Ch. 7 the physics of lungs and breathing

objectives

- At the end of this chapter the student will be able to:

1. List the physiologic function of the lungs.
2. List the components of the respiratory system.
3. Explain the process of respiration and gas exchange in the lungs.
4. State Dalton’s law of partial pressures and Henry’s law of solubility.

5. Compare between Oxygen and Carbon dioxide according to their roles in breating.

6. Define the respiratory quotient.

7. Define the spirometer and list lung volumes.

8. Explain

Pressure-air flow- volume relationships of the lungs.

9. Discuss physics of alveoli then list some common lung diseases.

1 –a/ Physiologic function of the lungs:

- Exchange of O_2 and CO_2 .
- Blood pH (acidity) regulation :
  $CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + CO^-_3$
- Heat and fluid balance :
  moisture and heat air .
- Speech .

1-b/ The airways:

- Trachea – bronchi – terminal bronchioles – respiratory bronchioles – alveolar ducts – alveolar sacs .
- 23 bifurcations.
- Respiration mainly in alveoli (2^{23}~ 8 million alveolar sacs).

1-c/ Airway clearance :

- Ideal habitats for germs.
- Large particles settle in upper airway and smaller ones in alveoli (~ 1 µm).
- Clearance mechanisms:

a- Large airways, nasal passage → coughing, sneezing

b- Upper airways → ciliated, mucous elevator; clearance in 24 h.

c- Alveoli → macrophages; clearance over several weeks or longer.

1-d/ Specific problems :

- Asbestos : needle-like, does not clear easily → leads to fibrosis → lung stiffens.
- Smoking kills cilia.
- Excess mucous secretion, nonfunctioning cilia → airway narrowing.

2 – Breathing rate :

- Men breathe about 12 times per minute at rest .
- Women breathe about 20 times per minute at rest .
- Infants breathe about 60 times per minute .

3 – respiration :

- In breathing 6 liters of air per minute ≈ the volume of blood the heart pumps per minute .
- Breathing consists of two processes, inspiration and expiration.
- Inspired air consists of 80% N_2 and 20% O_2 ; i.e. 1728 L of O_2 enters lung and only 400 L absorbs which represents about 23%.
- Expired air consists of 80% N_2 , 16% O_2 and 4% CO_2 .
- The amount of air in breathing is about 10 kg/day .
- The amount of O_2 absorbed in the lungs is about 0.5 kg ≈ 400L .

3 – respiration :

- The amount of CO_2 is smaller in expiration .
- There are little amount of water in expiration .
- 12 rpm (respiration rate) $_x$ 0.5 L (tidal volume) = 8640 L/day (faster in women).
- O_2 consumption is determined by metabolic rate.
- Combustion : food + O_2 → water + CO_2 + energy .
- Rise in CO_2 , H^+ or fall in O_2 stimulates breathing.
- Breathing is controlled primarily by PCO_2 in blood.

4 – Interaction of blood and lungs :

- Blood is pumped from the heart to the lungs under relatively low pressure; it is about 20 mmHg in the main pulmonary artery which is 15% of the main blood circulation.
- The lung offer little resistance to the flow of blood. 1/5 volume of body's blood is in the lungs. 70 mL of that blood is in the capillaries getting O_2 at any time .
- The surface area between air and blood in the lungs is about 80 m^2 .
- 70 mL of blood were spread over 80 m^2 ;the resulting layer of blood would be about 1µm thick which is less than the thickness of single RBC .

5 – Processes of gas exchange in the lungs :

- Perfusion: getting the blood to the pulmonary capillary bed .
- Ventilation: getting the air to the alveolar surfaces .
- If either process fails the blood will not be properly oxygenated .

Types of ventilation – perfusion areas :

a- Areas with good perfusion and good ventilation , in normal lungs this type accounts for over 90% of the total volume.

b- Areas with good ventilation and poor perfusion , e.g. pulmonary embolism where the blood flow to part of a lung is blocked by a clot.

c- Areas with poor ventilation and good perfusion , e.g. pneumonia where air passages in the lungs are obstructed .

6 – Transfer of O_2 and CO_2 in the body takes place by two ways :

a- Diffusion.

b- Chemical combination with hemoglobin Hb .

Diffusion

Diffusion : molecules of a particular type diffuse from a region of higher concentration to a region of lower concentration until the concentration is uniform.

Each molecule collides about 10^{10} times/s with the neighboring molecules :

$D = \lambda(N)^{1/2}$; where D is the travelled distance by the molecule after (N) collisions , and λ is the mean free path or the average distance between collisions which is 10^{-7}m in air and 10^{-11}m in the tissue .

Diffusion depends on the speed of the molecules and it increases with temperature .

Since $N \alpha \Delta t$; where Δt is the diffusion time .

Therefore $D \alpha (\Delta t)^{1/2}$.

The diffusion of O_2 and CO_2 in tissue is about 10000 times slower than it is in air , but the tissue thickness the molecules must diffuse through in the lungs is very small (~ 0.4 μm) and diffusion through the alveolar wall takes place in much less than 1s .

Dalton's law of partial pressures :

In the mixture of gases , each gas makes its own contribution to the total pressure as though it were alone. Or in another expression :

The total pressure in a gas is equal to the sum of its partial pressures:

$$P = \sum P = PO_2 + PN_2 + PCO_2 + PH_2O$$

Dry atmospheric air at pressure 760 mmHg consists of :

O_2 : PO_2 = 150 mmHg which is about 20% of the 760 mmHg .

N_2 : PN_2 = 610 mmHg which is about 80% of the 760 mmHg

<u>Henry's law of solubility</u> :

The amount of gas dissolved in a liquid is proportional to the pressure of that gas .

In the capillaries the blood and O_2 will be in contact , so O_2 will dissolve in the blood until the PO_2 in the blood and outside will be the same , then the number of O_2 molecules that are escaping from the blood each second is the same as the number that are entering in .

The amount of gas dissolved in blood depends on the type of the gas .

At body temperature 1L of blood plasma at PO_2 of 100 mmHg will hold only 2.5 cm^3 of O_2 at normal pressure and temperature (NTP) , while the same amount of plasma at PCO_2 of 40 mmHg will hold 25 cm^3 of CO_2 .

A comparison between O_2 and CO_2 according to their roles in breathing :

	O_2	CO_2
1	It is not very soluble either in blood and water.	It is more soluble than O_2 .
2	Molecule of O_2 diffuses faster through the alveolar wall because of its smaller mass.	It is larger in mass so slower in diffusion through the alveolar wall .
3	Smaller number molecules in solution so the transport is not very efficient.	Greater number molecules in solution than O_2 ,so the transport is more efficient than O_2 .
4	If a disease causes the alveolar wall to thicken , the transport of O_2 is hindered more than CO_2 .	If a disease causes the alveolar wall to thicken , the transport of CO_2 is hindered less than O_2 .

At each breath about 500 cm^3 of fresh air (PO_2 of 150 mmHg) mixes with about 2000 cm^3 of stale air in the lungs to result in alveolar air with a PO_2 100 mmHg . PCO_2 in the alveoli is about 40 mmHg .

The expired air contains about 150 cm^3 of fresh air from the trachea that was not in contact with alveolar surfaces, so expired air has a slightly higher PO_2 and lower PCO_2 than the alveolar air.

The percentages and partial pressures of O_2 and CO_2 in inspired , alveolar , and expired air :

Air type	O_2%	PO_2 mmHg	CO_2 %	PCO_2 mmHg	H_2O vapour %	PH_2O mmHg
Inspired air	20.9	150	0.04	0.3	……… ……...	…… …… …
Alveolar air	14.0	100	5.6	40	……… ……...	…… …… …
Expired air	16.3	116	4.5	32	100	47

Respiratory exchange ratio (respiratory quotient R) :

$R = CO_2$ output / O_2 intake .

Or : CO_2 expelled/ O_2 absorbed .

R is slightly less than 1 (it is about 0.8).

2000 Cal /day : absorb 400 L O_2 and expel less than 400 L CO_2 .

The role of N_2 :

- N_2 from the air does not play any known role in body function although it is dissolved in the blood at its partial pressure .
- A deep sea-diver breathes air at much higher pressure under water than when he is at sea level , so increased PN_2 causes more N_2 to be dissolved in his blood and tissue.
- Bends : is a serious problem caused by the N_2 bubbles in the joint when the diver surfaces too rapidly .

In spite of the stale air in the alveoli , the O_2 rapidly diffuses through the stale air to reach the surface of the alveoli because of its higher concentration. Then O_2 is dissolved in the moist alveolar wall and diffuses through into the capillary blood until the PO_2 in the blood is equal to that in the alveoli. This process takes less than 0.5 s .while CO_2 in the blood diffuses even more rapidly into the gas in the alveoli until PCO_2 in the blood is the same as in the alveolar gas .

- ✓ 200 cm^3 O_2 /1000 cm^3 of blood : by chemical combination with Hb.
- ✓ 2.5 cm^3 O_2 / 1000 cm^3 of blood : by diffusion in solution .

Diffusion into blood stream :

Diffusion processes due to differences in the concentration level are described by Fick's first diffusion law :

$$(dn/dt) = D(A/d) \times \Delta C$$

Where n is the number of diffusing molecules ; D is the diffusion coefficient ; A is the area of the membrane ; d is the thickness of the membrane ; and ΔC is the concentration difference . i.e diffusion is proportional to concentration gradient .

Diffusion law can be reformulated in terms of the difference in partial pressure *ΔP* :

$$(dn/dt) = K(A/d) \times \Delta P$$

Where K is the Krogh diffusion coefficient which is proportional to *D* but has different values and dimensions . i.e. diffusion is proportional to the gradient in partial pressure .

For gas mixture in the alveoli

$Kco_2 \approx 23\ Ko_2$ i.e. for carbon dioxide the diffusion coefficient is 23 times larger than for oxygen due to the difference in partial pressures .

The equalization between the O_2 partial pressure in the alveoli and in the blood capillary follows an exponential behavior .

Solving the Fick differential equation for the diffusion :

$(d\Delta P/dt) = -(1/\tau_0) * \Delta P(t)$

$\Delta P(t) = \Delta P(t_0) * e^{-(t/\tau 0)}$

τ_0 is the time constant for the diffusion process which depends on the diffusion coefficient and the volume of the alveoli bubble V_1 and the volume of the capillary blood vessel V_2 :

$\tau_0 = -(1/D_L) * \{(V_1 V_2)/ (V_1 + V_2)\}$ where D_L is the O_2 diffusion coefficient of the lung .

with the assumption that all of the O_2 flow into the alveoli is absorbed through the membranes :

$(dno_2/dt) = Fo_2 = K(A/d) \times \Delta P(t) = D_L \times \Delta P(t)$

Where the O_2 diffusion coefficient of the lung $D_L = K \times (A/d)$; $\Delta P(t)$ is the O_2 partial pressure difference between the alveoli volume and the capillary blood stream which changes with time over the diffusion process until the O_2 partial pressures (or O_2 concentrations) in the alveoli and the blood vessel are equalized.

Example : O_2 diffusion coefficient of an average lung .

For simplification we may neglect the time dependence of the pressure equalization and adopt an average pressure difference $(\Delta P)_{average}$ between the alveoli bubble and the blood vessel . This modifies the equation for the diffusion flow :

$$(dno_2 / dt) = Fo_2 = D_L \times (\Delta P)_{average}$$

$(\Delta P)_{average}$ is approximated as the mean value of partial pressure difference averaged over the entire time of the diffusion process .

For the average adult the mean value of the partial pressure difference for oxygen is :

$(\Delta P)_{average} \approx 10[mmHg]$,

The oxygen flow for an adult at rest is :

$Fo_2 \approx 300[ml/min]$.

Using typical alveoli parameters $A=80\ cm^2$, $d=0.001\ mm$, the value for the O_2 diffusion coefficient is estimated :

$D_L \approx 30\ [ml/(min.mmHg]$

$K = D_L \times (d/A) \approx 5 \times 10^{-6}\ [cm^2 / s.kPa]$.

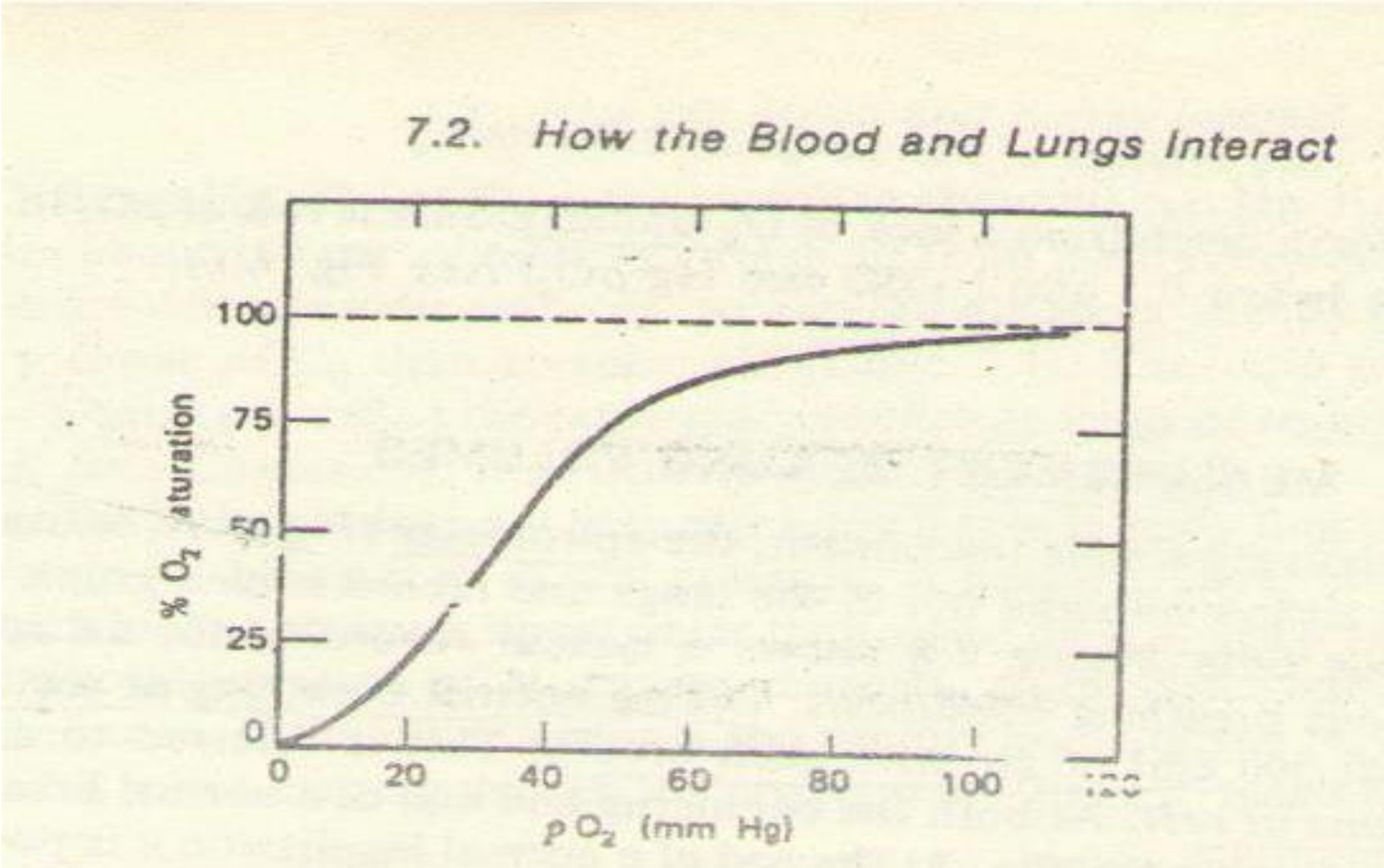


Fig. (7.6) The percent O_2 saturation of the blood as a function of PO_2 in the alveoli .

7 – Lung volumes :

Lung volumes can be measured by using spirometer , it used to measure airflow into and out of the lungs and record it on a graph of volume versus time as shown in the figure below :

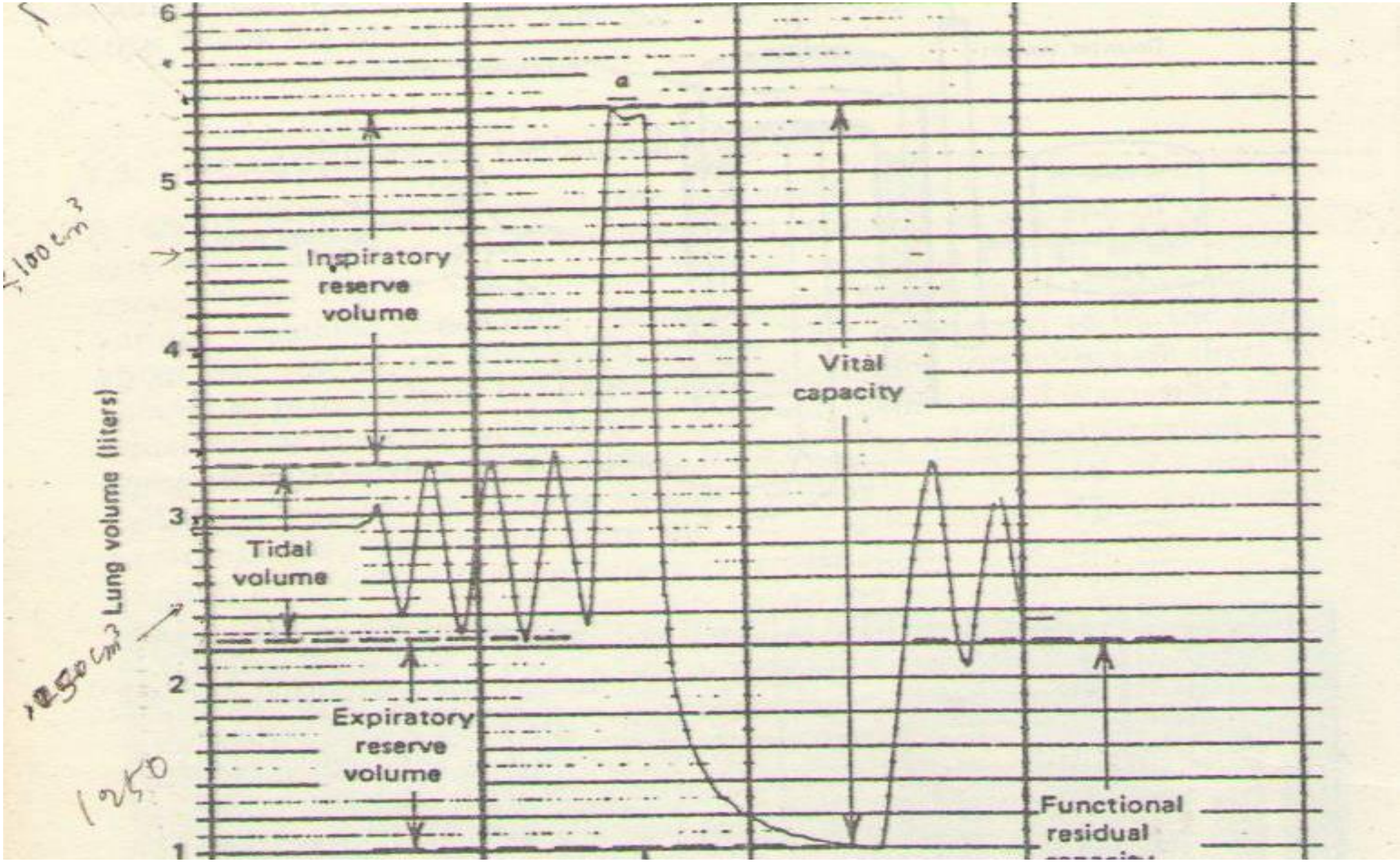


Fig. (7.8) shows the various volumes and capacities of the lungs made by spirometer .

Lung volumes :

- Tidal volume at rest (TV) : is the lung volume during breathing when about 500 cm^3 of air is inhaled .
- Inspiratory reserve volume (IRV) : is the amount of additive volume when additional air is taken in with some effort at the end of normal inspiration .
- Expiratory reserve volume (ERV) : is the volume of the lung when more air can be forced out of the lung at the end of normal expiration .
- The functional residual capacity (FRC) : is the volume of the remaining air in the lungs after a normal expiration , this is stale air that mixes with the fresh air of the next breath . It is 30% of the volume after expiration, it is about 2 L .
- Vital capacity (VC) : is the capacity of the lungs during deep breathing (i.e. deep inhalation and exhalation) , it is about 5 L .

Lung volumes :

- Residual volume (RV) : is the volume of air that stay in the lungs after deep exhalation . It is about 1L for an adult . The (RV) can be determined by having the subject breathe in a known volume of an inert gas as (He) and then measuring the fraction of (He) in the expired air .
- Respiratory minute volume : is the amount of air breathed in one minute .
- Maximum voluntary ventilation : is the maximum volume of air that can be breathed in 15 s (this is a useful quantity) .
- vital capacity (VC)=tidal volume(TV)+inspiratory reserve volume(IRV) + expiratory reserve volume(ERV).
- Functional residual capacity(FRC)=residual volume(RV)+ expiratory reserve volume(ERV).

Notes :

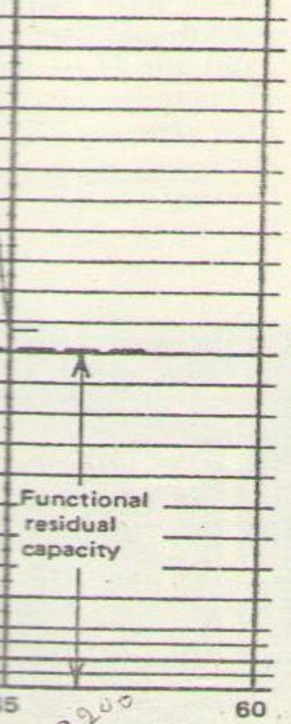
- TV is considerably larger during heavy exercises .
- The maximum rate of expiration after a maximum inspiration is useful test for emphysema and other obstructive airway .
- Expiration of 70% of VC in 0.5 s is normal .
- Expiration of 80% of VC in 1 s is normal .
- Expiration of 94% of VC in 2 s is normal .
- Expiration of 97% of VC in 3 s is normal .
- Normal flow rates are 350 to 500 L/min .

Notes :

- <u>Anatomic dead space</u> : is the volume of the trachea and bronchi since air in this space is not exposed to the blood in the pulmonary capillaries. It is typically 150 cm^3.
- <u>Physiologic or alveolar dead space</u> : is the space that the alveolar capillaries are not perfused with blood and the O_2 is not absorbed in these alveoli .

8 – Pressure –air flow- volume relationships of the lungs :

The pressure difference needed to cause air to flow into or out of the lungs of a healthy individual is quite small . It is about a few centimeters of water . (fig. 7.9)



g. 7.7*b*. It shows the
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7.4. PRESSURE-AIRFLOW-VOLUME RELATIONSHIPS OF THE LUNGS

The pressure, airflow, and volume relationships of the lungs during tidal breathing for a normal subject and for a patient with a narrowed airway are shown in Fig. 7.9. The pressure difference needed to cause air to flow

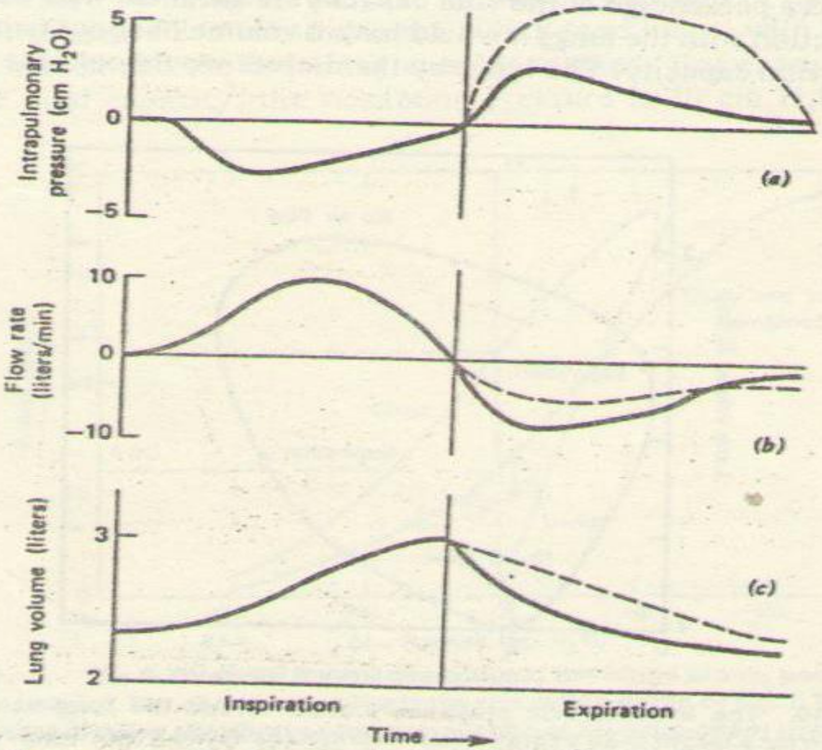

Figure 7.9. Typical pressures (a), flow rates (b), and lung volumes (c) during quiet respiration for a normal individual (solid line) and a patient with a ...

Fig. 7.9 : (a) Typical pressures, (b) Flow rates, (c) Lung volumes; (solid line : normal), (dashed line : patient with a narrowed airway)

Negative pressure causes air to flow to the lungs through airways during inspiration , while during expiration the pressure increases to positive value to cause the air to flow out of the lungs . (see the relationships in the figure for normal and abnormal individual) .

Also see the figures (7.10),(7.11),(7.12),(7.13) into or out of the lungs of a healthy individual is quite small. Note that the pressure difference (Fig. 7.9*a*) is only a few centimeters of water for a normal individual. Figure 7.9*b* shows the rate of airflow into and out of the lungs in liters per minute, and Fig. 7.9*c* shows the lung volume during the breathing cycle.

Since the esophagus passes through the chest, it reflects the pressure between the lungs and chest wall (intrapleural or intrathoracic space). It is possible to measure the pressure in the esophagus with a pressure gauge. This pressure is normally negative (−10 mm Hg) due to the elasticity of the lungs (see Section 7.6). In Fig. 7.10, the intrathoracic pressure (measured in the esophagus) is plotted versus the tidal lung volume during respiration. Figure 7.11 shows the pressure-volume curves for three different breathing rates—slow, moderate, and fast.

The lungs and chest wall are normally coupled together. The behavior of the system is the result of the combination of the physical characteristics of the two. Figure 7.12 shows curves of volume versus pressure for the chest wall and lungs separately and for the two together. The volume is given as a percentage of the vital capacity. If the chest wall were free of its interaction with the lungs it would have a volume of about two-thirds of the total vital capacity. The lungs by themselves would collapse and have

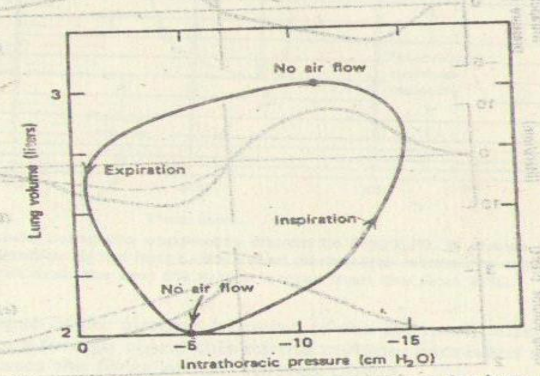

Figure 7.10. The intrathoracic pressure plotted versus the lung volume during respiration for a larger than average tidal volume. (Adapted from Hildebrandt, J., and Young, A.C., in T.C. Ruch and H.D. Patton (Eds.), *Physiology and Biophysics*, 19th ed., © W.B. Saunders Company, Philadelphia, 1965, p. 754.)

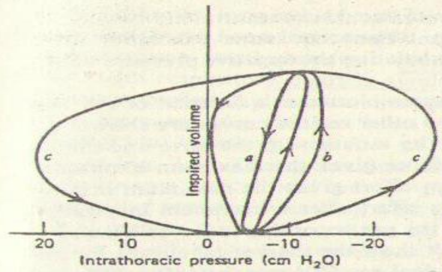

Figure 7.11. The *P-V* curves for three different breathing rates: (*a*) very slow breathing of about 3 breaths/min: (*b*) about 40 breaths/min; and (c) maximum breathing rate of about 150 breaths/min. (Adapted from Hildebrandt, J., and Young, A.C., in T.C. Ruch and H.D. Patton (Eds.), *Physiology and Biophysics*, 19th ed., © W.B. Saunders Company, Philadelphia, 1965, p. 754.)

essentially no air volume. Together the lungs and chest wall come to a relaxation volume (FRC) at about 30% of vital capacity.

The combined curve in Fig. 7.12 shows the pressure-volume relationship obtained by filling the lungs to known percentages of the vital capacity. The pressure is measured in the mouth (and lungs) with the nose and mouth closed and the breathing muscles relaxed. For example, at about 60% of vital capacity, the relaxation pressure is 10 cm H_2O. Since the

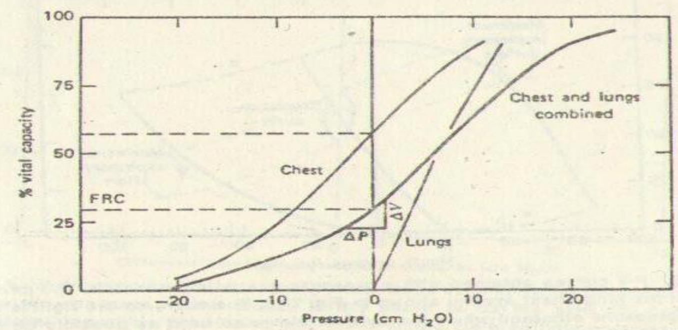

Figure 7.12. The *P-V* curves for the chest alone, the lungs alone, and the chest and lungs combined. The combined curve is the relaxation curve of Fig. 7.13. The slope of the combined curve $\Delta V/\Delta P$ gives the compliance of the lung-chest system. If the vital capacity is 5 liters, $\Delta V/\Delta P$ = 0.2 liter/cm H_2O. (Adapted from Hildebrandt, J., and Young, A.C., in T.C. Ruch and H.D. Patton (Eds.), *Physiology and Biophysics*, 19th ed., © W.B. Saunders Company, Philadelphia, 1965, p. 749.)

Fig. 7.10: the intrathoracic pressure plotted versus the lung volume during respiration for larger than average tidal volume.

Fig. 7.11:the P-V cuves for three different breathing rates :(a) very slow of about 3 breaths/min. (b) about 40 breaths/min. (c) maximum breathing rate of about 150 breaths/min.

Fig. 7.12: the P-V curves for the chest alone ,the lungs alone, and the chest and lungs combined. The slope of the combined curve ΔV/ΔP gives the compliance of the chest-lung system.

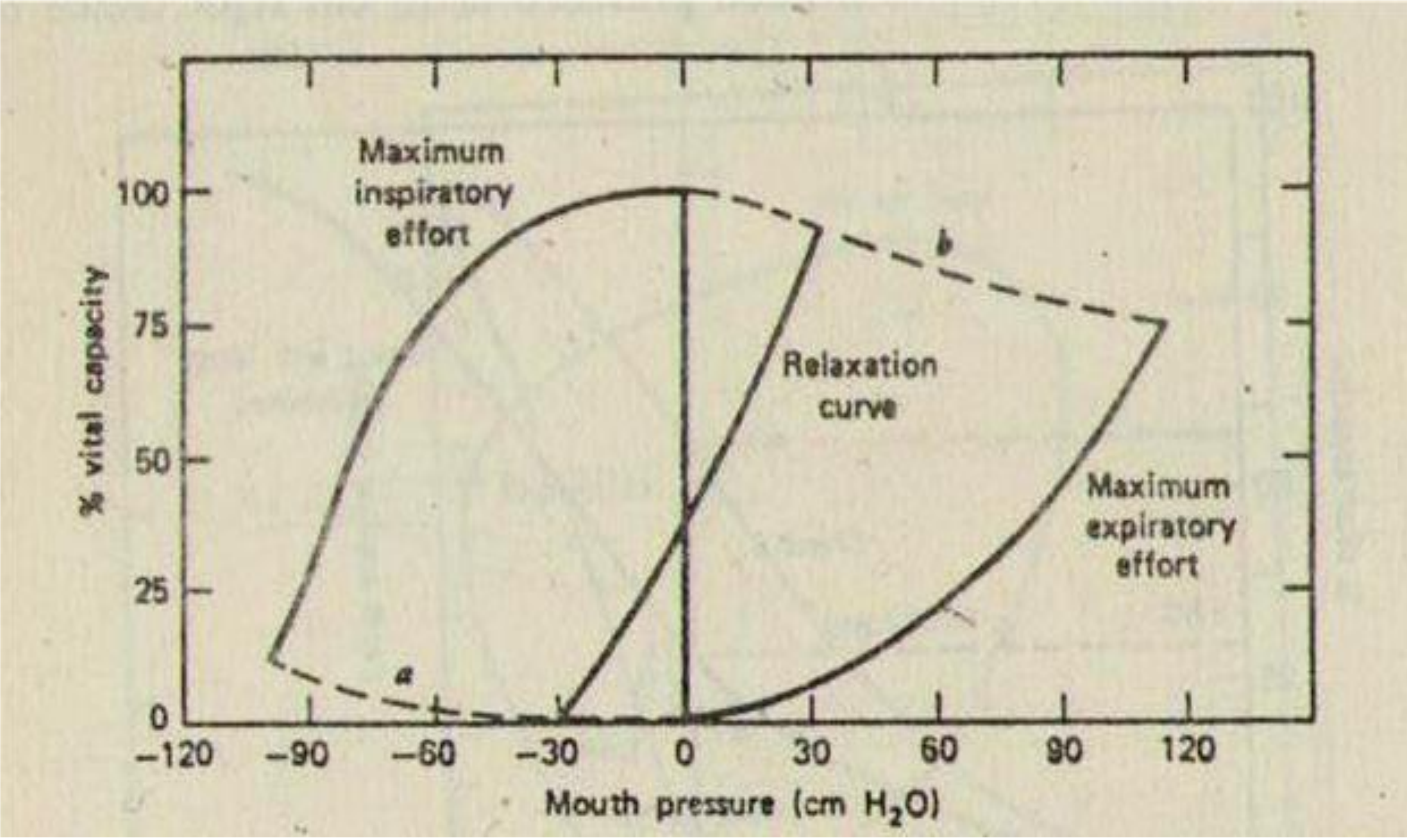

Fig. 7.13 : P-V curves obtained with a pressure gauge in the mouth , the dashed curves (a) and (b) are the theoretical curves for Boyles law PV= constant.

9 – Compliance (C) :

Is the change in volume produced by a small change in pressure.

$C = (\Delta V/\Delta P)$ L/cm H_2O

In normal adults (ΔV/ΔP) is in the range (0.18…0.27) L/cm H_2O.

Less than 0.18 is stiff lung or fibrotic lung .

More than 0.27 is flabby lung .

chest wall is at equilibrium at this volume, this pressure is produced by the elastic properties of the lung. When the same relaxation measurements are made after a forced exhalation the negative pressure values of Fig. 7.12 are obtained.

The relaxation pressure curve is again plotted as a function of the vital capacity in Fig. 7.13. In addition, two other related curves are shown. All of these pressures are measured in the mouth with the nose and mouth closed. Exhaling with the greatest force gives the maximum expiratory effort curve. Inhaling with maximum effort gives the maximum inspiratory effort curve. Forced expiratory effort after a maximum inspiration (100% of vital capacity) compresses the gas according to Boyle's law, PV = constant. The dashed lines *a* and *b* show the theoretical curves for the pressure-volume relationship of an ideal gas (PV = constant) at 0% and 100% of vital capacity.

Compliance is an important physical characteristic of the lungs. Compliance is the change in volume produced by a small change in pressure, that is, $\Delta V/\Delta P$ (see Fig. 7.12). Compliance is usually given in liters per centimeter of water. Compliance in normal adults is in the range of 0.18 to 0.27 liter/cm H_2O. It is generally about 25% greater in men over age 60 than in younger men. There is little change in women with age.

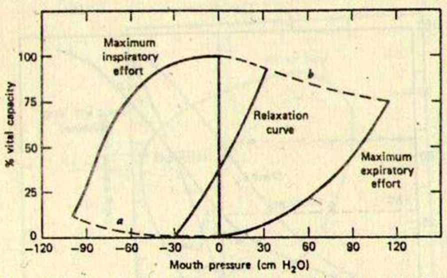

Figure 7.13. ***P-V*** **curves obtained with a pressure gauge in the mouth. The center curve is for the lung-chest system shown in Fig. 7.12. The curve on the right is the maximum pressure obtained when the subject blows as hard as possible on the gauge. The curve on the left is obtained by maximum suction. The dashed curves *a* and *b* are the theoretical curves for Boyle's law *PV* = constant. (Adapted from Hildebrandt, J., and Young, A.C., in T.C. Ruch and H.D. Patton (Eds.), *Physiology and Biophysics*, 19th ed., © W.B. Saunders Company, Philadelphia, 1965, p. 738, after Rahn et al., *Amer. J. Physiol.*, 146, 1946, pp. 161–178.)**

A stiff (fibrotic) lung has a small change in volume for a large pressure change and thus it has a low compliance. A flabby lung has a large change in volume for a small change in pressure and has a large compliance. Infants with respiratory distress syndrome (see Section 7.5) have lungs with low compliance. In some diseases, such as emphysema, the compliance increases (see Section 7.9).

During tidal breathing, the *P-V* curve forms a closed loop like those shown in Fig. 7.14. The cycles flow clockwise on the loops. The middle loop represents typical tidal breathing at normal pressure. Loop *b* represents positive pressure breathing where the air supply pressure is about 30 cm H_2O greater than the pressure on the chest wall. Positive pressure breathing is often used therapeutically in resuscitation and in relief of obstructive airway disease. For positive pressure breathing the inspiratory muscles are not used but the expiratory muscles are. Loop *c* in Fig. 7.14 represents negative pressure breathing. This can occur when a per-

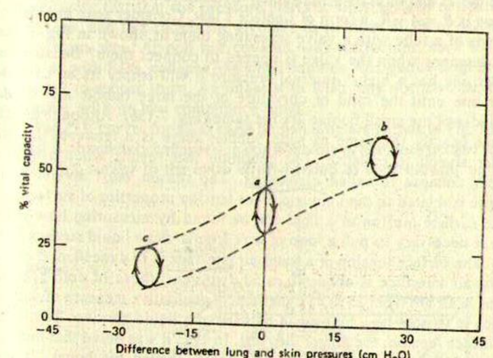

Figure 7.14. ***P-V*** **curves for tidal breathing under three conditions: (*a*) normal breathing where the pressure in the mouth is the same as on the skin, (*b*) positive pressure breathing with a tight-fitting face mask where the breathing muscles must work to expire, and (c) snorkel (underwater) breathing where the pressure on the chest is greater than in the mouth and the inspiratory muscles are under continuous tension. (Adapted from Hildebrandt, J., and Young, A.C., in T.C. Ruch and H.D. Patton (Eds.), *Physiology and Biophysics*, 19th ed., © W.B. Saunders Company, Philadelphia, 1965, p. 739, after Rahn et al., *Amer. J. Physiol.*, 146, 1946, pp. 161–178.)**

Fig. 7.13 : P-V curves obtained with a pressure gauge in the mouth , the dashed curves (a) and (b) are the theoretical curves for Boyles law PV= constant.

Fig. (7.14) see the difference between tidal breathing , positive pressure breathing and negative pressure breathing .

10 – Physics of alveoli :

- The alveoli are physically like millions of small interconnected bubbles.
- Surfactant : is a unique fluid lining in the alveoli, it is necessary for the lung to function properly.

RDS : respiratory distress syndrome is a case especially in new born infants (premature) characterized with the absence of the surfactant. (compliance is low).

Pressure-radius relationship:

To understand the physics of alveoli consider it like a bubble ,so :

Pressure (P)α 1/radius(R)

Pressure (P) α surface tension (γ)

P = 4γ/R ………a form of Laplace's law .

- There is a tendency for smaller alveoli to collapse.
- Atelectasis : a condition when a sizable number of alveoli collapse.
- The reason most alveoli don't collapse is related to unique surface tension properties of surfactant.

A qualitative measure of surface tension is to note how long small bubbles of a liquid survive. The lower the surface tension the longer they last.

Surface tension of the surfactant is not constant, surface tension γ decreases as the size of the alveoli decrease during expiration.

For each alveolus there is a size at which the surface tension decreases sufficiently fast that the pressure starts to drop instead of continuing to increase, so the alveolus stabilize at (1/4) its maximum size.

<u>Two forces keep the lungs from collapse</u> :

1. Surface tension between the lungs and the chest wall.
2. Air pressure inside the lungs.

The flow of air in the lungs is analogous to the flow of current in an electrical circuit :

Current flow	Air flow
Ohm's law $R = V/I$	$R_g = (\Delta P/V)$ cm $H_2O/(L/s)$
R : resistance	R_g : airway resistance
V : voltage	ΔP :pressure difference
I : current	V or ΔV/Δt :flow rate
Time constant for a capacitor RC to discharge through R.	Time constant for the lung R_gC, where C is the compliance.

11 – Work of breathing :

- The amount of work done in normal breathing accounts ~ 2% of the total energy consumed.
- Work of breathing is the work done in stretching the springs representing the lung-chest wall-diaphragm system.
- During normal breathing no work is done during expiration.

- The work of breathing during heavy exercise may amount to 25% of total energy consumption.
- The work done in breathing can be determined by the measurement of extra O_2 consumed as the breathing rate is increased under resting conditions.
- The amount of O_2 consumed is directly related to the calories of food burned.

12 – Some common lung diseases :

1. RDS : respiratory distress syndrome, in infants the case of the absence of the surfactant, low compliance.
2. Emphysema : the divisions between the alveoli breakdown, high compliance, increased R_g , increased FRC and increased RV.
3. Asthma : increased R_g , normal compliance and high FRC.
4. Fibrosis of the lungs : low compliance, normal R_g and low diffusion of O_2 .