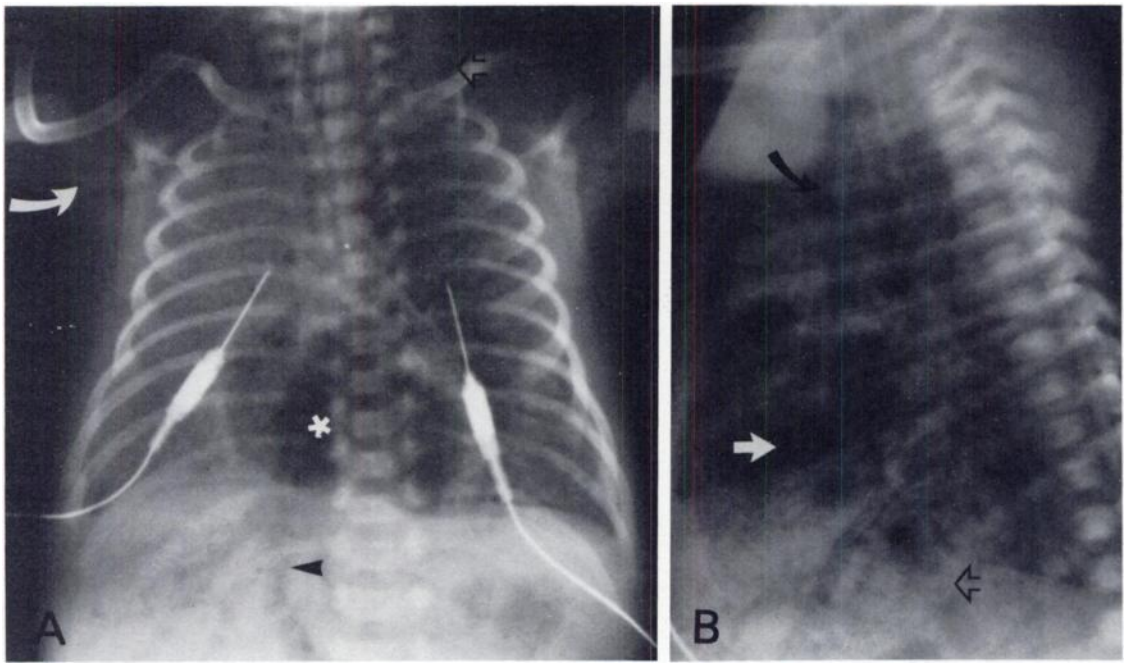

Fig. 3.—Case 3. *A*, Anteroposterior chest film showing subcutaneous emphysema (*open arrow*), pulmonary interstitial emphysema, intracardiac air (*asterisk*), air in peripheral arteries and veins (*curved arrow*), and air in hepatic veins (*arrowhead*). *B*, Lateral chest film showing air in cardiac chambers (*white arrow*), inferior vena cava (*open arrow*), and brachiocephalic arteries (*curved arrow*).

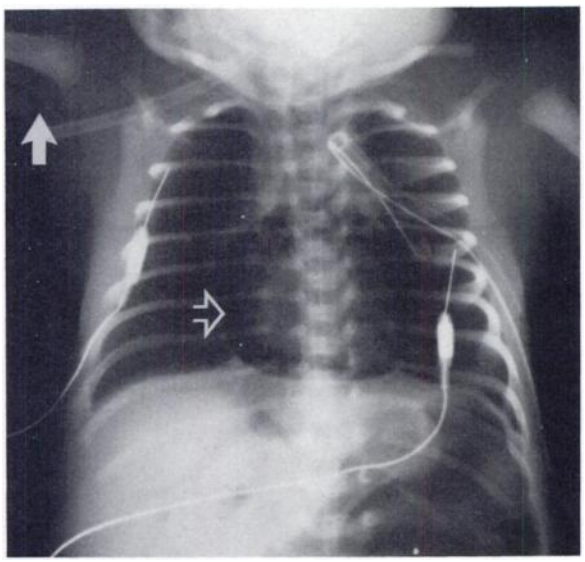

Fig. 4.—Case 4. Chest film showing pneumopericardium (*open arrow*) and intravascular air in axillary artery (*solid arrow*) and hepatic veins. Small pneumomediastinum also present.

present in both the arterial and venous circulations simultaneously [9, 10], as in the majority of our cases. Passage of the small gas bubbles through the capillary bed has been suggested as the mechanism of entrance into the venous system [12]. Autopsy studies have consistently failed to demonstrate the actual site of communication between the tracheobronchial tree and the vascular space [8, 9], as in our cases.

The occurrence of systemic air embolism is not limited to patients who are being treated with positive pressure ventilation. It has been described following surgical procedures [11], trauma [12], in submarine personnel [14], and in asthmatics [15].

It has been suggested that the varying distribution of the intravascular air is related to a differential buoyancy effect [11, 13], with clinical symptoms being related to the localization of the gas within the organs in question. The erect position is said to cause predominance of neural symptoms, whereas the Trendelenburg position causes collection of air within the coronary arteries with cardiac symptoms predominating [13].

In the neonate, this differentiation of clinical symptoms does not usually become evident. This is likely the result of two factors: (1) the relative amount of air entering the vascular space in these infants tends to be quite large compared to the vascular space itself, and (2) the small size of the infant's vascular space results in almost immediate widespread distribution of the air to the various organ systems.

This complication is virtually always a fatal one, with air being noted on radiographs made immediately prior to or following the patient's demise [3, 6, 8, 9]. Obtaining immediate postmortem films in order to more accurately diagnose this condition has been advocated [8, 10]. However, these should be interpreted with caution since rapid postmortem accumulation of gas is a constant physiologic occurrence and may result in inaccurate evaluation [16].

The radiographic diagnosis is made by visualization of air within the systemic vascular circulation. Air may be

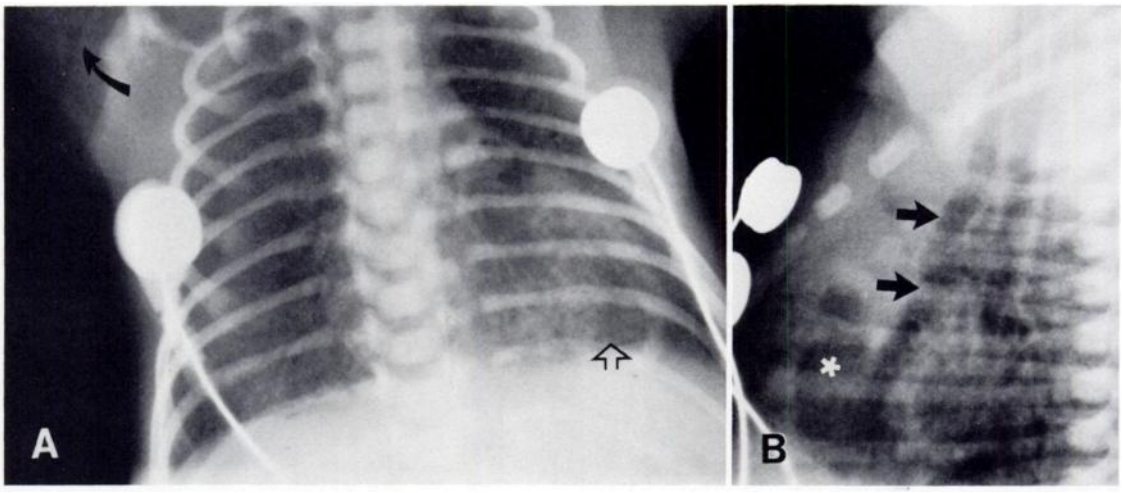

Fig. 5.—Case 5. *A*, Anteroposterior chest film prior to death showing air within heart (*open arrow*) and axillary artery (*solid arrow*). *B*, Lateral chest film showing air in right ventricle (*asterisk*), aorta, and brachiocephalic vessels (*arrows*).

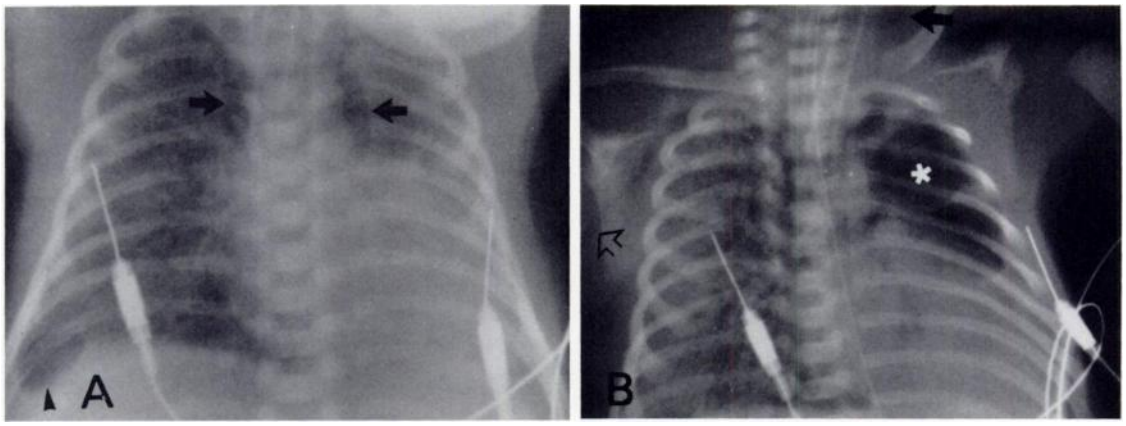

Fig. 6.—Case 6. *A*, Chest film showing pneumomediastinum (*arrows*) and small basilar pneumothorax (*arrowhead*). Endotracheal tube is in place. *B*, Chest film 1 day later showing cystic collection of extrapulmonary air left hemithorax (*asterisk*). Note intravascular air in left jugular (*solid arrow*) and right brachial/axillary vein (*open arrow*).

present within the cardiac chambers, hepatic veins, great vessels, peripheral vasculature, or pericardium. Air is most frequently noted within the heart and hepatic veins on the same film [8–10].

Our case 6 is unique in several respects: (1) the diagnosis was made only in retrospect; (2) at no time did the patient exhibit cerebral, cardiac, or other evidence of acute distress; and (3) this is the first reported neonate to survive the entity. The presence of air in both the right subclavian and left internal jugular vein, plus the fact that the intravenous fluid administration had been discontinued for over 12 hr prior to radiography, excludes the possibility of accidental intravenous air injection. The presence of air only in the venous system at the time of the examination is most likely a function of the time sequence involved. Since the film was exposed for "routine follow-up evaluation of a pneumomediastinum," it is most probable that the air had already entered and dissipated from the arterial side of the circulation and was in the process of being absorbed from the venous system. The lack of clinical signs demonstrates that this entity may be present even more frequently than is recognized, and that asymptomatic or subclinical cases may occur.

Unfortunately the diagnosis of systemic air embolism in the neonate is usually determined radiographically after the infant has exhibited severe clinical deterioration, most commonly vascular collapse and decompensation. It is important for both the radiologist and clinician to be aware of this complication of positive pressure ventilation. With the widespread acceptance of positive pressure ventilation as a part of therapy for the respiratory distress syndrome of infancy, it is likely that this severe complication will become more and more frequent. Pulmonary interstitial emphysema secondary to alveolar rupture is usually a preceding event. The radio-

graphic finding of air within the systemic arterial and venous circulation confirms the diagnosis. Our case 6 demonstrates that this condition is not universally fatal, and, in fact, clinical signs or sequelae need not be evident in every instance.

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