Pulmonary Circulation

resin cast of pulmonary arteries

resin cast of pulmonary veins
Blood Flow to the Lungs

Pulmonary Circulation

Systemic Circulation
Blood supply to the conducting zone provided by the systemic circulation (≈2% of C.O.)

Blood supply to the respiratory zone provided by the pulmonary circulation

Systemic Circulation

Pulmonary Circulation

Tissues
< 500 ml blood in pulmonary circulation

75 ml blood in pulmonary capillaries
Gas Exchange in the Lungs Takes Place at the Respiratory Zone of the Airways [Airways with Alveoli]

- gas exchange: across small pulmonary arterial vessels [histologically not capillaries-functionally capillaries] & pulmonary capillaries

- there are about 280 billion pulmonary capillaries for about 300 million alveoli resulting in a gas exchange surface of about 60-100 m²
Comparison of Vascular Pressures in the Systemic & Pulmonary Circulations

- 10 fold difference in mean arterial pressure
- structural basis: less smooth muscle in pulmonary vessels
  - greater distensibility + greater compressibility
- major drop in pressure in the pulmonary circulation is through capillaries
- major drop in pressure in the systemic circulation is through the arterioles
Pulmonary Vascular Resistance

\[ \text{PVR} = \frac{\Delta P}{\Delta Q} = \frac{\text{PPA} - \text{PLA}}{\text{C.O.}} \]

\[ = 15 - 5 / 5 \]

\[ = 2 \text{ mmHg/L/min} \]

A Swan-Ganz catheter introduced through a peripheral vein (femoral/brachial/jugular), advanced toward the chest by normal flood flow, allows for RA, RV & pulmonary artery “wedge” [estimates LA] pressures.
Passive Influences on PVR

Difference in Surrounding Pressure

- **Alveolar vessels** [pulmonary capillaries] – alveolar pressure
- **Extra-alveolar vessels** [pulmonary arteries & veins] - intrapleural pressure

Lung inflation:

- collapses **alveolar vessels** via stretch of alveolar wall
- expands **extra-alveolar vessels** via radial traction
Lung Volume Affects Pulmonary Vascular Resistance

Total resistance is the sum of alveolar and extra-alveolar resistances.

Pulmonary vascular resistance

RV FRC TLC

Static lung volume

Alveolar blood vessels

Extra-alveolar blood vessels

Total
Passive Influences on PVR

Distention & Recruitment

Increase in perfusion pressure [pulmonary artery pressure] results in distension & recruitment \( \Rightarrow \) decreasing PVR.

How can vessels be open but have no flow?

Consider very low pressure systems, e.g. garden hose with multiple small holes. At low enough pressure, only a few holes drizzle water: sufficient difference in resistance that flow is diverted to the path with least resistance.
### Active Influences on Pulmonary Vascular Resistance

<table>
<thead>
<tr>
<th>Increase</th>
<th>Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alveolar Hypoxia</strong></td>
<td></td>
</tr>
<tr>
<td>Alveolar Hypercapnia</td>
<td></td>
</tr>
<tr>
<td><em>humoral: NE / E</em></td>
<td><em>humoral: Ach</em></td>
</tr>
<tr>
<td><em>humoral: Histamine</em></td>
<td><em>humoral: Bradykinin</em></td>
</tr>
<tr>
<td><em>humoral: PGF2$\alpha$ / PGE2</em></td>
<td><em>humoral: PGE1</em></td>
</tr>
<tr>
<td><em>humoral: Thromboxane</em></td>
<td><em>humoral: nitric oxide</em></td>
</tr>
<tr>
<td><em>humoral: Angiotensin</em></td>
<td></td>
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</tbody>
</table>

- **physiologic role of humoral factors?**
- There is sparse sympathetic & parasympathetic innervation of the pulmonary vasculature and the effect of stimulation of these nerves is controversial.
Summary & Query

• Consider the factors that affect pulmonary vascular resistance (PVR). How do these differ from factors that affect systemic vascular resistance (TPR)

• Contrast the effect of low oxygen on vessel diameter in the pulmonary versus systemic circulation.

How is this difference useful?

When is it not beneficial?
There is a hydrostatic pressure difference of about 23 mmHg from the top to bottom of the lungs (30 cm height).

**Hydrostatic Pressure (P)**

\[ P = \rho h g \]

- \( \rho \) = density of the fluid
- \( h \) = height (depth) of fluid column
- \( g \) = acceleration of gravity
Measuring Pressure - a Relative Difference

units: cm H$_2$O vs mmHg

There are 13.6 mm H$_2$O (or 1.36 cm H$_2$O) for every 1 mm Hg pressure
The Starling Resistor Again!

If $P_v > P_A$, the driving pressure $= P_a - P_v$

If $P_A > P_v$, the driving pressure $= P_a - P_A$
The “Zones” of the Lung: The Interaction of Gravity & Extravascular Pressures

- arterial & venous hydrostatic pressures from the tip to the base due to gravity
- constant alveolar pressure

- the pulmonic valve ≈15 cm below the tip of the lungs, Pa ≈ 15 mmHg
- note the relative alveolar, arterial & venous pressure in each “zone” + determine the driving pressure
- zone III: additional contributing factor distention & recruitment of vessels
Zone Model versus Reality

- **Zone I**: at rest, during systole $\text{Pa} > \text{PA}$. Potential to function as alveolar dead space ventilated but not perfused when $\text{PA} > \text{Pa}$; e.g., patient on high PEEP; after hemorrhage; low Pa (anesthesia).

- **Zone II**: exercise leads to an increase in C.O. & Pa, boundary between Zone II & III shifts up.

- **Zone III**: consider changes in body position.
• At the base of the lungs, radial traction on extra-alveolar vessels is less [less negative pleural pressure] hence there is greater contribution to resistance to flow.
Consider the average range of total alveolar ventilation and blood flow (perfusion) to through the pulmonary circulation and their ratio and compare it to regional lung units.

\[ Q_c = 4-6 \text{ L/min} \]

\[ V_A = 4-6 \text{ L/min} \]

\[ V_A/Q_c = 0.8-1.0 \]

The consequence of V/Q matching at alveolar level is important to gas exchange.

To appreciate the importance of V/Q matching at alveolar level, consider a scenario where there is perfusion to only the L-lung & ventilation to only the R-lung. What would the V/Q be?
Regional Distribution of Blood Flow

Blood Flow

Q per unit lung volume

Rib number

Bottom 5 4 3 2 Top
Regional Distribution of Alveolar Ventilation

![Graph showing the regional distribution of alveolar ventilation](image)

- **VA**: per unit lung volume
- **Rib number**: Bottom to Top

**Ventilation** decreases as the rib number increases from Bottom to Top.
note the greater gradient for blood flow relative to ventilation
Partial Pressure of Respiratory Gases in Hypothetical Gas Exchange Units

\[
\begin{align*}
O_2 &= 150 \\
CO_2 &= 0 \\
\downarrow \\
O_2 &= 100 \\
CO_2 &= 40 \\
\hline
O_2 &= 40 \\
O_2 &= 100 \\
CO_2 &= 45 \\
CO_2 &= 40 \\
\end{align*}
\]

Ideal Lung

\[V/Q = 1\]

normal \( V/Q \)
Partial Pressure of Respiratory Gases in Hypothetical Gas Exchange Units

"Shunt Like"  
V/Q = 0

Ideal Lung  
V/Q = 1

zero  low V/Q  normal V/Q
Partial Pressure of Respiratory Gases in Hypothetical Gas Exchange Units

O₂=150
CO₂=0

O₂=100
CO₂=40

O₂=40
CO₂=45

O₂=100
CO₂=40

Ideal Lung
V/Q=1

Dead Space
V/Q=∞

normal V/Q → high V/Q → infinity
Partial Pressure of Respiratory Gases in Hypothetical Gas Exchange Units

"Shunt Like"  $V/Q=0$

Ideal Lung  $V/Q=1$

Dead Space  $V/Q=\infty$

O₂=40  CO₂=45  O₂=40  CO₂=45  O₂=40  CO₂=45

O₂=150  CO₂=0

O₂=100  CO₂=40

O₂=150  CO₂=0

zero ← low $V/Q$ ← normal $V/Q$ → high $V/Q$ → infinity
V/Q Mismatch & Partial Pressure of O₂ & CO₂

shunt: V/Q = 0

dead space: V/Q = ∞
Differentiate between the apex & the base:

- the site with highest V/Q
  lowest PCO₂ + highest PO₂

- the site with the greatest quantity of gas exchange