QUIZ 3

SOLUTIONS
These are normal values of physiological parameters for a 70 kg person.

\[ R_{rs} \text{ (respiratory system R)} = 4 \text{ mbar}\cdot \text{s/l} \]
\[ C_{cw} = 200 \text{ ml/mbar} \]
\[ C_{lung} = 200 \text{ ml/mbar} \]
\[ V_D \text{ (Anatomic)} = 150 \text{ ml} \]
\[ V'O_2 = 274 \text{ ml/min} \]
\[ V'CO_2 = 220 \text{ ml/min} \]
\[ RQ = 0.8 \]
\[ Q_s/Q_T \text{ (Shunt fraction)} < 0.05 \]
\[ Q_T \text{ (cardiac output)} = 5 \text{ l/min} \]
\[ P_{atm} = 760 \text{ mmHg} \]
\[ P_vCO_2 = 46 \text{ mmHg} \]
\[ P_vO_2 = 40 \text{ mmHg} \]
\[ P_aCO_2 = 40 \text{ mmHg} \]
\[ P_aO_2 \text{ (at room air)} = 100 \text{ mmHg} \]
\[ (A - a)DO_2 \approx 6-10 \text{ mmHg} \]
\[ pH = 7.4 \]
\[ cHb = 15 \text{ g/100ml-blood} \]
\[ \text{Hb O}_2 \text{ Binding capacity} = 20.1 \text{ ml O}_2/100\text{ml blood} \]
\[ \text{FRC} = 2.4 \text{ l} \]

The normal hemoglobin O\textsubscript{2} saturation curve is also included and should be used only when there is no alternative data available.

The first two problems are cases that include certain respiratory physiologic abnormalities. You can use the normal values as a reference, or in absence of additional information.
Problem 1 (Case 1)

A patient comes to the emergency ward with shortness of breath and wheezing. He is breathing room air at a rate of 30 breaths per minute, and the pulse oximeter shows his arterial blood saturation to be $S_{aO_2} = 0.80$.

Arterial and mixed venous blood samples are taken at arrival and reveal the following values:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{vCO_2}$</td>
<td>44 mmHg</td>
</tr>
<tr>
<td>$P_{vO_2}$</td>
<td>27 mmHg</td>
</tr>
<tr>
<td>$P_{aCO_2}$</td>
<td>39 mmHg</td>
</tr>
<tr>
<td>$P_{aO_2}$ (at room air)</td>
<td>20 mmHg</td>
</tr>
</tbody>
</table>

The blood gas data comes with a computer generated caution questioning the validity of the measurements.

A. Please identify which of the four blood gas values may have an error and explain your reasoning. (25%)

$P_{aO_2}$ cannot be correct for two reasons:

(i) $P_{aO_2}$ is always $\geq P_{vO_2}$  
(ii) $P_{aO_2} = 20$ is not compatible with $S_{aO_2} = 0.8$. In fact $S_{aO_2} \approx 0.35$.

B. You need to make a best guess to treat the patient with the knowledge available to you; can you find an approximate value of the erroneous blood gas? (25%)

For $S_{aO_2} = 0.8$, $P_{aO_2} = 45$ (from the $O_2$ saturation curve).
C. The patient is given 100% O\textsubscript{2} by mask and one hour later his blood gases come back:

\begin{align*}
P_{\text{vCO}_2} &= 48 \text{ mmHg} \\
P_{\text{vO}_2} &= 47 \text{ mmHg} \\
P_{\text{aCO}_2} &= 42 \text{ mmHg} \\
P_{\text{aO}_2} &= 60 \text{ mmHg}
\end{align*}

This time without caution notes.

What can you say about the cause of gas exchange impairment in this patient? (50%) Hint, you can ignore the oxygen carrying capacity of plasma in your calculations.

\textit{From alveolar gas eq:}

\begin{equation*}
P_{\text{A}_2O_2} \approx F_{\text{lO}_2} (P_{\text{atm}} - P_{\text{H}_2O}) - \frac{P_{\text{aCO}_2}}{RQ} \\
= 1(713) - \frac{42}{0.8} = 660 \gg 60
\end{equation*}

\textit{Given that the patient is breathing at } F_{\text{lO}_2} = 1, \textit{this large } 660 - 60 = (A - a)_{\text{DO}_2} \textit{ gradient can only be explained by shunt.}

\textit{Using the approximate shunt equation}

\begin{equation*}
\frac{Q_s}{Q_t} = \frac{1 - sat_{a,O_2}}{1 - sat_{v,O_2}} = \frac{1 - 0.9}{1 - 0.82} = \frac{0.1}{0.18} = 0.56
\end{equation*}

\textit{This patient has a 56% shunt fraction.
Problem 2 (Case 2)

The same patient eventually develops respiratory failure and is placed on a mechanical ventilator adjusted to parameters matching his tidal breathing:

\[ VT = 390 \text{ ml} \quad f = 30 \text{ bpm} \quad T_{ins} = 40\% \quad T_{exp} = 50\% \quad F_iO_2 = 0.50 \]

And his blood gases are measured as:

\[ P_{vCO_2} = 42 \text{ mmHg} \]
\[ P_{vO_2} = 45 \text{ mmHg} \]
\[ P_{aCO_2} = 40 \text{ mmHg} \]
\[ P_{aO_2} = 275 \text{ mmHg} \]

\[ \dot{V}_O_2 = 274 \text{ ml/min} \]
\[ \dot{V}_CO_2 = 220 \text{ ml/min} \]

The ventilator output shows the following screen

Figure 2:
A. Is this patient exhibiting dynamic hyper-inflation, and why or why not? (25%)

Yes, because expiratory flow at the end of exhalation is non-zero.

B. Can you estimate the patient’s respiratory system mechanical parameters: Resistance and Compliance? (25%)

\[
R = \frac{P_{\text{peak}} - P_{\text{plateau}}}{V} = \frac{21 - 11}{V_T/t_{\text{insp}}} = \frac{10}{\left(\frac{390}{2 \times 0.4}\right)} = 2.05 \text{ mbar} \cdot \text{s/L}
\]

\[
C = \frac{V_T}{P_{\text{peak}} - P_{\text{ini}}} = \frac{390}{21 - 16} = 78 \text{ ml/mbar}
\]

\[
RC = 78 \times 0.0205 = 1.6 \text{ sec}
\]
C. The attending MD suggests decreasing frequency while keeping the inspiration (insufflation in Germanic English) and exhalation time % unchanged. What frequency and tidal volume would you choose? Assume that the VD physiologic remains unchanged. (50%)

(Note: if you decide to use VD anatomic in your calculation, you will lose 25% of the question points.)

To avoid hyperinflation:

\[ t_{exp} \geq 4 \times RC = 4 \times 1.6 = 6.4 \text{ sec} \]
\[ t_{exp} \% = 50\% \Rightarrow f_2 = \frac{1}{0.5} \times 60 = 4.7 \text{ bpm} \]

To keep a constant \( \dot{V}_A \), we need to calculate a \( V_T \) such that

\[
(V_T_1 - V_D) f_1 = (V_T_2 - V_D) f_2 \\
V_T_2 = (V_T_1 - V_D) \frac{f_1}{f_2} + V_D
\]

We know that

\[
\frac{V_D}{V_T} = 1 - \frac{V_{CO_2}}{V_T f F_{ACO_2}} \quad \text{where } F_{ACO_2} \approx \frac{P_{ACO_2}}{(P_{aim} - 47)}
\]

\[
\frac{V_D}{V_T} = 1 - \frac{220}{390 \times 30 \times \frac{40}{713}} = 0.665 \\
V_D = 0.665 \times 390 = 259.35 \text{ ml} \\
V_{T_2} = (390 - 259.35) \frac{30}{4.7} + 290.35 \\
\quad = 1124 \text{ ml} \\
V_{T_2} = 1.124 L \\
f_2 = 4.7 \text{ bpm}
\]
Problem 3

Pulmonary fibrosis is a debilitating disease of the lung characterized by replacement of elastin by collagen and resulting in a decrease of lung compliance. In severe cases, lung transplant is the only option for survival. To maximize organ availability and reduce post-operative mortality, usually unilateral lung transplant is conducted.

A. First draw the normal chest wall and lung compliance curves. Then draw changes that result from pulmonary fibrosis ($C_L$ reduced by 1/2). Assume that compliances are linear and that the chest wall compliance does not change. What happens with FRC in pulmonary fibrosis? (25%)

![Diagram of normal lung, fibrotic lung, and after transplant showing changes in compliance curves and FRC calculations.]

For CW:

$$V_{CW} = V_{CW_0} + P_{PL}C_{CW} \rightarrow P_{PL} = \frac{V_{CW} - V_{CW_0}}{C_{CW}}$$

For lungs:

$$V_L + \left( \begin{array}{c} P_{e_0} - P_{PL} \end{array} \right) C_L = -P_{PL}C_L \rightarrow P_{PL} = \frac{-V_L}{C_L}$$

FRC = Lung Volume, where $V_L = V_{CW}$ and $P_{PL_{CW}} = P_{PL}$.
\[
\Rightarrow \frac{V_{CW} - V_{CW_0}}{C_{CW}} = -\frac{V_L}{C_L}
\]

For \( V_L = V_{CW} = FRC \)

\[
FRC - V_{CW_0} = -FRC \frac{C_{CW}}{C_L}
\]

\[
FRC = \frac{V_{CW_0}}{1 + \frac{C_{CW}}{C_L}}
\]

For normal lung

\[
C_{CW} = C_L \rightarrow FRC = \frac{V_{CW_0}}{2}
\]

For fibrotic lung

\[
C_{LF} = \frac{C_L}{2} \rightarrow FRC = \frac{V_{CW_0}}{1 + \frac{1}{1/2}} + \frac{V_{CW_0}}{3}
\]

B. Second, draw the effects of replacing one of the lungs with a normal donor lung. What will be the new FRC after surgery? You can assume that both right and left lungs have equal compliance before surgery. (25%)

After transplant:

\[
C_{L,post} = \frac{C_L}{4} + \frac{C_L}{2} = \frac{3}{4} C_L
\]

\[
\uparrow_{\text{fibrotic}} \quad \uparrow_{\text{transplanted \ “normal”}}
\]

So

\[
FRC = \frac{V_{CW_0}}{1 + \frac{4}{3}} = \frac{3}{7} V_{CW_0}
\]
C. How does the amount of pressure required to inspire a similar tidal volume compare between before and after surgery? (25%)

**Total lung compliance**

**Before transplant:**

\[ C_{LF} = \frac{1}{2} C_L = \frac{V_T}{\Delta P} \Rightarrow \Delta P = \frac{V_T}{C_L} \]

**After transplant:**

\[
\begin{align*}
C_{L, post} &= \frac{C_{LF}}{2} + \frac{C_L}{4} + \frac{C_L}{2} = \frac{3}{4} C_L \\
\Delta P_{after} &= \frac{V_T}{\frac{3}{4} C_L} \Rightarrow \Delta P_{after} = \frac{4}{3} \left( \frac{V_T}{C_L} \right) \\
\Delta P_{before} &= \frac{V_T}{\left( \frac{C_L}{2} \right)} = 2 \left( \frac{V_T}{C_L} \right)
\end{align*}
\]

*For the same \( V_T \)*

\[
\frac{\Delta P_{after}}{\Delta P_{before}} = \frac{4}{2} = \frac{2}{3}
\]

*After transplant the person needs two-thirds the pleural pressure to generate the same total \( V_T \).*

D. In what proportions is the tidal volume distributed between both lungs? (25%)

\[ V_T \text{ distributes with regional } C. \]

\[ \begin{array}{c}
V_T_{\text{transpl}} \\
\frac{C_L}{2}
\end{array} \quad \begin{array}{c}
V_T_{\text{fibrotic}} \\
\frac{C_L}{4}
\end{array} \quad \frac{C_{CW}}{2} \quad \frac{C_{CW}}{4}
\]

\[ V_{\text{transpl}} = 2V_{\text{fibrotic}} \]