Solutions to Homework Assignment – Module 11

1. [20 points] Discuss/explain the meaning of the term *conducting airways*. Discuss/ explain the physiological function(s) of the conducting airways.

   Conducting airways provide a path for air between the atmosphere and the gas exchange units (the alveoli). No gas exchange (i.e., O_2, CO_2) occurs between air in the conducting airways and pulmonary capillary blood (B&L[6+], page 420; B&L[7], page 436; Vander[14], pages 443 - 444; West[10, pages 2 - 3 and Figures 1.4 and 1.5). The upper conducting airway also serves to warm and humidify entering (inspired) air (B&L[6+], page 417; B&L[7], page 434) and to remove particulates from the inspired air. The remainder of the conducting airways also serve to remove particulates from the inspired air.

2. [20 points] Discuss/explain the physiological mechanism(s) by which and the location(s) at which particulates in atmospheric air are removed before they reach the alveoli AND discuss/explain the fate of such particulates that <u>do</u> reach the alveoli.

   Particulates in air inhaled through the nose can be trapped in nose hair or can be trapped in nasal mucus, either by direct impact or by settling out subsequent to flow stagnation caused by turbulent flow as a result of inlet air impacting the nasal turbinates. Particulates making it further down the respiratory tree can be trapped in airway mucus; these trapped particulates are moved towards the mouth (to be expectorated or swallowed) by cilia that form a “mucus escalator” (B&L[6+], pages 477 – 479; B&L[7], pages 498 - 501; West[10], page 10 and chapter 9. Particulates that reach the alveoli can be cleared by lymphatic drainage and/or by being phagocytized by alveolar macrophages. (B&L[6+], page 479; B&L[7] page 501; West[10], page 10 and chapter 9; video 2, slide 8.

3. [20 points] Discuss/explain the anatomical/physiological mechanism(s) by which air is moved from the atmosphere into the alveoli during inspiration, and from the alveoli to the atmosphere during expiration.

   Air is moved both to and from the alveoli by bulk flow down a pressure gradient. During resting inhalation pressure in the thorax is reduced such that it is below atmospheric pressure (the diaphragm contracts, moving down into the abdomen, increasing the volume of and decreasing the pressure in, the thorax). During forced inhalation the external intercostal muscles contract, lifting the ribs “up and out”; this further increases the volume of the thorax, which further reduces intrathoracic pressure. Lung volume increases as the thorax expands, reducing alveolar pressure, thus creating a pressure gradient to drive flow from the atmosphere into the alveoli.

Rev 0, 4/6/16 - adapted from Spring 2016
Rev 1, 11/6/17 - Change language of questions to match Rev 1 of homework assignment, update refs to include B&L[7] and West[10], some changes to language of responses.
Rev 2, 8/3/18 - update to 601; no changes to content.

At exhalation the diaphragm relaxes, reducing thoracic volume and increasing pressure on the lung and, hence, the alveoli. The pressure gradient now favors gas flow from the alveoli to the atmosphere. During forced exhalation the internal intercostal and abdominal wall muscles contract, further increasing pressure on the lungs and, gain hence, on the alveoli, creating an even greater pressure gradient for flow from the alveoli to the atmosphere (See B&L[6+], pages 432 – 436; B&L[7], page 443; Vander[14], §13.2.

4. [20 points] What are the physical factors that directly determine airway resistance (to the flow of air)? Of these factors, which are under physiological control for the purpose of affecting airway resistance?

As with any rigid[1] tube, the resistance, R, to flow, assuming laminar flow, is equal to the pressure drop, P, across (inlet to outlet) the tube divided by the flow, Q, through the tube:

$$R = \Delta P/Q$$

Taking into account the properties of the flowing “fluid” (air) and the dimensions of the tube, we get:

$$R = \frac{8\eta l}{\pi r^4}$$

Where η is fluid viscosity, l is the length of the tube, and r is the (inner) radius of the tube. As a practical matter only r, the tube radius, is under physiological control; this is achieved by modulating the degree of contraction of the smooth muscles wrapped around the circumference of the airways (B&L[6+], pages 435 – 437; B&L[7], pages 456 - 458; West[10], pages 122 - 124). Recall also the material on resistance in the circulatory system in chapter 17 of B&L[6+] and of B&L[7].

5. [20 points] Discuss/explain the mechanism(s) by which and the location(s) at which forced expiration affects airway resistance.

Forced expiration, by reducing the volume of the thoracic cavity[2], increases pressure on the lung, which increases the pressure surrounding airways, which reduces their diameter, thereby increasing their flow resistance. In addition, there is an internal pressure drop along airways engendered by flow (from alveoli

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[1] Medium and small airways are no more rigid tubes than medium and small vessels in the circulatory system. Still, the formulas for resistance provided are at least a first approximation; more importantly, they allow you to think about what physiological factors affect airway resistance.

[2] Abdominal muscles contract, forcing abdominal contents to press upward on the diaphragm, pushing it into the thoracic cavity. Internal intercostals contract, drawing the ribs “down and in”, further reducing the volume of the thorax.

toward the mouth/nose) that contributes to the airway transmural pressure (higher outside than inside) being enough to narrow, and at some point to close, airways (B&L[6+], pages 439 – 441; B&L[7], pages 460 - 461; West[10], pages 128 - 132).

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