Flight Physiology

Science of Air Travel With Neonatal Transport Considerations

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ABSTRACT
Air transportation, by rotor wing and fixed wing, is a frequent method of neonatal transportation. There are many risks involved in air transportation. It is well documented that the safety of rotor wing flights has been questioned. Fixed wing transport is viewed as a safer mode of transportation. Air transportation has risks other than vehicle accidents, and increasing altitude encountered in both fixed and rotor wing transportation can cause significant distress to both the transport crew and the patient. Knowledge and awareness of these risks by the flight team can help to alleviate unnecessary risks and complications encountered during air transportation and ensure a safe arrival of both the team and the patient.
Key Words: altitude, flight physiology, hypoxia, neonatology

Neonatal air transport is a common mode of transferring infants with specialized needs to regional centers that offer NICUs with specialized care and access to neonatal and pediatric specialty consultation and care. Air transportation is often the mode of choice when time is critical in obtaining such services for an infant. Air transportation however is not without risk. Commonly considered risks include weather and equipment and/or vehicle failure, which may cause accidents. A very real but often-unrealized complication is the stress of air travel on both the flight crewmembers and the already-compromised infant. These stresses include, but are not limited to, hypoxia, noise, vibration, temperature, and decreased humidity. These stresses are considered and understood in the principles of flight physiology. Proper preparation and anticipation of the effects of air transport by the hospital staff and the transport crew can help to alleviate the impact of these stresses and ensure a safe and uneventful transport.

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The environmental changes encountered in air transport are stressful. Normal healthy human physiology allows for acclimation to these changes.[1] Infants requiring medically necessary transport are already in a compromised medical state and will have decreased ability to acclimate to the changes of pressure and altitude encountered by air travel. Even changes in altitude within a pressurized cabin can cause additional stress and deterioration of the infant's condition.

Simple Gas Laws and Hypoxia

There are several simple physical gas laws that aid in understanding the effects of flight physiology on the flight crew and patient. Those laws that have the greatest effect during air transport on the medical patient are Boyle's Law and Dalton's Law.

Boyle's Law states that at a constant temperature the volume of gas varies inversely with pressure, where $P_1V_1 = P_2V_2$. We encounter this most commonly with altitude changes in which atmospheric pressure decreases as altitude increases. As altitude increases, the pressure exerted by the atmosphere decreases allowing the gas within a given space to expand (increase in volume). Simply stated, as altitude increases, the atmospheric pressure decreases and gas within a space (volume) expands.[2]

Within the human body, there are several air spaces that are commonly affected by changing

TABLE 1. Effects of Altitude on Oxygenation

Altitude, ft	Barometric Pressure, mm Hg	PA_{O_2}, mm Hg	Pa_{O_2}, mm Hg	Pa_{CO_2}, mm Hg	Oxygen Saturation
Sea level	760	159.2	103	40	98
8000	565	118.4	68.9	36	93
10 000	523	109.6	61.2	35	87
15 000	429	89.9	45	32	84
18 000	380	79.6	37.8	30.4	72
20 000	349	73.1	34.3	29.4	66

Abbreviations: PA_{O_2}, partial pressure of alveolar oxygen; Pa_{O_2}, partial pressure of arterial oxygen; Pa_{CO_2}, partial pressure of arterial carbon dioxide.

barometric pressure, these include the middle ear, sinuses, and the gastrointestinal tract/bowel. Additional spaces of air that are concern during the transport of a medical patient may include the lungs, the pleural space (pneumothorax), intracranial space, and intraocular space. As increased altitudes are reached during air transport, the expansion of gas in these spaces has the potential to cause significant distress to the patient.

The second gas law that affects flight physiology is Dalton's Law (law of partial pressure), which states that the pressure of a gaseous mixture is the sum of the individual or partial pressures of all the gases in that mixture, where $P_T = P_1 + P_2 + P_3 \ldots$. For example, the earth's atmosphere consists of nitrogen, oxygen, and other gases. P_T (the total pressure) of these gases is equal to 1, with P_1 (nitrogen) = 0.78, P_2 (oxygen) = 0.21, and P_3 (other gases) = 0.1.[2]

When these principles are combined, it is evident that as altitude increases the volume of a gas within a space will increase. It is also evident that the percentage of a gas within the volume does not change. For example, percentage of oxygen remains 0.21, but oxygen is dispersed in a greater volume. The pressure exerted on that volume decreases as altitude increases. This becomes significant for gas exchange within the lungs as altitude increases, because even though the same amount of oxygen is present, the molecules are farther apart and the pressure in the alveoli is decreased, in effect, "pushing" less oxygen from the alveoli into the blood stream. When less oxygen transfers into the blood stream, the result is a decreased concentration of saturated hemoglobin or lower oxygen saturations (Table 1).[2]

Hypoxia results when there is an inadequate supply of oxygen for cell function, this is the most dangerous stress encountered with increased altitude in air transport. Two methods of reducing the risk of hypoxia in air transport are increasing barometric pressure during transport (pressurization of the cabin) and administering supplemental oxygen (Table 2).[1] While pressurization of the cabin can help to alleviate the risk of hypoxia, it is important to realize that most cabins are pressurized between 5000 and 8000 ft, still creating a high-altitude environment during air transport.[3]

Other Environmental Stresses of Air Transport

In addition to expanding air spaces (Boyle's Law) and decreased oxygen availability (Dalton's Law), there are additional environmental changes including temperature, humidity, noise, and vibration that are encountered during air transport that impose stress on both the transport crew and the infant.[2] Temperature decreases by 2°C for every 1000 ft gained in altitude. During the course of a transport,

TABLE 2. The Effects of Supplemental Oxygen and Oxygen Availability at Altitude

	Altitude (feet)			
	0	10 000	20 000	30 000
Pa_{O_2}				
Fi_{O_2} 0.21	100	50	13	0
Fi_{O_2} 0.50	307	194	107	45
Fi_{O_2} 1.00	663	436	262	138

Fi_{O_2}, fractional inspired oxygen.
Pa_{O_2}, partial pressure of arterial oxygen.

the team will encounter wide ranges of temperatures. While such ranges can be minimized by heat within the aircraft and isolette, they cannot be eliminated. As altitude is increased, there is a decrease in humidity, making the high altitude environment dry with risk of dehydration. Additional stresses encountered by the team are increased noise and vibration. Short-term exposure to increases in noise contributes to fatigue. Long-term repetitive exposure to noise can contribute to hearing loss. Vibration is not often considered a stress but can have effects similar to exercise when encountered for sustained lengths of time. When vibration is ongoing, heart rate and respiratory rate are increased, which can decrease the ability to concentrate and contribute to fatigue.

Air transport is most commonly utilized for the patients who have critical medical needs. It is vital that the team providing care during transport be able to perform quickly and efficiently in order to ensure safe transport of their patient. The environment encountered in air transport imposes stress and can cause fatigue and reduced ability to function. It is important that efforts to minimize the effects of stress on the crew be considered. Such efforts include, but are not limited to, adequate crew rest prior to transport; avoidance of foods/drinks that are gas producing; not flying with an ear infection, upper respiratory tract infection, or sinus infection; minimizing heat loss with proper clothing; and minimizing dehydration with increased fluid intake.[1]

Special Considerations for the Neonatal Patient

There are many challenges in transporting the neonatal patient. The large majority of neonatal transports are infants who have recently been born, exiting a very stable balanced environment (the uterus) and transitioning to the extrauterine environment. Under ideal circumstances, this transition happens quickly and with very few complications. However, approximately 1% of all births result in a need for more extensive resuscitation[2] and further specialized medical care. It is these infants who generally require transport by a neonatal transport team. These infants have not transitioned well and require artificial efforts to maintain breathing, glucose levels, and often blood pressure. They are already stressed by their environment. Exposing these infants to the stresses of air transport may be the only way to ensure that they receive the specialized care they need, but it may also lead to complications related to their present illness. For example, a small, stable pneumothorax may develop into a larger tension pneumothorax, leading to bradycardia, hypotension, and hypoxia. Bowel obstruction or increased intestinal air may increase causing localized ischemia, necrosis, or perforation, or may cause tension on the diaphragm decreasing lung capacity and leading to respiratory distress.[1] Some of the most fragile and unstable infants who require emergency transport are those with congenital diaphragmatic hernia. The severity of their condition is directly related to their ability to oxygenate, which is affected to a great extent by the space occupied in the thoracic cavity by bowel. Bowel with increased intestinal air will negatively impact oxygenation. These infants require supplemental oxygenation and usually ventilation for adequate oxygen exchange, with air transport they will require more.

When transporting ill neonates, special considerations must be made by the transport team prior to air transport in order to ensure a safe and uneventful trip. Placing a nasogastric tube or orogastric tube will help to alleviate increased intestinal air. Placement of a chest tube in an infant with a small to moderate pneomothorax prior to transport may minimize deterioration of the infant due to the development of a tension pneumothorax during ascent to altitude.[3] Adequate methods for oxygenation in any compromised infant should be considered.

Very low-birth-weight infants are dependent on an artificial environment for their every need, ventilation, oxygenation, temperature, glucose, and humidity. It must be recognized that each of these needs will be affected by air transport and measures should be taken to correct the encountered stresses of flight. There are times when the modes of transportation, that is, fixed wing versus rotor wing, should be considered. In fixed wing transports, the cabin can be pressurized and there is often better control of temperature, noise, and vibration. Rotor wing cannot provide pressurization, and noise and vibration may be worse than those in a fixed wing aircraft.

Air transport provides an efficient method of transportation of the neonatal patient in need of

Definitions

Barometric pressure or *atmospheric pressure* is the force per unit area exerted against a surface by the weight of air above that surface in the Earth's atmosphere.

If the barometric pressure at sea level = 1, the barometric pressure at 18 000 ft will be 0.5.

F_{IO_2}: fractional inspired oxygen

P_{AO_2}: oxygen tension in the alveoli

P_{aO_2}: partial pressure of arterial oxygen

P_{aCO_2}: partial pressure of arterial carbon dioxide

Hypoxia: inadequate supply of oxygen for cell function

Hypoxemia: poor tissue oxygenation

Fixed wing: airplane

Rotor wing: helicopter

specialized care and/or treatment. Air transportation is not without risk. Understanding basic principles of flight physiology will assist the hospital staff and neonatal transport team in thorough assessment and planning prior to transport. Proper planning will facilitate to minimize the risks and potential complications encountered during air transport.

References

1. Woodward GA, Vernon DD. Aviation physiology in pediatric transport. In: Jaimovich DG, Vidyasagar D, eds. *Pediatric and Neonatal Transport Medicine*. 2nd ed. Philadelphia, PA: Hanley & Belfus Inc; 2002:43-54.
2. American Academy of Pediatrics. Guidelines for air and ground transport of neonatal and pediatric patients. In: *Task Force on Interhospital Transport*. 2nd ed. Elk Grove Village, IL: American Academy of Pediatrics; 1999.
3. Bossley C, Balfour-Lynn IM. Taking young children on aeroplanes: what are the risks? *Arch Dis Child*. 2008;93:528-533.