Chapter 4

Hypoxia and Oxygenation

Hypoxia is a serious threat to patients and escorts alike when they fly. Air medical escorts need to understand what causes hypoxia, why some people are more likely to become hypoxic as well as the signs and symptoms of hypoxia. This knowledge will enable air medical escorts to take steps to prevent hypoxia and to treat it if it does occur.

Learning Objectives

Upon completion of this chapter, the participant should be able to:

- Define hypoxia.
- Describe the four types of hypoxia.
- List at least 3 factors affecting an individual's susceptibility to hypoxia.
- List the stages of hypoxia and describe their corresponding signs and symptoms.
- Describe two treatments for hypoxia.
- Describe the relationship between the flow rates and oxygen concentrations delivered by common oxygen delivery devices.
- Describe the effect of altitude on oxygen regulators.
- Calculate the amount of oxygen needed for a flight, given flow rate and expected flight time.

Types of Hypoxia

Definition

Hypoxia is an insufficient supply of oxygen to meet the demands of the body.

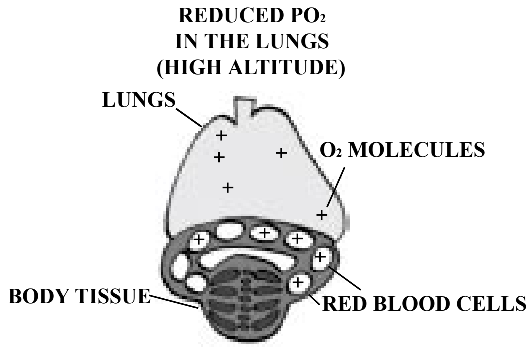
Types

There are four basic types of hypoxia.

1. **Hypoxic hypoxia** occurs when there is a deficiency in oxygen exchange in the lungs. Some causes include:

   - Decreased partial pressure of oxygen available at altitude.
   - Conditions that block the exchange at the alveolar capillary level (e.g. pneumonia, pulmonary edema, asthma, drowning).

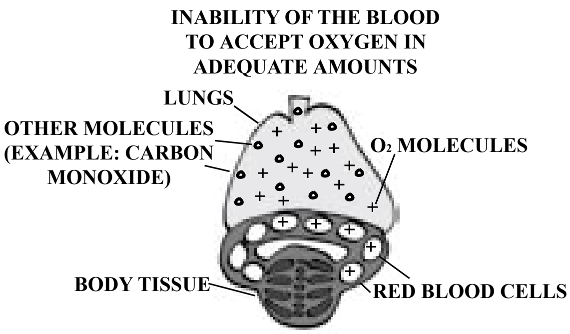
The picture below illustrates hypoxic hypoxia:



HYPOXIC HYPOXIA

2. **Anemic (hypemic) hypoxia** occurs when the body cannot transport the available oxygen to the target tissues. Causes include:

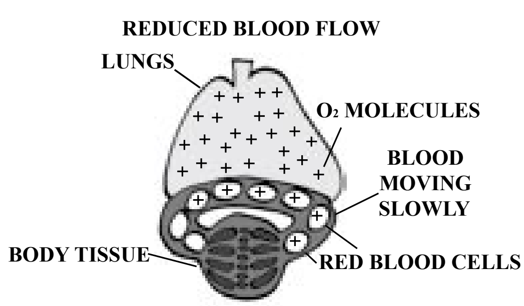
   - Anemia from acute or chronic blood loss.
   - Carbon monoxide poisoning.
   - Medications such as aspirin, sulfonamides and nitrites.
   - Methemoglobinemia.
   - Sickle cell disease.



ANEMIC HYPOXIA

3. **Stagnant hypoxia** occurs when there is insufficient blood flow. Causes include:

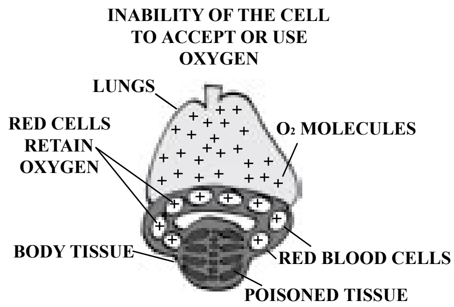
- Heart failure.
- Decreased circulating blood volume.
- Vasodilatation.
- Venous pooling due to G-forces.
- Continuous positive pressure ventilation.
- G-forces.



STAGNANT HYPOXIA

4. **Histotoxic (histologic) hypoxia** occurs when the body's tissues are not able to use the oxygen that has been delivered to them. This is not a "true hypoxia" because the tissue oxygenation levels may be at or above normal. Causes include:

- Cyanide poisoning.
- Alcohol consumption.
- Narcotics.



HISTOLOGIC HYPOXIA

Whatever the cause or causes of a patient's hypoxia, it is important to recognize the potential for, and symptoms of, hypoxia early.

Susceptibility to Hypoxia

Factors

Everyone becomes hypoxic to some degree when exposed to decreased partial pressures of oxygen at altitude. Some factors beyond atmospheric pressure can cause some people to react as they would at altitude even when they are at sea level. These are what create a person's physiologic altitude. The following factors affect physiologic altitude.

- Smoking (due to high baseline levels of carboxyhemoglobin)—3 quick cigarettes or 1–1.5 pk/day = 2,000 foot physiological altitude.
- Alcohol consumption (due to histotoxic hypoxia)—one ounce of alcohol = 2,000 foot physiological altitude.
- Coffee (secondary to the stimulant effects of caffeine)—5 cups = 2,500 foot physiological altitude.
- Anemia (due to anemic hypoxia)

Altitude Equivalents for Anemic Patients

Hemoglobin Level g Hg/100 ml	Acute Anemia	Chronic Anemia
15	0	0
14	1,200	800
13	2,400	1,500
12	3,500	2,300
11	4,800	3,200
10	6,000	4,000
9	7,200	4,800
8	8,400	5,600
7	9,500	6,300
6	11,000	7,200

The following factors also can affect the body's response to changes in altitude.

- Medications, such as aspirin, nitrites and sulfa.
- Chronic Obstructive Pulmonary Disease (COPD).
- Diet.
- Level of physical fitness.
- Emotional state.
- Baseline metabolic rate.
- Fever or low body temperature (higher temperature tends to lower hemoglobin (Hgb) O_2 saturation).
- High or Low pH:
    - Low pH makes it harder for the hemoglobin to bind to oxygen (requiring a higher partial pressure to achieve the same oxygen saturation), but it makes it easier for the hemoglobin to release bound oxygen.
    - High pH makes it easier for the hemoglobin to pick up oxygen but harder for it to release it to the tissues.

- Duration of exposure to altitude—the longer the exposure, the more profound the affect.

- Change in altitude—the greater the change in altitude, the greater the affect.

The sum of a person's actual altitude, his or her physiological altitude, along with the duration of exposure and the degree of change in altitude help determine how each person will react during air medical transport flights.

Stages of Hypoxia

There are four stages of hypoxia. The amount of time spent in any one of these four stages may vary, and each patient and provider is likely to respond differently to the same conditions. The air medical escort needs to be alert to the signs and symptoms of hypoxia.

There are four stages of hypoxia:

1. **Asymptomatic or Indifferent**
   People are not generally aware of the effects of hypoxia at this stage. The primary symptoms are a loss of night vision and a loss of color vision. These changes can occur at relatively modest altitudes (as low as 4,000 feet) and are probably most significant to pilots operating at night. Arterial oxygen saturations are typically between 90 and 95 percent.

2. **Compensatory**
   In healthy people, this stage may occur at altitudes between 10,000 and 15,000 feet. The body generally has the ability to stave off further effects of hypoxia by increasing the rate and depth of ventilation and cardiac output. Arterial oxygen saturations during this phase are typically between 80 and 90 percent.

3. **Deterioration or Disturbance**
   In this state, people are unable to compensate for the lack of oxygen. Unfortunately, not everyone recognizes or experiences the signs and symptoms associated with this stage. If they do not, they cannot take steps to correct the problem. The list below shows the signs that are associated with this stage:

- Shortness of breath/air hunger
- Cyanosis
- Drowsiness
- Headache
- Euphoria
- Aggression
- Poor Judgement
- Incoordination
- Difficulty with simple tasks
- Diminished vision
- Tingling
- Numbness
- Hot/cold flashes

Arterial oxygen saturations during this phase typically are between 70 and 80 percent.

4. **Criticial**
This is the terminal stage leading up to death. People are almost completely incapacitated physically and mentally. People in this stage will lose consciousness, have convulsions, stop breathing and finally die. Arterial oxygen saturations are less than 70 percent.

Prevention and Treatment

The prevention and treatment of hypoxia in the airborne environment can be accomplished in two ways:

- Provide sufficient oxygen
- Fly at a lower altitude

Unfortunately, it is not always possible to do both. Pilots must fly aircraft at safe altitudes for terrain and weather. Air medical escorts should communicate with pilots prior to and during flights about the effects of elevation. They should be prepared to ask the pilot to fly lower if needed. Air medical escorts should provide adequate amounts of oxygen to prevent their patients from deteriorating when flying at any altitude. When patients are on oxygen before a flight, it can be challenging to determine their increased oxygen needs resulting from the additional stress of altitude and flight.

Quantity

How much oxygen is enough?

The following table is a guide to assist air medical escorts in determining their patients' oxygen needs. The chart shows the oxygen concentration needed to maintain oxygen saturation at different altitudes. If a patient is on a given amount of oxygen at sea level (column marked SL), the flow rate to keep saturation levels above 90 percent at 10,000 feet can be found on the same row in the column labeled "10." Generally it is advisable to keep oxygen saturations above 90 percent in patients who do not have COPD.

Fraction of Inspired Oxygen (FIO_2)	Altitude x 1,000 feet										
	SL	2	4	6	8	10	12	14	16	18	20
	.21	.23	.24	.27	.29	.31	.34	.37	.41	.45	.49
	.30	.32	.35	.38	.41	.45	.49	.53	.59	.64	.71
	.40	.43	.47	.51	.55	.60	.65	.71	.78	.85	.94
	.50	.54	.58	.63	.69	.75	.81	.89	.98		
	.60	.65	.70	.76	.83	.89	.98				
	.70	.76	.82	.89	.96						
	.80	.86	.94								
	.90	.97									
	1.00										

The table has empty spaces at certain FIO_2/altitude combinations. Above these altitudes patients cannot be saturated with oxygen.

In general, oxygen toxicity is not a problem for most patients (even neonates) for at least 24 hours. This means that:

- Hypoxic or decompensated patients should not have oxygen withheld from them.
- Chronic obstructive pulmonary disease (COPD) patients who are hypoxic and decompensating need oxygen.
- Escorts should attempt to keep COPD patients at their "normal" oxygen saturation.

Oxygen Delivery Devices

The chart below lists oxygen devices available for medevacs; the concentration that can be delivered from a given device, oxygen flow rates and comments about each:

Device	Concentration	Flow (L/min)	Comments
Nasal Cannula	24–44%	1–6	• Well tolerated. • Does not work well with a blocked nose. • Delivers low concentrations of oxygen. • Oxygen should be humidified for longer flights. • The patient must have adequate ventilation.
Simple Face Mask	40–60%	6–8	• Delivers medium concentrations of oxygen. • May not be tolerated by some patients—feels like something is “smothering” them. • Must be removed if oxygen supply is interrupted. • Requires adequate oxygen flow rates or patients may re-breathe carbon dioxide. • Oxygen should be humidified for longer flights. • The patient must have adequate ventilation.
Non-Rebreather Mask	60–80%	8–15 (enough to keep bag partially inflated)	• Delivers higher oxygen concentrations. • May not be tolerated by some patients—feels like something is “smothering” them. • Requires that the mask fit correctly and flow be adequate to keep reservoir bag from collapsing completely if it is to be effective. • Requires adequate oxygen flow rates or patients may re-breathe carbon dioxide or receive too little oxygen. • Must be removed if oxygen supply interrupted. • Oxygen should be humidified for longer flights. • The patient must have adequate ventilation.

Device	Concentration	Flow (L/min)	Comments
Bag Valve Mask	60–90%	15+	• Delivers high concentrations of oxygen under pressure. • Should be used with an airway adjunct (e.g. oropharyngeal airway (OPA), nasopharyngeal airway (NPA), combi-tube or ET tube). • May be used with patients with inadequate ventilation. • Requires skill and usually two people if using mask. • Use of "humidifier*" tube for patients on longer flights.
Transport Ventilator	21–100%	Varies	• Allows fewer people to manage a patient's airway and ventilation. • Often conserves oxygen resources by not requiring free flow at high rates. • Requires higher skill level and Training. • Higher cost. • A "humidifier*" tube should be used for patients on longer flights.

*Specially designed "humidifiers" are available for intubated patients. They use a sponge-like material to trap exhaled moisture to reduce the drying effects of being ventilated. These are different from the "water bottle" type of humidifier used with free-flow oxygen.

Oxygen Regulator at 8,000 feet

Rate Set (L/min)	Actual Flow (L/min)
2	2.6
4	5.3
6	7.9
8	10.6
10	13.2
12	15.8

Oxygen regulators are generally calibrated for use at sea level; actual flow rates vary with altitude. At 8,000 feet a regulator set to deliver 2 L/min. will actually deliver 2.6 L/min. The table at left shows the actual regulator flow at 8,000 feet.

Oxygen Supplies

Tank Life

The number of oxygen tanks needed on a transport can be determined by calculating how long each tank will last. The formula below gives the escort this information.

$$\frac{\text{Tank Pressure} - 200\ (\text{residual}) \times \text{Tank Factor}}{\text{Flow Rate (L/min)}} = \text{Minutes of Oxygen}$$

Tank Factors
D tank = 0.16
E tank = 0.28
M tank = 1.37
H tank = 3.14

Residual—air medical escorts should plan on leaving some oxygen in the tanks when on flights. 200 psi is a generally accepted amount to leave in the tank.

For example:
If a "D" tank has 2,000 psi showing on the gauge, the flow rate is 4 L/min, and you are traveling in a pressurized aircraft with a sea level cabin pressure, how long will the tank last?

$$\frac{\text{2,000 (Tank Pressure)} - \text{200 (residual) X 0.16 (Tank Factor)}}{\text{4 [Flow Rate (L/min)]}} =$$

$$\frac{2{,}000 - 200 \text{ X } 0.1}{4} \longrightarrow \frac{288}{4} \longrightarrow \text{72 minutes}$$

If a flight is expected to take four hours, at least four D-tanks would be required. The following factors should be included in the calculation:

- Ground time at the sending facility or scene.
- Ground time at the receiving facility.
- Ground transportation at both ends.
- Expected flight time.

It is prudent to build in extra time, as unexpected delays can occur.

Other Considerations

There are a number of other things to consider about oxygen supplies.

- Large commercial carriers (e.g. Alaska Airlines) only permit oxygen bottles from their own vendor to be brought on board their aircraft. The airline makes arrangements to provide oxygen, but it requires advance notice. In an emergency setting Alaska Airlines requires 24 hours notice to ensure oxygen availability. In a non-emergency setting (like a patient planning to return home after hospitalization) Alaska Airlines requires a minimum of 48 hours notice.
- Changing regulators on oxygen bottles is NOT permitted while on-board any large commercial aircraft operating under FAA part 121.
- Changing regulators or oxygen bottles operating under FAA part 135 and 91 is strictly controlled. The air medical escort should discuss this issue with the pilot prior to a flight.

Monitoring Oxygen Levels

Pulse oximeters are the most common device for monitoring patients' oxygen status. While a useful tool, pulse oximeters are not a replacement for an arterial blood gas or for looking at the patient. They simply measure the saturation of the hemoglobin present in the blood, not the actual amount of oxygen in the blood. Pulse oximeters cannot differentiate which gas is bound to the hemoglobin, so readings are falsely elevated in carbon monoxide poisoning. Low flow states (shock), cold, and bright light can also make the readings unreliable.

Portable blood gas analyzers are available, but the cost, the need for CLIA certification, training, and support limit the availability of these devices.

Summary

The recognition, prevention, and treatment of hypoxia requires an understanding of the pathophysiology that leads to hypoxia, the signs and symptoms of the condition, and the methods of preventing and treating it. Familiarity with the capabilities and limitations of medevac equipment is important for medevac escorts to enable them to respond rapidly and effectively to changes in their patients' conditions.