ACNN Queensland - Education Series

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Regardless of where you work in your role as a neonatal nurse, it is likely that you will provide care for a neonate who is about to, is being, or has been retrieved by air. Following on from this, it is quite likely then that you will be responsible for the preparation, transport of, or admission of a neonate who requires aeromedical retrieval. For neonatal nurses, having this knowledge is critical in not only understanding what changes can occur in flight and how that might impact on outcomes, but also informs your preparation of, or ongoing care of the patient.

Neonatal aeromedical retrievals is a wide-ranging subject, so it isn't possible to cover all aspects of interest in one article. The material is separated into a series, where a few key concepts will be provided in each article to broaden your knowledge of the subject.

Neonatal aeromedical retrievals series: Environment, team, & patient.

Article One:

As background, aeromedical transports can be unpredictable and exciting. They can also be long, tiring and tedious. However, it is not uncommon for the transport working environment to change abruptly, therefore it remains a challenge to provide neonatal patient care at the standard we are accustomed to in a fixed unit setting.

At the beginning of this theoretical discussion about aeromedical transport, it is timely to reflect on the neonate at the centre of the aeromedical retrieval process. For them, this is an episode of care that is **high risk**. For teams providing this care, we must understand that the risks involved are not just **actual** risks; perhaps more importantly, they are **potential** risks.

> What you don't expect to happen may happen, if you don't prepare for it, you (and the patient) have a problem.

Much of the challenge inherent to aeromedical retrievals is around aviation physiology and what physical changes occur as a result. This is primarily linked to **basic physics** regarding the gas laws, pressure changes at altitude, and the stressors related to the forces of inertia and vibration. There are also several environmental limitations that add to the complexity of aeromedical retrievals which the series will expand on.

The relevant concepts are easily explained and understood (I know, everyone hates physics 😊)

In this article we will start with oxygenation and how it interacts with:

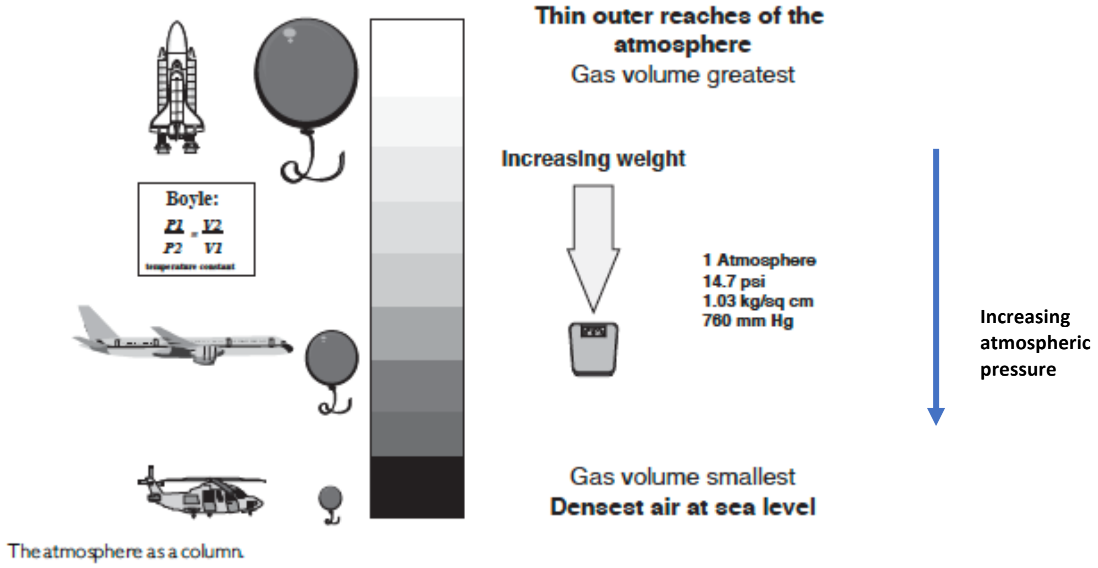
- atmospheric pressure and what exactly is it
- how pressure changes at altitude
- what is the relevant gas law
    - N.B. the name of the gas law is not that important, but the concepts are
- aeromedical transport of neonatal patients

Atmospheric pressure – basic summary

Put simply, the atmosphere is the air column, or the layer of environmental air that sits above us. This layer of air weighs something. The weight of the air layer exerts a pressure that can be measured. At sea level this measured pressure is referred to as atmospheric pressure. The conventional calculation states that if the environmental temperature is constant at 15° Celsius, the atmospheric pressure equals **760 mmHg** (also known as 1 atmosphere).

When we ascend above sea level, the weight of the layer reduces and the air becomes less dense (i.e. the particles move farther apart), therefore the amount of atmospheric pressure also decreases. If we do the reverse and descend from a higher altitude to a lower, the air increases in density, the weight of the layer increases, and the amount of atmospheric pressure is increased.

Figure 1. The atmosphere.[1]



Composition of air

Environmental air is composed of different gases. Each gas exerts their own percentage component, or **partial pressure**, of the total atmospheric pressure. There is also a small amount of partial pressure taken up by water vapour. The sum of all the gas partial pressures must equal 100%.

The two most abundant gases in the atmosphere are nitrogen and oxygen (O_2). Approximately 78% of the air around us consists of nitrogen, **21% consists of O_2**, and the remainder consists of trace percentages of argon, helium, carbon dioxide and other gases.

Partial pressure of gases at sea level

At sea level where the atmospheric pressure is 760mmHg, the following calculations demonstrate how we arrive at the partial pressure of the two most abundant environmental gases:

- Nitrogen – calculated by 78% x 760 mmHg = 593 mmHg;
- Oxygen – calculated by 21% x 760 mmHg = 160 mmHg

We breathe in all the environmental gases including nitrogen, but only the O_2 is absorbed and is a critical element for cellular respiration. As you know, carbon dioxide (the end product of cellular respiration) is breathed out along with all unused gas components, as well as some O_2 at a reduced percentage following cellular usage.

Partial pressure at altitude

The **percentage** (21%) **of O_2** that is present in air is **constant** at different altitudes. As we have discussed however, total atmospheric pressure drops as you ascend to higher altitudes; each of the partial pressures comprising the total atmospheric pressure also drops.

The gas particles are still there, but they are not as compressed and sit further apart. Of importance to humans, this effectively **decreases** the **partial pressure of O_2 that is available** to be inspired.

As an unpressurised aircraft gains altitude, the greater the potential for insufficient delivery of oxygen to the tissues and resultant **hypoxia**.

To give an example:

- At around 3000 metres altitude, the atmospheric pressure is 523.2mmHg
- O_2 continues to be present at 21% of this total pressure
    - To calculate
        - the partial pressure of O_2 at this altitude is (21% x 523.2) **109.8 mmHg**
    - This is compared with **160mmHg** at sea level – you can see how this may impact on a patient.
- For some patients this may lead to a hypoxic state that is not tolerated without intervention
- This concept is nicely depicted in Table 1 on the following page.

Relevant gas law

Dalton's law

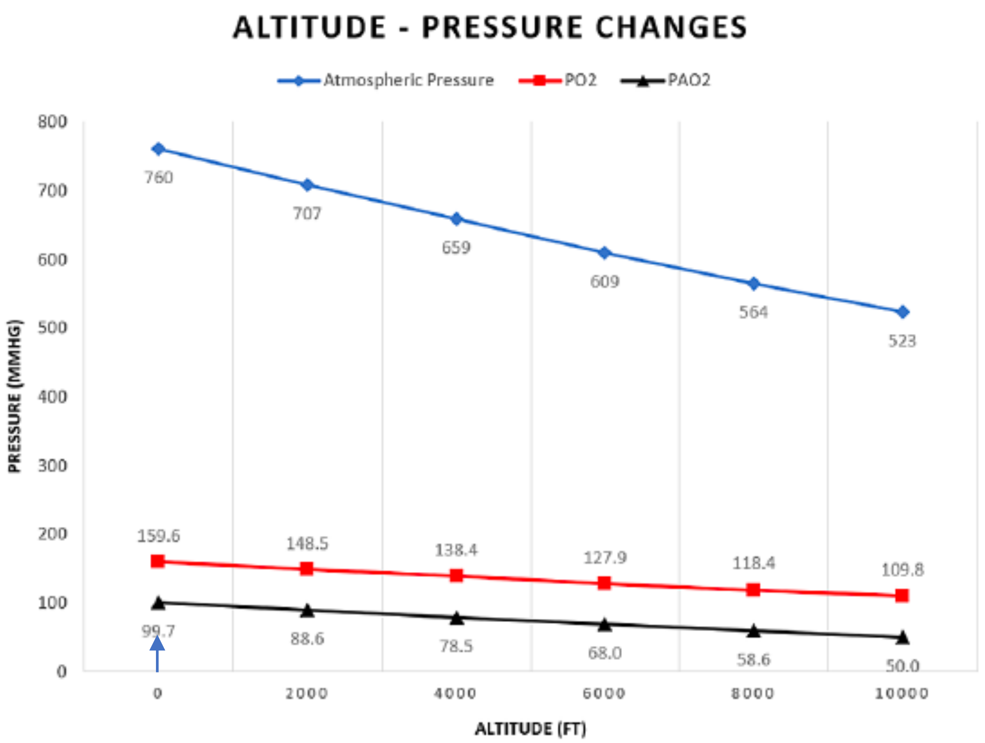
- Within a combination of gases, the total pressure = the sum of the partial pressures of each individual gas present in that mixture (P total = P1 + P2 + P3 + …. Pn etc)
- Partial pressure of O_2 (thus the O_2 available to be inspired) depends on the total atmospheric pressure *at that altitude*.

Take home message: Altitude may cause, or exacerbate hypoxia

During flight transport at altitude, pressurising the cabin to sea level and adding oxygen are 2 ways to counteract the hypoxia experienced due to the lower partial pressure of oxygen.

Figure 2. Relationship between altitude and atmospheric pressure.[2]

PO_2 = partial pressure of O_2. PAO_2 = partial pressure of alveolar O_2.



Partial pressure in the lungs and circulation

Inspired O_2 moves from the alveoli > the pulmonary circulation via a pressure gradient.

Alveolar partial pressure of O_2 is higher than arterial partial pressure, which creates the necessary diffusion gradient required for arterial O_2 delivery. Diffusion occurs across the alveolar capillary membrane, into the bloodstream, and on to the tissues.

The expected range of arterial partial pressure of O_2 in the neonate is around 50-80mmHg, but varies according to disease process, age and method of O_2 delivery/respiratory support.

As we have previously discussed, the partial pressure of atmospheric O_2 at altitude, is less than at sea level.

As less O_2 is available to be inspired at altitude:

- the partial pressure of O_2 in the alveolus is reduced >
- the pressure gradient between alveolus and capillary circulation lessens >
- reducing the partial pressure of O_2 in the blood >
- reducing oxygen delivery at the tissue level

In an aeromedical retrieval context, we may see this in our neonatal patient as desaturations, or consistently poor saturation percentages. We respond by increasing the inspired O_2 percentage or other respiratory support settings if relevant.

Altitude is a highly relevant factor influencing patient stability in aeromedical transport. It can be particularly problematic when a neonate has severe pre-existing respiratory disease and is on maximal support, such as ventilation in 100% O_2, with inhaled nitric oxide delivery; and/or the neonate is anaemic.

Optimising oxygen delivery

This table has been borrowed from the JCU Graduate Certificate of Aeromedical Retrieval Coursework. It was originally borrowed by the course coordinator from a military training manual. You already have an appreciation of the reduced availability of oxygen at altitude, but this table provides guidance regarding what increased O_2 delivery at altitude looks like as the patient ascends.

Take some time to look through the variables.

Table 1: Oxygen administration chart

Cabin altitude	Oxygen percentage																
10,000	30	36	44	51	58	65	73	80	87	94	100						
9,000	29	35	42	49	56	63	70	77	84	91	98	100					
8,000	28	34	40	46	54	61	67	74	81	87	93	100					
7,000	27	32	39	45	52	58	65	71	78	84	91	97	100				
6,000	26	31	37	44	50	56	62	69	75	81	87	94	100				
5,000	25	30	36	42	48	54	60	66	72	78	84	90	96	100			
4,000	24	29	35	41	46	52	57	64	70	75	81	87	93	97	100		
3,000	23	28	33	39	45	50	56	61	67	73	78	84	89	95	100		
2,000	23	27	32	38	43	48	54	59	64	70	75	81	86	91	97	100	
1,000	22	26	31	38	41	47	52	57	62	67	73	78	83	88	93	98	100
Sea level O2 requirement	21	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100

(pink)	At all altitudes above 1000 feet, when 100% O2 is being delivered, the partial pressure to deliver more than the corresponding sea level requirement is not achievable (e.g., 100% O2 at 8000 feet only provides a 75% sea level equivalent; 100% O2 at 4000 feet can only provide a 90% sea level equivalent)
(hatched)	Desired sea level equivalent cannot be obtained at these levels

To use the table:
- Find desired % of oxygen required to deliver adequate blood oxygen levels (by saturation monitoring) along the bottom row
- Find the cabin altitude of the aircraft from the left column
- The number obtained is the amount of oxygen that must be delivered in flight to obtain the desired sea level equivalent
- Actual oxygen delivered should be determined by Hb and patient condition as well

A comment on acute anaemia, oxygenation and altitude

As you are aware, anaemia is a factor in reduced tissue oxygenation. However, even in an anaemic state, O_2 saturation can be close to 100% - effectively all this is telling you is that close to 100% of the circulating red blood cells are carrying O_2.

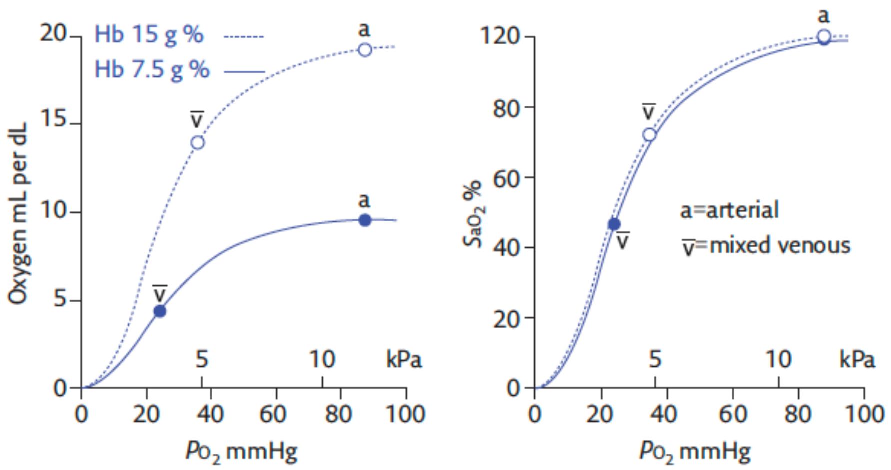
> It doesn't tell you that the patient has insufficient circulating red blood cells.

When a patient reaches a sufficiently anaemic state, **the blood O_2 content** (the amount of O_2 in mL/dL being carried by the blood) becomes markedly reduced. This has a big influence on how much O_2 can be delivered at the tissue level.

Review Figure 3 below.

- On the left graph, you can see that the O_2 content of the anaemic patient (unbroken line) is half that of the patient with normal Hb (dotted line).
- On the right graph, the saturation curve of each patient is almost identical

Figure 3. Relationship between anaemia and oxygen content of the blood, compared with oxygen saturations in the oxygen dissociation curve.[3]



What happens in real clinical circumstances is that when haemoglobin concentration is reduced to half of the normal value, this is accompanied by a similar (half) reduction in blood O_2 **content** (measured as mL/dL). There is however no (or very little) change in % O_2 saturation, or of the partial pressure of arterial O_2.

> Take home message: A patient with acute anaemia being transported via aeromedical retrieval is likely to need increased O_2 delivery. This will be exacerbated at altitude, where partial pressure of oxygen is reduced.
>
> Blood product administration to correct anaemia may need to be considered.

Optimising oxygen delivery

Remembering that **adequate oxygen content** of the blood and tissues is key to good cellular function, not just O_2 saturations being within range - flying at altitude will place extra stressors on the physical capacity of your patient who is already unwell, with a likely increased metabolic demand for oxygen.

It is therefore useful to think about what factors may be influencing oxygen demand as you prepare your patient for transport. Some examples include respiratory distress, persistent pulmonary hypertension of the newborn, tachyarrhythmias, hyperthermia (consider iatrogenic), acute blood loss/anaemia, seizures, hypoglycaemia and sepsis.

The points below are not intended to direct all actions taken, but prompt you to think about what actions can be taken to reduce oxygen demand and optimise the patient's transport. These factors need to be placed in the context of gestation, age in hours and delivery/resuscitation history:

- Oxygen requirement, work of breathing, pre and post ductal saturations, blood gas measurements, Hb, Xray results prior to departure (and rule our air leak)
- Heart rate, blood pressure (invasive [accurate transducer level height] vs non-invasive, [accurate cuff size for neonate and correct placement]), cap refill and peripheral perfusion, pulse volume, urine output
- Drainage of gas cavities that may impede respiratory/airway status – e.g. NG tube placed on free drainage, contents emptied pre-departure
- Adequate antibiotic coverage
- Temperature, and temperature trend, warmth of peripheries
- BGL results and trend, maintenance fluids running
- Level of agitation, sedation requirements

Take home message: Adequately oxygenating your patient during aeromedical transport is reliant on complex, interdependent factors. Meticulous attention to detail and constant observation is needed before, during and after the transport event.

This concludes the current content – you've probably had enough for now!

Subsequent articles in this series will expand on additional gas laws, environmental stressors, and physical limitations in the aeromedical retrieval of neonates.

Diagrams and tables within this article have been specifically attributed, and all other references are supplied as a bibliography from which content was drawn.

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