Intrapulmonary Shunts and $O_2$ Transport

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Where We’re Going

Some basic principles and definitions

Quantitating intrapulmonary “true” shunts

Intrapulmonary arterio-venous pathways
Causes of Decreased $P_{aO2}$

**Extrapulmonary**
- Decreased $V_A$
- Decreased $P_{IO2}$

**Intrapulmonary**
- Slow alveolar-capillary diffusion
- $V_A/Q$ mismatching
- “True” shunts
Definitions and Basic Principles

Physiological Shunt (a.k.a. "Venous Admixture"): The fraction of mixed venous blood that does not become oxygenated as it moves from the right atrium to the left ventricle.
Effect of a Shunt on Arterial Oxygenation at Sea Level

<table>
<thead>
<tr>
<th>% Shunt</th>
<th>Approximate Arterial $P_{O_2}$</th>
<th>$O_2$ Content</th>
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<td>50</td>
<td>35</td>
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(Is arterial $P_{CO_2}$ affected?)
Physiological Shunt Diagram

\[ \frac{Q_s}{Q_T} = \frac{C_{aO_2} - C_{capO_2}}{C_{\tilde{H}O_2} - C_{capO_2}} \]
Physiological Shunt ($Q_S$) Includes

1. **Extrapulmonary R→L Anatomic Shunt**
   (normally ~ 1% of cardiac output)

2. **Intrapulmonary “True” Shunt**
   a. Flow past unventilated or collapsed alveoli
      (e.g., due to edema, pneumonia, atelectasis)
   b. Anatomic arterio-venous pathways

3. **Intrapulmonary Regions with Low $V_A/Q$**
   $V_A$ not zero but blood is not completely oxygenated
   (A virtual shunt, not a “true” shunt)
Low $V_A/Q$ Regions Contribute to the Physiological Shunt
Quantitating Physiological Shunts is Difficult

- Cannot measure $C_{\text{capO}_2}$, can estimate making assumptions that may not be accurate.
- “Insoluble” radioactive gases: Inject $^{85}\text{Kr}$ or $^{99m}\text{Tc}$ in saline i.v., sample arterial blood.
Eliminating the Effect of Low $V_A/Q$ Regions

- Breathing room air, $Q_S/Q_T$ is the Physiological Shunt
- Breathing 100% O$_2$, $Q_S/Q_T$ is the Extrapulmonary Anatomic Shunt + Intrapulmonary True Shunt
Rationale for 100% O$_2$ Method

While breathing 100% O$_2$, the blood flowing past lung regions with low $V_A/Q$ values will become completely oxygenated.

This eliminates the “virtual” part of the physiological shunt due to low $V_A/Q$ regions.
100% O₂ Method for $Q_S/Q_T$

$$Q_S/Q_T = \frac{(C_{aO2} - C_{\text{capO2}})}{(C_{VO2} - C_{\text{capO2}})}$$

- Have patient breathe 100% O₂ for 15-20 min.
- Simultaneously sample pulmonary and systemic arterial blood, measure $P_{aO2}$, %satₐ, $P_{vO2}$ & %satᵥ.
- Calculate $P_{\text{capO2}}$ from:
  $$P_{\text{capO2}} = P_{AO2} = (P_B - 47) \times \frac{(P_{aCO2}/R)}{\sim (713 \text{ mm Hg}) \times \frac{P_{aCO2}}{0.8}}$$
- Calculate O₂ contents ($C_{O2}$) from:
  $$C_{O2} \text{ [vols%]} = (1.39 \times [\text{Hb}] \times \%\text{Sat}) + 0.003 \times P_{O2}$$
Sources of Error in the 100% O\textsubscript{2} Method

1. Incomplete N\textsubscript{2} washout

2. Not measuring $C_{vO2}$ but assuming $(C_{aO2} - C_{vO2})$

3. Should measure pulmonary venous blood O\textsubscript{2} content to determine intrapulmonary shunts. Measuring systemic arterial O\textsubscript{2} content will include extrapulmonary R -> L shunts.

4. Breathing 100% O\textsubscript{2} increases intrapulmonary “true” shunts.
Does breathing 100% O₂ increase the true shunt in a healthy person?


- Healthy subjects, age 21-60
- Used MIGET to estimate $V_A/Q$ distribution and true shunt
What is the Multiple Inert Gas Elimination Technique (MIGET)?

- **Principle**: Exhalation of an “inert” gas by the lungs from the blood stream depends upon the solubility of the gas and the distribution of $V_A/Q$ in the lungs.

- Continuously infuse (i.v.) six inert gases with different solubilities: sulfur hexafluoride, cyclopropane, ethane, enflurane, diethyl ether & acetone.

- After 20-30 min. simultaneously sample mixed venous blood, arterial blood and expired gas; measure gas concentrations by gas chromatography.

- Fit the blood and expired gas data to a 50-compartment log-normal $V_A/Q$ distribution model, including compartments with $V_A=0$ (intrapulmonary true shunt) and $Q=0$ (alveolar dead space).
Distributions of $V_A$ and $Q$ in a Healthy Young Man
Effect of Breathing 100% O\textsubscript{2} on the True Shunt in a Healthy 22 Year Old

3 of 4 developed a shunt breathing 100% O\textsubscript{2}, average 0.5% of CO.
Effect of Breathing 100% O₂ on the True Shunt in a 44 Year Old

5 of 5 developed a shunt breathing 100% O₂, average 3.2% of CO.
Why does this happen?


1. $N_2$ is relatively insoluble in blood so its presence stabilizes alveoli with low $V_A/Q$. When $N_2$ is replaced by $O_2$, in low $V_A/Q$ alveoli $O_2$ may enter blood faster than it is brought in by $V_A$. This results in atelectasis and an intrapulmonary true shunt is created.
2. As alveolar $P_{O_2}$ increases while breathing 100% $O_2$, in regions with a low $V_A/Q$ there will be a decrease in hypoxic vasoconstriction. This will increase $Q$, $V_A/Q$ will thus become smaller and atelectasis will become even more likely.
Therefore:

Breathing 100% O$_2$ increases the intrapulmonary true shunt in people with healthy lungs.

So, breathing 100% O$_2$ must also increase the intrapulmonary true shunt in people with lung disease, especially if low V$_A$/Q regions are present.
Physiological Shunt ($Q_S$) Includes

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Intrapulmonary Arteriovenous (IPAV) Pathways

- Connections between pulmonary arteries and veins that bypass capillaries
- Good evidence that they exist in some people but flow is very small
- Measured IPAV flow 0.06-0.07% of total flow in isolated, perfused healthy human lungs
Questions about IPAV Pathways

- **How common are they?**
  
  “Pulmonary arteriovenous malformations” are uncommon (2-3 per 100,000 people). Other IPAV pathways?

- **Are they functionally “true” shunts?**
  
  Do they decrease arterial $P_{O_2}$?

Controversies arise because of the way intrapulmonary shunts are defined:

- Anatomists, pathologists, radiologists define based upon what they see.
- Physiologists, some clinicians define based upon function.
Detecting IPAV Pathways

- **Contrast echocardiography**
  Inject agitated saline i.v., look for microbubbles in left ventricle after 3-4 cardiac cycles. (There are issues.)

- **Radionuclide perfusion scanning**
  Inject $^{99m}$Tc-labelled albumin particles (>20µm diameter) i.v., look for appearance in brain and kidneys.

- **Pulmonary angiography**
  Visualize pathways after injecting radiopaque dye.

These methods all give semi-quantitative results.
Physiological Studies

For the past decade, A. T. Lovering, et al. have extensively studied IPAV shunting using contrast echocardiography. They observed in healthy people:

- IPVA shunting increases with exercise
- IPVA shunting increases at rest with decreased $F_{IO2}$

Mechanisms are not yet understood.
Current Controversy

Lovering et al. believe the increased IPAV shunting they observed contributes to a decrease in arterial $\text{P}O_2$ in exercise and hypoxia. If true, this has implications for clinical true shunt measurements.

Wagner, et al. disagree; pointing out that there are no data to support this and this is also inconsistent with their MIGET results.

Bottom Line

- For research purposes quantitating physiological shunts or intrapulmonary true shunts is difficult. MIGET is the best technique, but is not perfect.

- For clinical purposes measurements of intrapulmonary true shunts can provide useful information, but results are estimates and must be interpreted with care.