RSPT 1307: RESPIRATORY PHYSIOLOGY
VENTILATION
Section 2, Part A

I. PRESSURE DIFFERENCES ACROSS THE LUNGS

A. Driving pressure: $P_1 - P_2$
   1. pressure difference must exist between two points in a tube or vessel for flow to occur
   2. example -

B. Transairway pressure (Pta): Pta = Pb - PA
   1. definitions
      a. Pb = barometric pressure
      b. PA = alveolar pressure
   2. Pta can either be positive or negative
   3. moves air into an out of lungs

C. Transpulmonary pressure (Ptp): Ptp = PA - Ppl
   1. definition - Ppl = pleural pressure
   2. examples
      a. inspiration -
      b. exhalation -

D. Transthoracic pressure (Ptt): Ptt = PA - Pb
   1. similar to transairway pressure (Pta)
   2. can either be positive or negative

E. Role of the diaphragm in ventilation
   1. during inspiration the diaphragm flattens and increases the thoracic volume
      a. Ppl and PA decrease -
      b. if PA < Pb, then gas moves from atmosphere to lungs
      c. at end inspiration and end exhalation PA = Pb
   2. during exhalation the diaphragm relaxes and moves up
      a. thoracic volume decreases
      b. PA > Pb and air moves out
   3. during quiet respiration - diaphragm excursion is 1.5 cm and Ppl is 3 to 6 cm H_2O
      a. during deep inspiration Ppl may dec. 50 cm H_2O below atm. press.
      b. during forced expiration Ppl may rise to 70-100 cm H_2O above atm.

II. COMPLIANCE

A. Definition - compliance is a measure of the distensibility of the chest and/or lungs. It is the ease with which the lung volume is changed.
   1. compliance = change in volume / change in pressure
   2. compliance = Liters(BTPS)/cm H_2O or ml(BTPS)/cm H_2O
   3. increasing compliance - there is a larger volume change per unit of pressure change BREATHING BECOMES EASIER
   4. decreasing compliance - there is a smaller volume of change per unit of pressure change BREATHING BECOMES HARDER

B. Elastic recoil of the lung
   1. lungs are stretched during inspiration
      a. thorax enlarged by inspiratory muscles (diaphragm flattens)
      b. pleural surfaces are held together by negative pressures
   2. when inspiratory muscles relax - lungs return to resting expiratory level (REL)
   3. the greater the force applied (stress or pressure) the more the lungs stretch (strain or inc. volume)

4. compliance is dependent on the change in volume NOT the speed with which this new volume is attained
5. Hooke's law states that when a truly elastic body (spring) is acted upon by a unit of force, it will stretch 1 unit of length until the elastic limit has been reached
   a. elastance is the natural ability of matter to change shape from stress and then return to the original shape
   b. physiologically ELASTANCE = change in pressure / change of volume
   c. elastance is the reciprocal of compliance, when one inc. the other dec., converse is true also
6. elasticity of lungs vs. the thorax
   a. lungs alone have a volume less than RV
   b. thorax alone has a volume greater than FRC
   c. together and relaxed they are at FRC or REL
   d. forces that cause lung recoil
      i) elastic properties of lung tissue
      ii) surface tension produced by a fluid lining the alveolar surface
7. pressure-volume curves
   a. volume is on the Y axis
   b. pressure is on the X axis
   c. the slope represents the compliance and rises until the elastic limits of the lungs are reached
   d. breathing may occur at different points of the pressure volume curve
   e. compliance changes as the curve's slope changes
   f. if the slope is more vertical, the lungs are more compliant (low volumes)
   g. if the slope is more horizontal, the lungs are less compliant (high volumes)

C. Measuring lung compliance
1. transpulmonary pressure is used to calculate lung compliance
   a. alveolar pressure - intrapleural pressure
2. intraesophageal pressure is assumed to be equal to transpulmonary pressure at the end of inspiration and exhalation
3. a balloon is positioned in the lower third of the esophagus and inflated
4. static lung compliance or effective compliance
   a. esophageal pressures are measured and recorded as a person breathes in and holds a specific volume
   b. increasing volumes of gas are inhaled and pressure measurements are made
   c. volume is then plotted against pressure and a pressure-volume curve constructed
5. dynamic compliance is calculated by dividing the lung volumes change during a tidal breath by the simultaneous change of intrapleural pressure from the end of expiration to end inspiration
   a. intrapleural pressure is measured as a change in esophageal p.
   b. a 1 L lung volume change may produce a 5 cm H_2O pressure change
   c. compliance (CL) is 0.2 L (BTPS)/cm H_2O
6. compliance must be related to lung volume, usually related to FRC
   a. inflate lung with 1 L and obtain 5 cm H_2O pressure change compliance =
   b. newborn = .006 L/cm H_2O, when related to volume it equals .067 L/cm H_2O/L (FRC is 90 ml)

D. Measuring thoracic-lung compliance (Total compliance)
1. subject inspires a measured lung volume of air, closes mouth and nose, opens glottis, and relaxes muscle of respiration
2. repetition of this procedure at several volumes is done
3. volume measurements are plotted against pressure measurements

E. Measurement of thoracic compliance

$$\frac{1}{C\ total} = \frac{1}{C\ lung} + \frac{1}{C\ thoracic\ cage}$$

F. Pressure-Volume curves of patients on ventilators
1. effective dynamic characteristic curve (EDCC)
   a. peak pressure at specific tidal volumes
   b. curve reflects elastic and nonelastic resistance properties
   c. includes airway resistance factor (dynamic conditions)
2. effective static compliance curve (ESCC)
   a. graphic recording of plateau pressures at specific tidal volumes
   b. plateau pressure is pressure noted after gas flow ceases (static conditions)
   c. curve reflects elastic recoil - an indication of compliance
3. when EDCC and ESCC are plotted together the space between them reflects airway resistance
   a. as airway resistance increases the curves will move away or apart
4. conditions that affect the pressure-volume curves
   a. conditions in which both peak and plateau pressures are elevated
   b. conditions in which only the peak pressure is elevated
   c. conditions in which respiratory failure may occur without significant pressure change

G. Usefulness
1. if CL abnormal - some pulmonary abnormality exists
   a. change in FRC
2. if CL/FRC is abnormal
   a. change in quantity or quality of lung tissue
   b. presence of pulmonary edema
   c. alteration of surface tension in alveolar lining
3. compliance measurements are useful in ventilator patients
   a. thoracic-lung compliance (ESCC) is most often measured
   b. changes in compliance are more important than absolute compliance
4. excessive pressure ventilation to a low compliant lung may exert enough force to rupture alveoli near the surface of a lung
   a. barotrauma may allow air to enter pleura through rupture
   b. natural recoil of the lung causes the lung to collapse producing a PNEUMOTHORAX

II. SURFACE TENSION

A. Alveolar surface is lined with a liquid film
1. pressure required to inflate alveoli filled with fluid is less than 1/2 the pressure required to inflate air-filled lungs
2. alveoli have a liquid-air interface and recoil like a bubble
3. if filled with a fluid, alveoli would have a liquid-liquid interface
4. cohesive forces are stronger than adhesive forces at the surface of a fluid

B. Surface phenomena
1. if a loop of wire is dipped into a soap solution and then removed, the film of liquid will contract bending the wire into a smaller loop

   a. the surface film exerts a force perpendicular to any line on the surface
   b. the surface tension allows a needle to float on the water
2. surface under tension contracts to the smallest possible area
   a. surface molecules are pulled down
   b. the resulting force on the surface is interfacial tension or surface tension; surface tension = force/length
3. Laplace's law states that the pressure within a spherical liquid drop or bubble is inversely proportional to the radius
   a. drop $P = \frac{2T}{r}$
   b. bubble $P = \frac{4T}{r}$
   c. as surface tension increases or as radius decreases, the pressure required to maintain the volume of a bubble increases
   d. note that LaPlace's law does NOT state that surface tension varies with the size of the soap bubble
4. in a sphere the tension in the walls tend to make it smaller, but equal and opposite pressures from inside prevent it

C. Tension in the lung - the alveolus does not act like a soap bubble
1. surface tension is high when the alveoli is inflated and low when deflated (unlike a soap bubble)
   a. this phenomenon is due to a surface active substance - surfactant
2. surfactant is a phospholipid (dipalmitoyl lecithin)
   a. surfactant consists of lipid, lecithin, proteins and carbohydrates
   b. it appears in the lung between 22-24 weeks of gestation
   c. surfactant appears when the methyltransferase enzyme systems appear -
   d. prior to birth the lecithin-sphingomyelin ratios have been used to judge lung maturation -
   e. surfactant has a hydrophobic end - insoluble in water
   f. surfactant also has a hydrophylic end - soluble in water
   g. surfactant has a half-life of approximately 24 hours and is constantly being produced
   h. it has the lowest surface tension of any biological substance ever measured
3. as the lung inflates, the surfactant becomes less concentrated on the surface and surface tension increases
4. during exhalation, the surfactant becomes more concentrated and surface tension decreases
5. critical closing pressure: when the size of a bubble decreases it may reach a point where the attraction of the liquid molecules exceed the pressures holding the bubble (alveolus) open
   a. alveoli collapse
   b. this phenomenon is called ATELECTASIS

D. Physiological importance of surfactant
1. alveoli with low surface tension require low air pressure to maintain a given volume
   a. alveoli throughout the lung at a given time are not the same size but are being held open by equal pressure
2. surfactant concentrations that change as surface area change stabilize the alveoli and keeps them from collapsing
3. alveoli are not like soap bubbles
   a. a small soap bubble has high pressure while a larger one has low pressure
   b. small alveoli have pressures approximately equal to inflated ones

4. if surfactant is absent or inactive
    a. alveoli decrease in size
    b. T increases
    c. alveoli collapse
    d. the work of breathing increases

III. AIRWAY RESISTANCE

A. Airflow through bronchi and bronchioles is governed by Poiseuille's law
    1. Flow $= \dfrac{\pi r^4 (P_1 - P_2)}{8\,n\,l}$
    2. a pressure gradient is required to move air into the alveoli or out
    3. $P1 - P2 = \dfrac{\text{flow} \times 8\ n\ l}{\pi\ r^4}$
    4. resistance (R) = alveolar pressure /flow
    5. R = P1 - P2 / flow
    6. $R = \dfrac{8\ n\ l}{\pi\ r^4}$
        a. viscosity (n) of any gas is very small but may be significant with bronchoconstriction and turbulent flow
        b. radius of airway is very important due to bronchospastic changes
        c. length has only minimal effects

B. Characteristics of different types of flows
    1. laminar flow - gas flow is stream lined moving in parallel lines in one direction -
    2. turbulent flow - gas is moving through a tube at high speeds and in random chaotic motion -
    3. transitional flow - is a combination of laminar and turbulent flows, it occurs at branch points or distal to partial obstruction

C. Measuring airway resistance (RAW) requires three values -
    1. alveolar pressure -
    2. atmospheric pressure
    3. instantaneous air flow -
    4. normal values: 0.6 - 2.4 cm H_2O/L/sec
        a. 1/2 of all resistance is in the nasal passages

D. Factors influencing resistance
    1. obstruction of smaller airways

    2. physical factors
        a. R decreases as volume increases
        b. R increases as volume decreases

E. Neural regulation (sympathetic - relaxes; parasympathetic - constricts)
    1. bronchioles and alveolar ducts have smooth muscles that react to neural stimulation
    2. alveoli have sphincter-like muscles at the opening of the alveoli, contracts independently
    3. bronchoconstriction
        a. narrows bronchioles
        b. increases R
        c. decreases anatomical dead space (VDA)
        d. enlarges alveoli and FRC

4. stimulation of sphincter flattens alveoli and expels air (dec. FRC)
5. reflexes causing bronchoconstriction
    a. smoke inhalation
    b. arterial anoxemia
    c. increases in $PaCO2$
    d. cold air and pulmonary emboli
6. reflexes causing dilatation
    a. deep inspiration
    b. increase in systemic arterial blood pressure

F. Chemical regulation - affects bronchiolar smooth muscles by:
1. stimulating autonomic ganglia
2. stimulating or blocking receptor sites for postganglionic fibers
    a. adrenalin - bronchodilation
    b. acetylcholine - bronchoconstriction
3. direct action unrelated to nerve fibers
    a. histamine, bradykinin, SRS-A, leukotrienes

G. Effects of increased resistance
1. cannot expire in normal time
2. FRC increases
3. work of breathing increases
4. physiological deadspace increases
5. frequency increases (vent.) and alveolar ventilation decreases

H. Differential diagnosis of increased RAW
1. during exhalation only - airway collapse
2. during inspiration - upper airway obstruction
3. if reversed by therapy - smooth muscle constriction, edema or mucosal congestion, mucous plug
    a. if relieved by bronchodilator - muscle constriction
    b. if relieved by noradrenalin - vascular congestion

REGULATION OF AIRWAY RESISTANCE

System	Constriction	Dilatation
I. Nervous	1. parasympathetic	1. sympathetic - unsure if sym. postganglionic fibers act on a. receptors b. smooth muscles c. inhibit parasym. ganglion cells
	2. subepithelial receptors smoke, dust, chem. irrat.	2. deep inspiration
	3. arterial hypoxemia carotid, poss. aortic reflex centers	3. inc. systemic arterial pressure - carotid sinus
	4. inc. $PaCO_2$ - medullary receptors	
	5. by cold, emboli in pul. circ.	
	6. histamine in arterial (bronchial) or liberated locally by Ag-Ab rx.	

II. Chemical
Method of action -
a. stimulation of autonomic ganglion
b. liberating postganglionic mediators
c. stim. of blocking receptor sites of postganglionic fibers
d. direct action unrelated by nerve fibers or receptors

System	Constriction	Dilatation
	1. acetylcholine - parasym. receptor sites	1. isoproterenol, epinephrine norepinephrine - stim. recp. sites of sym. post-ganglionic fibers
	2. anticholinesterase agents - blocks enzyme cholinestrase	2. atropine - blocks effects of postganglionic parasym impulses
	3. propranolol - blocks B-adrenoreceptors	3. methylxanthines - blocks release of chemical mediators on mast cells
	4. low alveolar CO_2	4. steroids - reduce inflam-matory components, sensitizes adrenergic receptors sites
	5. histamine (chemical mediator) a. pulmonary circ. - alveolar sphincter, alveolar ducts b. bronchial circ. - bronchi, bronchioles	