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Respiratory Mechanics I

M1 – Cardiovascular/Respiratory Sequence
Louis D’Alecy, Ph.D.
Wednesday 11/12/08, 10:00
Respiratory Sequence
40 slides, 50 minutes

1. Introduction
   a) Text
   b) Testable content
   c) Respiratory disease
   d) Anatomy
2. Functions of Respiratory System
3. Mechanics of Ventilation I
“…a solid background in the aspects of pulmonary physiology essential to understanding clinical medicine.”
Testable Content
Levitzky’s Chapter Objectives
Handouts, Keywords and Lecture Content

Quiz # 3  11/16/07 will include both cardiovascular and respiratory questions.

REMINDER:
Final Comprehensive with Cardiovascular & Respiratory
Tuberculosis
Greatest single infectious cause of mortality worldwide. 2 million deaths/yr

Chronic Obstructive Pulmonary Disease (COPD)
Forth leading cause of death in US.

Bronchitis
Emphysema

Cystic Fibrosis
Most common lethal congenital disease

Asthma
Most common chronic childhood illness
Pneumonia
A leading cause of death among children throughout the world. Estimated 4 million children die per yr.

Influenza
Can be fatal, especially among the very young or very old. 1918 pandemic estimated to have killed 20-40 million worldwide

Respiratory Distress Syndrome
Major problem in prematurely born infants

Acute Respiratory Distress Syndrome (ARDS)
Fatal in about 60% of cases
RESPIRATORY DISEASE (3)

Respiratory Distress Syndrome
Major problem in prematurely born infants

Diffuse Interstitial Pulmonary Fibrosis

Anemia

Pulmonary Embolism

Pulmonary Hypertension

Common Cold
MUCUS ESCALATOR

ciliated airway epithelium

toward esophagus

mucus

cilia

smoke particles & bacteria

CO inhibits

D'Alecy
Please see: http://www.3dscience.com/img/Products/3D_Models/Human_Anatomy/Alveoli/supporting_images/3D_Model_Anat_Alveoli3_web.jpg
ALVEOLI ARE INTERFACE BETWEEN CARDIOVASCULAR AND RESPIRATORY SYSTEMS


Image of alveoli vasculature removed
<table>
<thead>
<tr>
<th>Generation</th>
<th>Area (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>trachea</td>
<td>0</td>
</tr>
<tr>
<td>bronchi</td>
<td>1</td>
</tr>
<tr>
<td>bronchioles</td>
<td>2</td>
</tr>
<tr>
<td>terminal bronchioles</td>
<td>5</td>
</tr>
<tr>
<td>respiratory bronchioles</td>
<td>16</td>
</tr>
<tr>
<td>alveolar ducts</td>
<td>17</td>
</tr>
<tr>
<td>alveolar sacs</td>
<td>18</td>
</tr>
</tbody>
</table>

2.54 cm² ~ Dime!

AREA for Diffusion

10⁴ cm² ~ Tennis court
### Table 1-5: Airway Dimensions

<table>
<thead>
<tr>
<th>Generation</th>
<th>Diameter, cm</th>
<th>Length, cm</th>
<th>Number</th>
<th>Total cross-sectional area, cm²</th>
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<td>12.0</td>
<td>1</td>
<td>2.54</td>
</tr>
<tr>
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<td>1.22</td>
<td>4.8</td>
<td>2</td>
<td>2.33</td>
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<td>0.83</td>
<td>1.9</td>
<td>4</td>
<td>2.13</td>
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<td>0.8</td>
<td>8</td>
<td>2.00</td>
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<td>0.10</td>
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<td>10³</td>
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<tr>
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<td>0.04</td>
<td>0.05</td>
<td>8 x 10⁶</td>
<td>10⁴</td>
</tr>
</tbody>
</table>

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PHYSIOLOGY=
Functions of Respiratory System (1)

• 1. Delivers oxygen to blood
• 2. Eliminates carbon dioxide
• 3. Regulates blood pH

All depend upon bulk flow and diffusion
Air Ventilation = 4 L/min

Blood CO = 5 L/min

Please see: http://www.kscience.co.uk/as/module1/pictures/alveolus.jpg
PHYSIOLOGY =
Functions of Respiratory System (2)

• 4. Traps and dissolves blood clots
   – (PE = PULMONARY EMBOLUS)
• 5. Forms speech sounds (phonation)
• 6. Facilitates smell (olfaction)
• 7. Defends against microbes
• 8. Adds or removes chemical messengers
STEPS IN RESPIRATION

Bulk flow --> Diff --> Bulk flow --> Diff --> Use

(1) Ventilation: Exchange of air between atmosphere and alveoli by *bulk flow*  
    Air

(2) Exchange of O₂ and CO₂ between alveolar air and blood in lung capillaries by *diffusion*  
    Blood

(3) Transport of O₂ and CO₂ through pulmonary and systemic circulation by *bulk flow*  

(4) Exchange of O₂ and CO₂ between blood in tissue capillaries and cells in tissues by *diffusion*  

(5) Cellular utilization of O₂ and production of CO₂
STEPS IN RESPIRATION

1. Ventilation (1)
2. Gas exchange (2)
3. Gas transport (3)
4. Gas exchange (4)
5. Cellular respiration (5)
STEPS IN RESPIRATION

- Air Bulk Flow
- Gas Diffusion

Ventilation (1)
Gas exchange (2)
Pulmonary circulation
Gas transport (3)
STEPS IN RESPIRATION

Gas Diffusion

Blood Bulk Flow
Bulk Flow Equation
Same for blood and air

\[
\text{Flow} = \frac{\Delta P}{R}
\]

Flow is directly proportional to the pressure difference.

“pressure gradient” or \( \Delta P \)
Flow is directly proportional to $\Delta P$ and directly proportional to airway radius to 4th power $r^4$

Radius later.

At rest No $\Delta P$ !!!! Thus no flow. So how do we move air in and out? Make a $\Delta P$ !!
BOYLE’S LAW:
At constant temperature, the pressure of a gas is inversely proportional to its volume.

Thus
If you $\downarrow$ volume $\rightarrow$ $\uparrow$ pressure

If you $\uparrow$ volume $\rightarrow$ $\downarrow$ pressure
RESPIRATORY PRESSURE UNITS =

- cm H$_2$O
- mm Hg

1 cm H$_2$O = 0.76 mm Hg

1 mm Hg = 1.36 cm H$_2$O

*****atmosphere
1 atmos = 760 mm Hg
BUT set to Zero… cm H$_2$O or mmHg ****

Pressure = \frac{force}{area} = \text{dynes/cm}^2

1 mm Hg = 1 Torr = 1333.22 dynes/cm$^2$
Pressure outside = $P_o = P_b = \ast$ atmospheric pressure $= \ast$ zero

$F = \frac{\Delta P}{R} = \frac{(P_o - P_A)}{R}$

Inspiration $\quad P_A < P_o \quad \downarrow P_A$

Expiration $\quad P_A > P_o \quad \uparrow P_A$

$P_{out} = \ast$ constant
Thoracic Cavity at Rest (equilibrium) between breaths

transmural pressures

Across chest wall

\[ P_{ip} - P_o = -4 \]
\[ -4 - 0 = -4 \]

Across lung wall

\[ P_A - P_{ip} = 4 \]
\[ 0 - (-4) = 4 \]

Transmural or alveolar distending pressure

Intraplural (ip) pressure
(Intrathoracic pressure)

\[ P_{ip} = -4 \text{ mm Hg} \]

“subatmospheric”

Elastic recoil
chest wall

Elastic recoil
alveolar wall
Chest At Rest

Lung “without chest” is much smaller

Chest “without lungs” is much bigger

When together (pulling in opposite directions)

Intraplural pressure is sub-atmospheric (- 4 mmHg)
Therefore if you make a hole in either the chest wall or the lung, the chest gets bigger and the lungs get smaller (collapses) as $P_{ip}$ goes to zero or atmospheric.
PNEUMOTHORAX (air in thorax)

Can be One-sided

Air intrapleural space

Hole in chest wall lets in air.

Chest wall expands

Lung collapses

atelectasis - collapse of (alveoli) lung

(atel -Gk - incomplete, ectasis -Gk - stretching out)

\[ P_{ip} = 0 \]

\[ P_{a} = 0 \]

\[ P_{ip} = -4 \text{ mm Hg} \]
Inspiration = chest (including lungs) made bigger

\[ P_b = 0 \]

\[ P_{ip} = -4 \text{ mm Hg} \]

\[ P_{A} = 0 \]

**Active**

\[ P_b = 0 \]

\[ P_{ip} = -7 \text{ mm Hg} \]

\[ P_{A} = 0 \]

End of normal inspiration****
Inspiration (rest & end)

\[ P_A = P_{ip} + \text{Alveolar recoil} \]

\[
\begin{align*}
0 &= -4 + 4 \quad \text{at rest} \\
0 &= -7 + 7 \quad \text{at end of inspiration}
\end{align*}
\]
Respiratory Air Flow = $\Delta P$

Inspiration

Expiration

$P_b = 0$ and so does $P_A$

$P_{ip}$ is $-4$ $-7$ $-4$

Flow

seconds

alveolar pressure, cmH$_2$O

airflow, liters/s

Source Undetermined
For **Inspiration**: You make the chest (volume) bigger and lower the $P_A$

By **active** contraction of skeletal muscle.

1. Diaphragm Contraction

2. External intercostal Contraction

3. Accessory Muscles of Inspiration Contraction
BOYLE’S LAW:
At constant temperature, the pressure of a gas is inversely proportional to its volume.

Thus
If you \( \uparrow \) volume \( \rightarrow \) \( \downarrow \) pressure
Inspiration

Increased volume of thoracic cavity - Decreased pressure in thoracic cavity.
External Intercostals
Sternocleidomastoideus

Scalenus medius
Expiration (Passive)

Inspiratory muscles relax.
Thoracic volume decreases.
$P_A$ increases (Boyle’s Law).

Air flows out by $\Delta P$. 
Normal Expiration:
Elastic recoil of lung returns volume to rest.

Normal Expiration
“relax”

If you ↓ volume
→ ↑$P_A$ Pressure

Forced Expiration
FORCED EXPIRATION

contract internal intercostal muscles

decreased thoracic volume

relaxed diaphragm pushed into thorax

contract abdominal muscles

ribs

internal intercostal muscles
Additional Source Information

for more information see: http://open.umich.edu/wiki/CitationPolicy

Slide 10: D’Alecy
Slide 11: Source Undetermined
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Slide 23: Source Undetermined
Slide 28: D’Alecy
Slide 29: D’Alecy
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Slide 32: D’Alecy
Slide 33: D’Alecy
Slide 35: Source Undetermined
Slide 38: D’Alecy
Slide 39: Gray’s Anatomy
Slide 40: Gray’s Anatomy; Gray’s Anatomy
Slide 43: D’Alecy