

# **Hypoxemia**

**Troy Schaffernocker, MD**

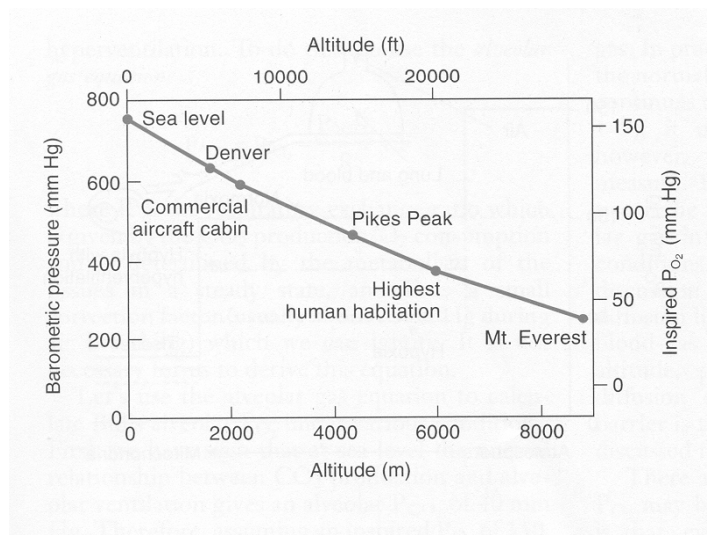
## **Hypoxemic Respiratory Failure**

- **Mechanisms of hypoxemia:**
  - ✓ **Decreased partial pressure of oxygen**
  - ✓ **Impaired diffusion**
  - ✓ **Ventilation/perfusion mismatch**
  - ✓ **Shunt**
  - ✓ **Hypoventilation**

# Decreased Partial Pressure of Oxygen

- Occurs at altitude
- Barometric pressure and altitude have a dramatic effect on oxygen tension
- Oxygen tension of inspired air:
  - ✓ Sea level = 150 mm Hg
  - ✓ Denver = 130 mm Hg
  - ✓ Mt. Everest = 43 mm Hg

## Effect of Barometric Pressure and Altitude on Oxygen



# Impaired Diffusion

- **Interstitial lung disease**
  - ✓ **Thickened interstitium impedes diffusion of oxygen from the alveolus to the capillary**
- **Early in course of ILD, hypoxemia usually not significant except during states of increased oxygen demand (exercise)**
- **Combination of impaired diffusion and increased transit time of blood through alveolar capillaries (due to increased cardiac output from exercise) results in hypoxemia**

# Ventilation/Perfusion

- **The adequacy of gas exchange in the lungs is determined by the balance between pulmonary ventilation and capillary blood flow.**
- **Expressed as the ventilation-perfusion (V/Q) ratio.**

## **Clinical Situation of Low V/Q (Shunt)**

- **V/Q = 0 is represented by true right to left shunting (intracardiac defect) with venous admixture of blood.**
  - ✓ Alveoli completely bypassed
- **Any situation where alveoli are filled (not ventilated):**
  - ✓ Blood, pus, water
  - ✓ Alveolar hemorrhage, pneumonia, CHF, ARDS
- **Atelectasis of lung**

## **Clinical Situations of High V/Q (Increase Deadspace)**

- **Pulmonary embolism**
- **Physiologic dead space as seen in COPD**
  - ✓ Normal response is to increase minute ventilation

# Hypoventilation

- Results in hypoxemia that is *always* associated with hypercapnia (by definition)
- Normal physiologic response to  $\uparrow$  PaCO<sub>2</sub> is to increase minute ventilation and thus alveolar ventilation

## Hypoxemia: Diagnosis and Monitoring

- Arterial Blood Gas (ABG)
- Alveolar Oxygen Tension
- Alveolar-arterial (A-a) Oxygen Gradient
- Oxygen Content and Delivery
- Pulse Oximetry

## Normal Arterial Blood Gases

AGE (Years)	PaO <sub>2</sub> (mmHg)	PaCO <sub>2</sub> (mmHg)	A – a PO <sub>2</sub> (mm Hg)
20	84-95	34-47	4-17
30	81-92	34-47	7-21
40	78-90	34-47	10-24
50	75-87	34-47	14-27
60	72-84	34-47	17-31
70	70-81	34-47	21-34
80	67-79	34-47	25-38

All values related to FIO<sub>2</sub> = 21% at sea level  
Adapted from Intermountain Thoracic Society  
Manual, 1984 44-45

## Variation in ABGs

Variation	PaO <sub>2</sub> (mm Hg)	PaCo <sub>2</sub> (mmHg)
Mean	13	2.5
95 <sup>th</sup> Percentile	+/- 18	+/- 4
Range	2 – 37	0 - 12

Represents variation over a 1-hour period in 26  
clinically stable ventilator dependent patients  
From Hess D, Agarwal NN. J Clin Monitor 1992

# Alveolar Oxygen Tension

- Determined by the alveolar gas equation:
- $(\text{Barometric pressure} - \text{H}_2\text{O vapor pressure})\text{FiO}_2 - \text{PaCO}_2/\text{Respiratory quotient}$ 
  - ✓  $(\text{BP} - \text{WVP})\text{FiO}_2 - \text{PaCO}_2/0.8$ 
    - $(760 - 47)0.21 - 40/0.8 =$
    - $150 - 50 = 100 \text{ mm Hg}$

# (A-a) Gradient

- Partial pressure of oxygen in the alveolus minus partial pressure of oxygen in an artery.
  - ✓  $[\text{FiO}_2 * (\text{Barometric pressure} - \text{water vapor}) - (1.25 * \text{PCO}_2)] - \text{PaO}_2$
- At Room Air
  - ✓  $[150 - (1.2 * \text{PCO}_2)] - \text{PaO}_2 = \text{A-a Gradient}$ 
    - Normal = 8 - 12 mmHg
    - Increases with age -  $\text{Age}/4 + 4$

## (A-a) Gradient

- Normal if hypoxemia is due to hypoventilation (e.g. narcotic overdose) or low atmospheric O<sub>2</sub> (e.g. high altitude).
- High if hypoxemia is due to V/Q mismatch (e.g. Pulmonary Embolus), Impaired Diffusion (e.g. ILD), or Shunt (e.g. ASD)

## Oxygen Saturation & Oxygen Delivery

- Remember oxygen content (CaO<sub>2</sub>) is a more important management measure than PaO<sub>2</sub>
  - ✓  $([Hb] * \%Sat * 1.34 \text{ ml/g}) + (PaO_2 * 0.003)$
- Oxygen delivery the key parameter
  - ✓ CaO<sub>2</sub> \* Cardiac output (CO)

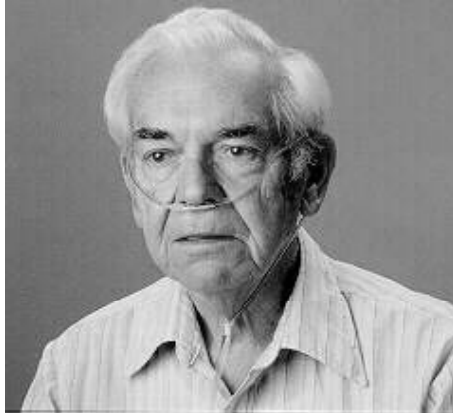


# Pulse Oximetry

- Uses the differential absorbance of light by oxyhemoglobin and deoxyhemoglobin to estimate the oxygen saturation
- Caveats:
  - ✓ Detection of Acute Hypoxemia may be slow
  - ✓ Does not measure ventilation
  - ✓ Ambient light
  - ✓ Electromagnetic Radiation
  - ✓ Severe Anemia
  - ✓ Hypoperfusion
  - ✓ Hypothermia
  - ✓ Venous Congestion
  - ✓ Nail Polish

# Oxygen Delivery Devices

# Nasal Cannula



1-6 LPM

\*1L=24%

\*2L=28%

\*3L=32%

\*4L=36%

\*5L=40%

\*6L=44%

## Advantages and Disadvantages of the Nasal Cannula

### Advantages:

- Comfortable
- Able to communicate
- Patient can eat and take oral medications.
- Easy to use at home.

### Disadvantages:

- Nasal obstruction may impede gas flow.
- May cause nasal mucosal drying (can be humidified with sterile water)

# Simple Mask

LOW FLOW Device



5-8 LPM

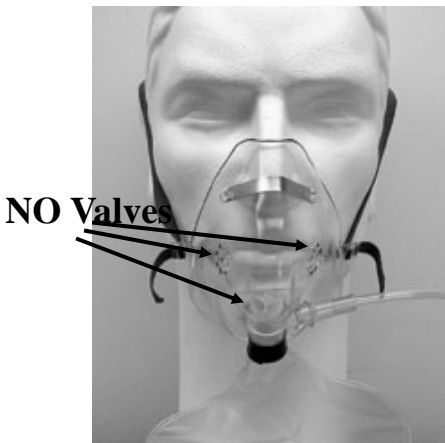
\* 5-6L=40%

\*6-7L=50%

\*7-8L=60%

- Flow should be set at 5 L/min or more in order to avoid rebreathing exhaled carbon dioxide (CO<sub>2</sub>)
- Least used mask do to unpredictable FI<sub>02</sub> percentage (easier to use Venti Mask)

# Partial Rebreather Mask



15 LPM

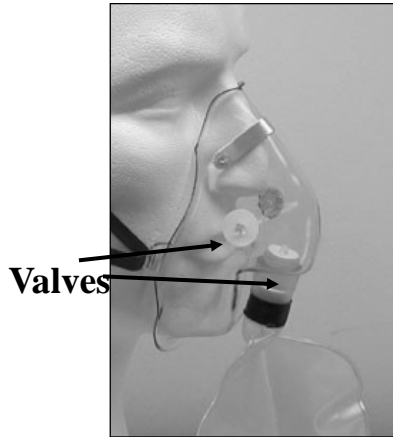
Bag should remain 1/3-1/2 full after the patient takes a deep breath

Delivers 60%-80% oxygen

- Must have all valves removed to be considered a Partial Rebreather Mask

# Non-Rebreather Mask

LOW FLOW Device



15 LPM

Bag should remain 1/3-1/2 full after the patient takes a deep breath

Delivers 90%-100% oxygen

- Must have all 3 valves

# Face Tent



Advantages:

- Designed for patients with facial trauma or surgery that cannot wear a regular mask or nasal cannula.

Disadvantages:

- Clumsy and uncomfortable
- Variable Flo<sub>2</sub> due poor mask seal

## Low-Flow Oxygen Delivery

Device	Reservoir Capacity (mL)	Oxygen Flow (L/min)	Approximate FIO <sub>2</sub>
Nasal Cannula	50	1	0.21 -0.24
		2	0.24 -0.28
		3	0.28 -0.34
		4	0.34 -0.38
		5	0.38 -0.42
		6	0.42 -0.46
Simple Face mask	150 -250	5-10	0.40 -0.60
Mask -reservoir bag	750 -1250		
Partial Rebreather		5-7	0.35 -0.75
Nonrebreather		5-10	0.40 -1.0

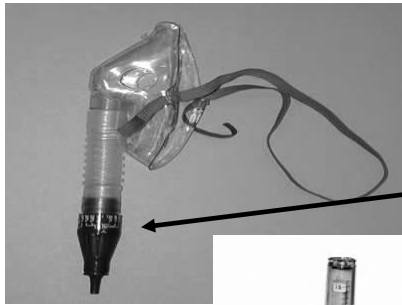
Estimated based on tidal volume of 500 mL, RR of 20 and I:E of 1:2  
From Shapiro BA, et al 1991

## Cool Aerosol Mask

- **High Flow Oxygen Delivery with High Particulate Humidity**
  - ✓ Hydration of airways for tenacious secretions
  - ✓ Treatment of Airway Edema
  - ✓ Accommodate High Liter Flow of High Flow Systems



# Venturi Mask (Venti Mask)



3-15 LPM

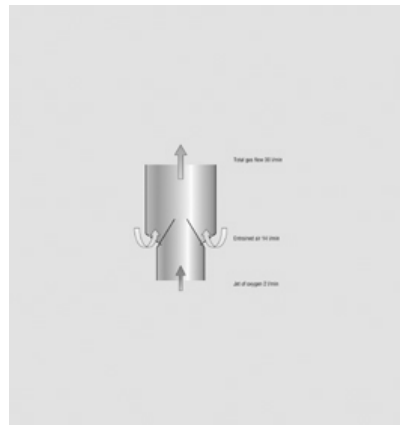
24%-50% (set on base of mask)

Set Flo<sub>2</sub> with percentage markings on the base of mask and adjust the oxygen flowmeter the the appropriate LPM



## Venturi Mask and Bernoulli's Principle

- **Bernoulli's Principle** : Pressure is least where the velocity of flow is the greatest.
- As  $F_{I_{O_2}}$  and entrained room air combine and flow through the constricted opening of the Venturi device the flow velocity to the patient increases greatly.
- By changing the opening size and oxygen flow the  $F_{I_{O_2}}$  can be varied.

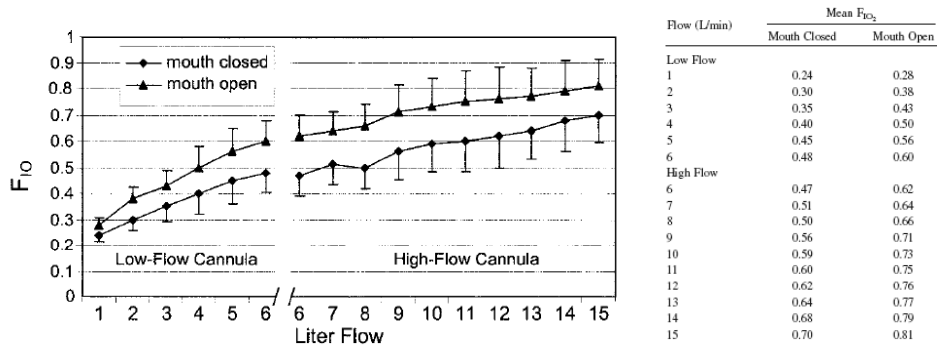


# HFNC (High Flow Nasal Cannula)

- Principle: In the past O<sub>2</sub> Delivery by nasal route was limited by the ability to humidify and warm the inspired gas.
- Provides adequately warmed and humidified gas
- Provides more “wash out” of the nasopharyngeal deadspace.
- Greater flow matches the patient’s natural inspiratory flow.
- High flow can be titrated to potentially provide positive distending pressure for lung recruitment.

Roca et al Respiratory Care 2010  
 Dewan et al Chest 1994  
 Spence et al Journal of Perinatology 2007

# O<sub>2</sub> Delivery



Wettstein et al Respiratory Care 2005

# HFNC

- **CONTRAINDICATIONS**

- ✓ Unable to protect their airway
- ✓ Inability to adequately ventilate
- ✓ Facial trauma
- ✓ Significant epistaxis (Nose bleed) or patients with nasal complications

- **COMPLICATIONS/  
PRECAUTIONS**

- ✓ Nasal dryness, edema or bleeding
- ✓ Drying mucous, mucous plugging or airway inflammation
- ✓ Sinusitis
- ✓ Inappropriate or interrupted oxygen flow may cause hypoxemia and or hypercapnia

# Non-invasive Ventilation

- **CPAP**

- ✓ Continuous Positive Airway Pressure

- **BiPAP/Bilevel**

- ✓ Bilevel Positive Airway Pressure

- **Best Evidence**

- ✓ COPD Exacerbations
- ✓ CHF (Congestive Heart Failure) with Pulmonary Edema



# Non-invasive Ventilation

- **Supportive Evidence**
  - ✓ **Facilitation of weaning and extubation in COPD**
  - ✓ **Immunosuppressed Patients**
  - ✓ **Extubation Failure in COPD or CHF**
  - ✓ **Prevention of Respiratory Failure in Asthma**
  - ✓ **Palliative**

## CPAP vs BiPAP/Bilevel

- **A trial of BiPAP may be worthwhile in patients who do not tolerate CPAP. This is particularly true for patients who seem likely to benefit from a low expiratory pressure:**
  - ✓ **patients with discomfort caused by exhaling against the CPAP**
  - ✓ **patients with mouth leaks despite optimization of the interface**
  - ✓ **and patients with musculoskeletal chest pain due to breathing at a higher functional residual capacity**

## **BiPAP/Bilevel**

- **Bilevel positive airway pressure (BiPAP) is a mode that delivers an inspiratory positive airway pressure (IPAP) and expiratory positive airway pressure (EPAP)**
- **The magnitude of the difference between IPAP and EPAP is directly proportional to the amount of tidal volume augmentation and the alveolar ventilation.**
- **If using a ventilator**
  - ✓ **Pressure Support + PEEP = IPAP**
  - ✓ **PEEP = EPAP**

## **Nasal vs Full Face Mask**

- **Nasal**
  - ✓ **Smaller**
  - ✓ **Easy to fit**
  - ✓ **Can have significant leak through mouth**
- **Full Face**
  - ✓ **Bulkier**
  - ✓ **Aspiration Risk**
  - ✓ **Claustrophobia**

## **Non-invasive Ventilation**

- **Contraindications**
  - ✓ **Respiratory Arrest**
  - ✓ **Anatomically unable to fit mask**
  - ✓ **Inability to protect airway**
  - ✓ **Inability to manage secretions**
  - ✓ **Inability to cooperate with therapy – poor mental status, agitation, etc**
  - ✓ **Aspiration Risk**
  - ✓ **Recent upper airway or upper GI surgery**

## **Mechanical Ventilation**

- **#1 Indication “If you think about it”**
- **Elective intubation is much safer than emergent intubation**
- **Airway control in an unstable patient is better for the patient**
- **Being on the ventilator does not create ventilator dependence – Severe illness creates ventilator dependence**

# Hypoxemia

**Outpatient  
Use of supplemental oxygen  
Ruthann Kennedy, RN**

## Indications for Oxygen

- Resting room air saturation  $\leq 88\%$
- $\text{PaO}_2 \leq 55$  mmHg
- Desaturation  $\text{SaO}_2 \leq 88\%$  with exertion
- During sleep: desaturation  $\text{PaO}_2 \leq 55$  mmHg or  $\text{SaO}_2 \leq 88\%$
- $\text{PaO}_2 \leq 59$  mmHg or  $\text{SaO}_2 \leq 89\%$  in the presence of cor pulmonale, right heart failure, hematocrit  $> 55\%$ .

# Ordering Oxygen

1. Qualification of oxygen need
2. Select DME
3. Written prescription
  - Flow rate, instructions & length of therapy
  - Example: Oxygen 2L/m with rest, and 4L/m with exertion and sleep, length of therapy -lifetime. Provide home and portable equipment

## Documentation requirements

- The desaturation must be obtained within 2 days of hospital discharge or within 30 days of outpatient testing
- Oxygen saturation  $\leq 88\%$ 
  - ✓ AT REST on room air
  - ✓ Requires no further testing

# Medicare Requirements

1. Resting, Room Air Saturation  $\geq 88\%$
2. Desaturation  $\leq 88\%$  with exertion or sleep
3. Improved saturation with the addition of supplemental oxygen

## Example

- 56 year old patient with interstitial lung disease presents with an initial room air  $\text{SaO}_2 = 90\%$ . While walking in the hall, the saturation drops to 84%. With the addition of supplemental oxygen at 2 L/m, the saturation increases to 95%.

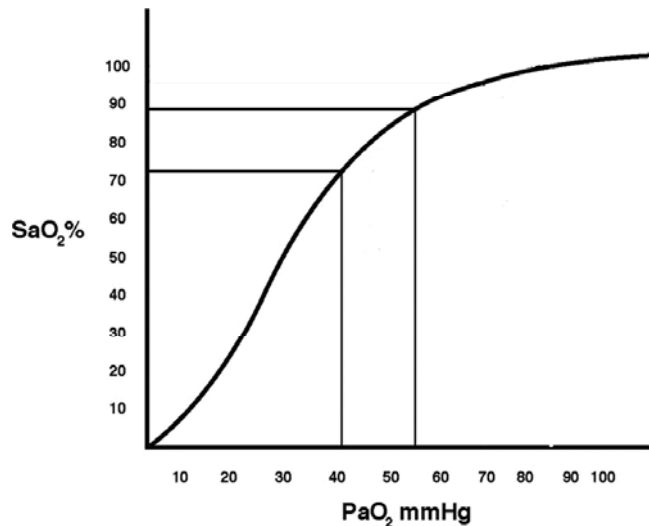
# Pulse Oximetry

- **Standard of care for the assessment of oxygen saturation**
- **“Fifth” vital sign**
- **Easily accessible**
- **Available from DME for patient use**

## Limitations of Pulse Oximetry

- **Digital injury, especially in conjunction with vasopressors**
- **Delay in the detection of acute hypoxemia**
- **Does not assess ventilation**
- **A significant drop in the PaO<sub>2</sub> must occur before the saturation decreases (oxygen hemoglobin dissociation curve)**

## Oxygen-Hgb Dissociation Curve



## Standard Oxygen Concentrator

- Non-portable, compressed air (gas)
- Oxygen delivery customarily up to 5L/m
- Special concentrators can deliver 10L/m
- Requires electricity



## Compact Oxygen Concentrator

- Compressed air
- Eclipse

Weight is approximately  
18 pounds



- ✓ 4 hour battery life or AC capable
- ✓ Continuous 0.5 – 3.0 L/m
- ✓ Pulse 0.5 – 6.0 L/m

## E tank (Compressed Oxygen)

- Tank Duration 5.7 hours with flow rate of 2L/m continuous.
- Commonly used in conjunction with wheeled cart
- “Portable” but not necessarily convenient for transportation
- Tank itself weighs 4-5 lbs and is 25 inches tall

# E cylinder



# Conserving Device

- **Reservoir Cannulas – Partial rebreather devices that store oxygen from exhalation**
  - ✓ Oximizer
  - ✓ Oximizer Pendant
- **Transtracheal oxygen**
- **Pulsed Delivery**

# Oximizer

- **Advantage: comfort and easy to use**
- **Disadvantage: cosmetic**
- **Extends larger than a nasal cannula and is clearly visible**



# Oximizer Pendant

- **Appears like a standard nasal cannula**
- **There is a pendant that sits on the upper chest**





# Transtracheal Oxygen

- **Advantages:**
  - ✓ Increased mobility and exercise
  - ✓ Lower oxygen flow requirements
- **Disadvantages**
  - ✓ Invasive
  - ✓ Dislodgement
  - ✓ Infection

# Transtracheal Oxygen



# Liquid Oxygen

- **LOX –liquid oxygen**
- **Reservoir – Home unit**
  - ✓ **Weighs 100-160 pounds when filled**
- **Portable unit**
  - ✓ **Examples: Helios, Escort, Spirit, Sprint**

# **LOX reservoirs and portables**

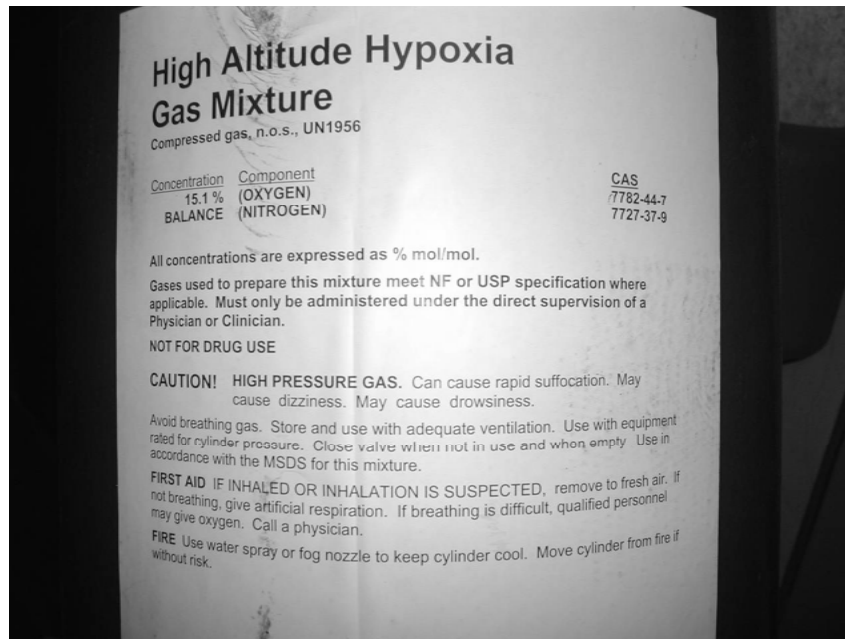


## **Advantages of Liquid Oxygen**

- **Reservoir holds 8-10 day supply of oxygen with continuous flow rate at 2L/m**
- **Does not require electricity resulting in an average monthly savings of \$70.**
- **Delivery of high flow – up to 15L/m**
- **Portable unit weighs 3.5 lbs with a duration time of 8 hours at 2L/m**

# Inflight Oxygen

- **HAHST : High Altitude Hypoxia Stimulation Test**
- **ABG drawn on 15% oxygen**
- **PO<sub>2</sub> < 50 mmHg indicative of need for supplemental O<sub>2</sub> in flight**



# Helios



## Disadvantages of Liquid Oxygen

- Requires hand and arm strength
- Requires hand eye coordination to fill portable tanks
- Connections can freeze. The actual temperature is negative 297°F.
- Reservoir has to be refilled by DME source



# SmartDose™

- **Automatically adjusting O<sub>2</sub> flow rate in continuous or pulse dosing.**
- **Available for use in conjunction with:**
  - ✓ **Compressed O<sub>2</sub>**
  - ✓ **Liquid O<sub>2</sub>**

## Product Comparison

Standard conserver	SmartDose™
Increased WOB	Decreased WOB
Lower dose size & flow rate with activity	Increased dose size & flow rate with activity
Triggered manually	Auto-adjusts before pt develops symptoms
Limits activity resulting in deconditioning	Promotes activity
Forces pt to focus on the device & disease	Allows pt to focus on living
	No additional cost

# SmartDose™

