MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Departments of Electrical Engineering, Mechanical Engineering, and the Harvard-MIT Division
of Health Sciences and Technology

6.022J/2.792J/BEH.371J/HST542J: Quantitative Physiology: Organ Transport Systems

PROBLEM SET 8

Assigned: April 9, 2004

Due: April 15, 2004

Problem 1

A student with a mild case of asthma was feeling perfectly well when she left for class. On the way to class she breathes cold, dry air and develops a moderate asthma attack. She takes an inhaled medication (isoproterenol) that relieves the symptoms.

A. Modeling the lung as a single resistor and a single capacitor attached in series, what are the peak-to-peak pleural pressure swings in each case below? Assume lung compliance C_L stays fixed at 0.1 L·cm H_2O^{-1}, that the student breathes using a square-wave flow pattern with equal inspiratory and expiratory times, and that R_{insp} and R_{exp} are equal.

	R_{aw} (cmH$_2$O·L^{-1}·s)	f (breaths/min)	V_T (ml)
Normal	1	20	500
Asthma	20	40	250
Treated	5	25	400

B. The situation described above has been idealized to keep the analysis simple. For example, in reality, inspiratory flow resistance during the attack will be significantly less than the resistance experienced during expiration. Why?

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Problem 2

A. The alveolus may be modeled as a simple thin-walled sphere of radius R. Derive the relationship between the pressure inside the alveolus, P, and the tension, T, in the wall. Hint: the answer is $P = 2T/R$.

B. Assume one has two bubbles of equal radius connected together by a tube. The bubbles contain a surfactant which causes their surface tension to change as their surface area, a, changes.
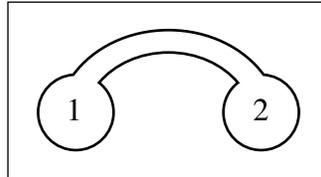
For each of the three surfactants listed below, the relationship between surface tension, T, and area, a, is given.

$$\text{surfactant 1:} \quad T = ka \quad k = \text{constant}$$

$$\text{surfactant 2:} \quad T = k\sqrt{a} \quad k = \text{constant}$$

$$\text{surfactant 3:} \quad T = \frac{k}{\sqrt{a}} \quad k = \text{constant}$$

Using Laplace's relationship, for each of the surfactants determine what will happen if the radius of one of the bubbles is increased. Why? Is the system stable?

2004/95

Problem 3

Consider a hypothetical patient without significant respiratory disease who enters the hospital for coronary bypass surgery. during anesthesia he will require mechanical ventilation which will be applied by a pump via an endotracheal tube. The lungs and chest wall (with respiratory muscles relaxed) of this patient have the characteristics illustrated in Figure 1.

Figure 1:
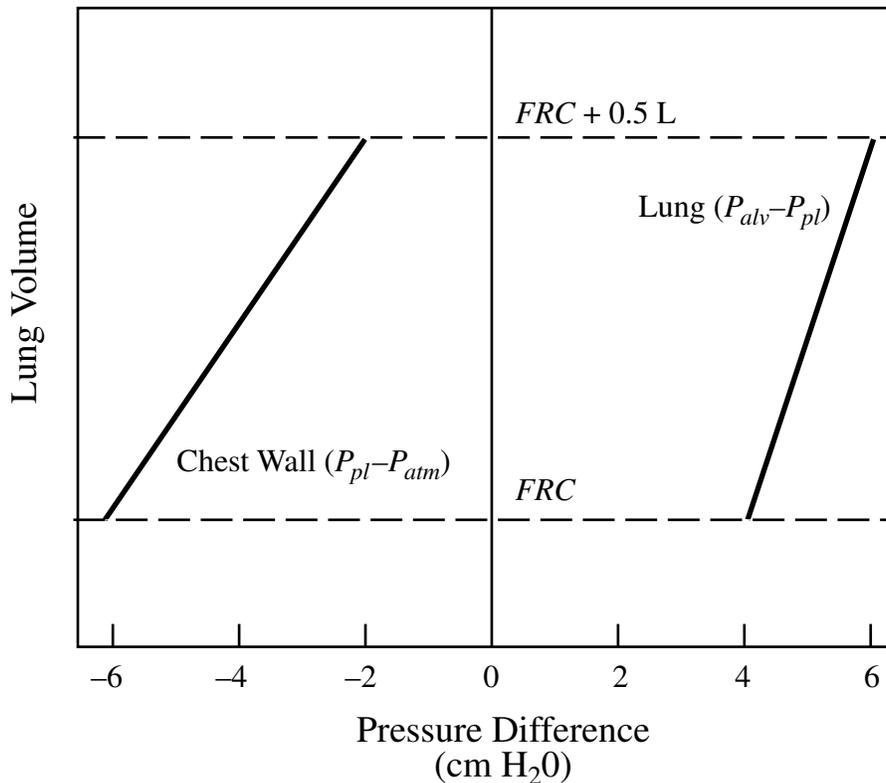
In all the following, for both normal and assisted ventilation, you may assume that:

- The patient's tidal volume remains constant at 0.5 L.

- His airways exhibit a flow resistance of 2 cm $H_2O \cdot L^{-1} \cdot s$ with negligible inertance.

- His inspiratory and expiratory flow rates are both 0.5 L/s and are constant during each phase of breathing.

- His lung volume at end expiration is maintained constant at the level indicated as *FRC* in Figure 1.

A. What is the value of $|P_{ao} - P_{alv}|$ (airway opening minus alveolar pressure) during inspiration and expiration at a constant rate of 0.5 L/s?

B. What is the total change in $P_{alv} - P_{pl}$ between end expiration and end inspiration?

C. Sketch on the provided graphs the time-course during one complete breathing cycle of P_{ao}, P_{pl}, and P_{alv} for each of the following cases (you may assume that Figure 1 still applies):
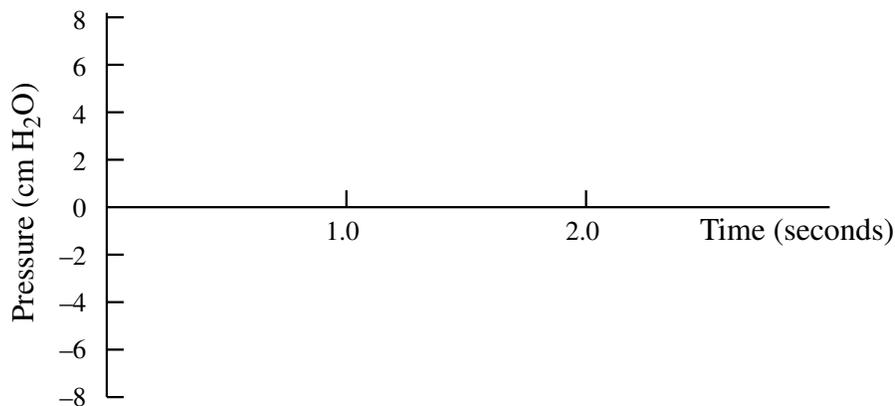
(i) During normal breathing before surgery.
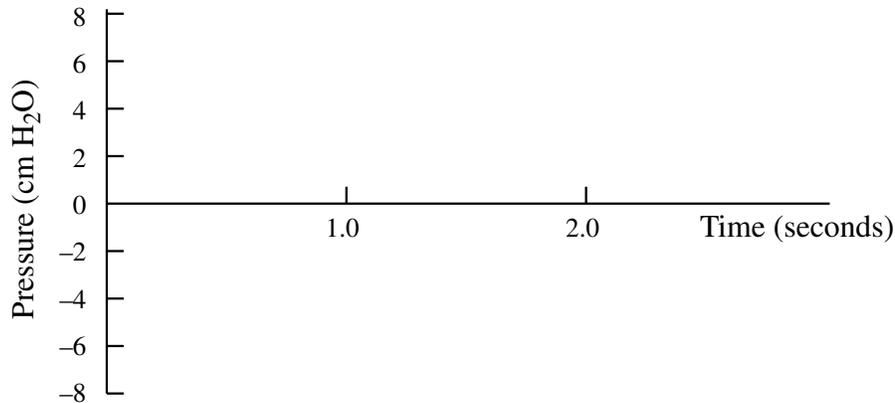
(ii) During mechanical ventilation applied at the mouth just prior to surgery. (Assume that the respiratory muscles are completely inactive.)
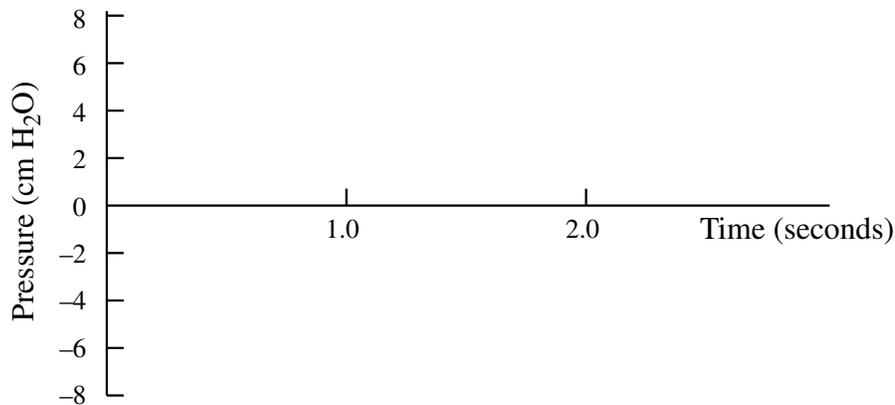
(iii) At some point during the surgical procedure, during mechanical ventilation, when the patient's chest wall is open and his lungs are exposed to atmospheric pressure.

Make sure you label each curve on each graph.

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