Lecture 6

Synapse Mentor Event

Friday
5:30pm @Gerts
FREE PIZZA +
DRINKS

RELAY FOR LIFE

Canadian Cancer Society

Saturday
7pm-7am

Sign Up Online

(link in list serve)

NTCs

PULS OFFICE
McMed 1017

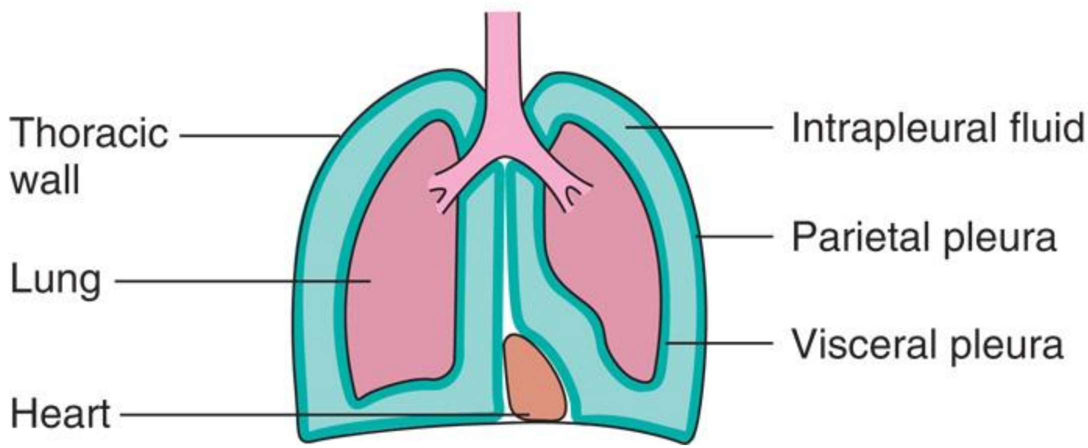
10:30am-2:30pm

$40

VII. MECHANICS OF THE VENTILATORY APPARATUS

A. Pleural Space

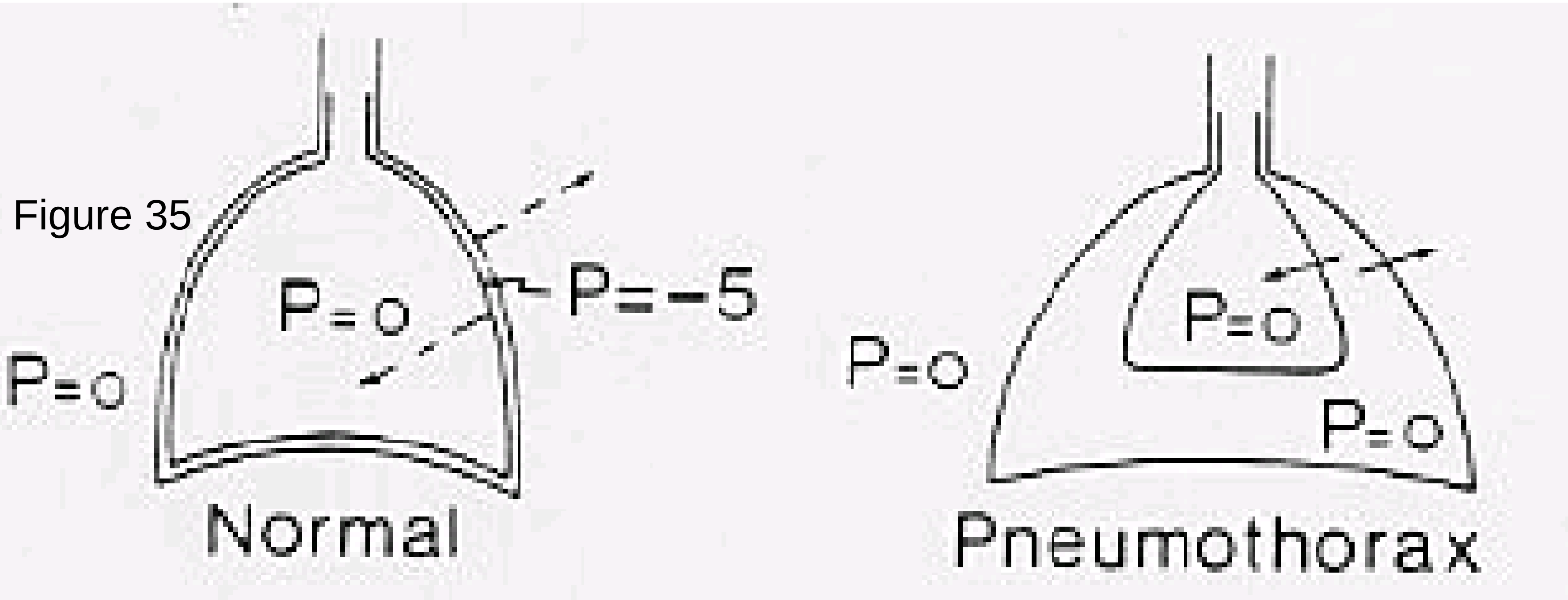
The lungs and the chest wall act in unison. Mechanically, the lung and chest wall operate in series with one another. However, the lungs are not directly attached to the chest wall.



Pleural Space (Cont'ed)

At rest, the pressure in the pleural space, the pleural pressure (Ppl), is negative. This is due to the opposing forces acting on the lung and chest wall. Indeed, if a hole is punctured through the chest wall (pneumothorax), the lungs collapse and the chest springs outwards.

Figure 35



Reproduced from West: Respiratory Physiology- the essentials.

B. Static Properties:

Elastic properties of the lungs and chest wall

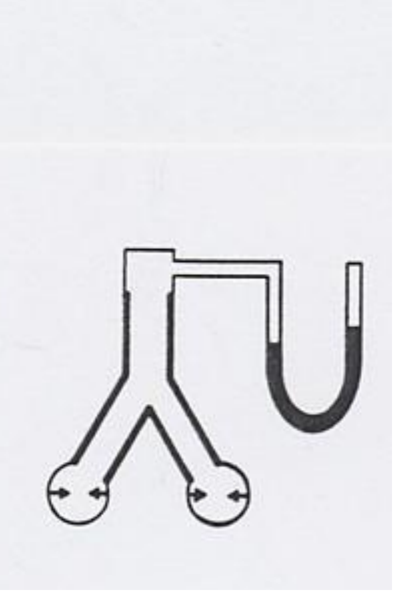
•To **evaluate the elastic properties** of the respiratory system (chest wall and lungs), we measure changes in the **recoil pressure** of each separate structure **for a given change in lung volume**.

•Lung **volumes** can be **measured** by **spirometry**.

•**Pressures** are **measured** using **manometers** or pressure transducers, referenced to atmospheric pressure.

•"**Negative pressure**" indicates a pressure **below atmospheric**, and "positive pressure" indicates a pressure above atmospheric pressure.

manometer



Elastic properties of the lungs and chest wall (Cont'ed)

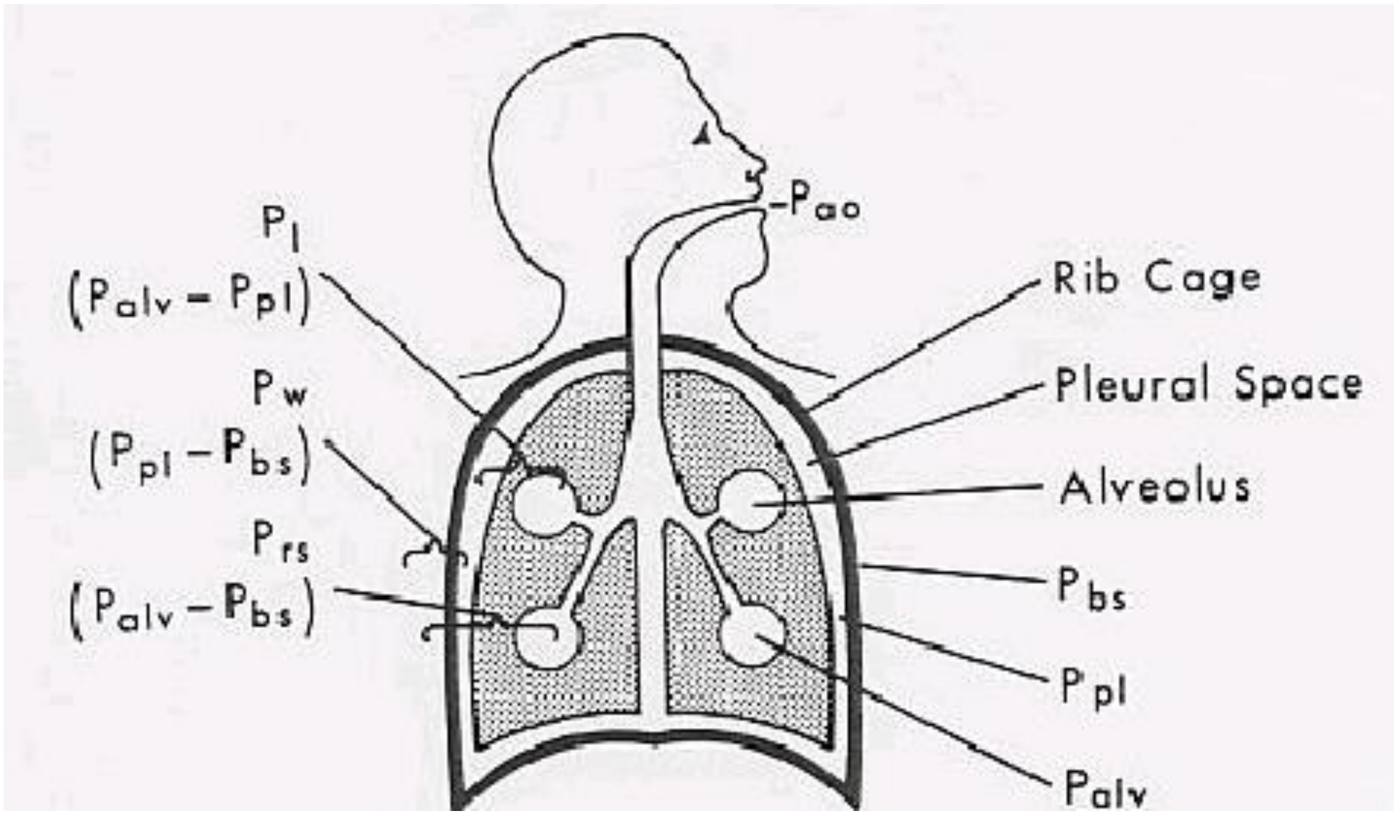
- Recoil pressure : pressure difference between the inside and outside (transmural pressure).

- Because the **esophagu**s is **located between the two pleural spaces**, esophageal pressure provides a **close approximation of Ppl**.

- Ppl can be **measured** using a flexible **balloon** introduced into the **esophagus**.

- The **body surface (bs)** is under **atmospheric pressure**.

Elastic properties of the lungs and chest wall



Reproduced from "The Normal Lung, Murray, 2nd ed. Saunders Company"

Note that in this static example, Pao= Pbs = Patm

C. Compliance

Compliance of the lungs:

•Compliance of the lungs, or chest wall, or total respiratory system, is a parameter that refers to the **ease** with which each of these structures can be distended.

$$\mathbf{C = \Delta V / \Delta P}$$

•The standard procedure for measuring the respiratory system compliance in humans is to determine the static pressure-volume relationship while lung volume is decreased step by step from TLC.

Static pressure-volume curve

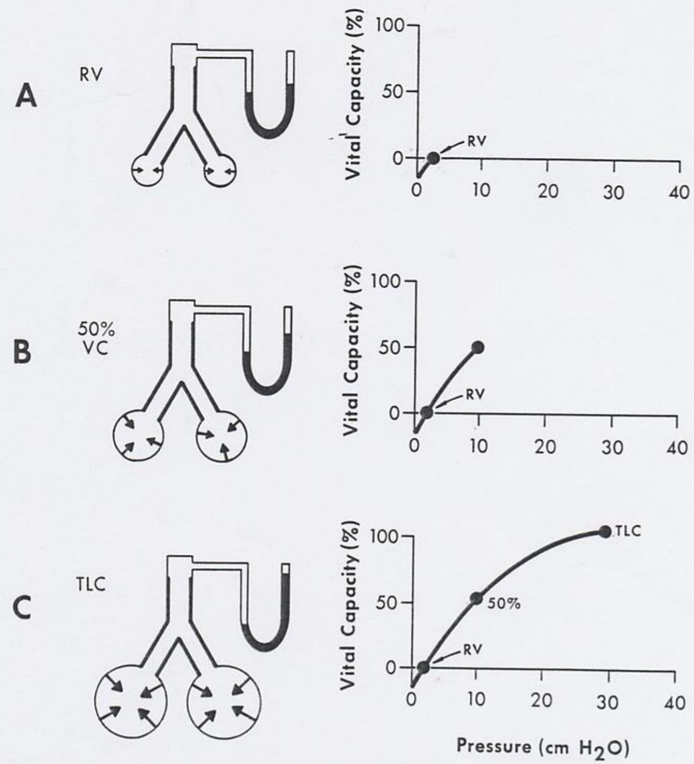


Figure 4–2. Schematic representation of the volume-pressure relationships of isolated lungs. *A*, Because excised lungs collapse to less than residual volume (RV), at RV a small recoil pressure (small arrows facing inward) is evident; this pressure is reflected in the slight deflection of the column in the manometer and the value on the horizontal (pressure) axis. *B*, At 50 per cent vital capacity (VC), the recoil pressure is increased (more and larger arrows than in *A*); thus more pressure is reflected in the manometer and on the horizontal axis. *C*, At total lung capacity (TLC), recoil pressure is maximal (normally about 30 cm H_2O).

Compliance

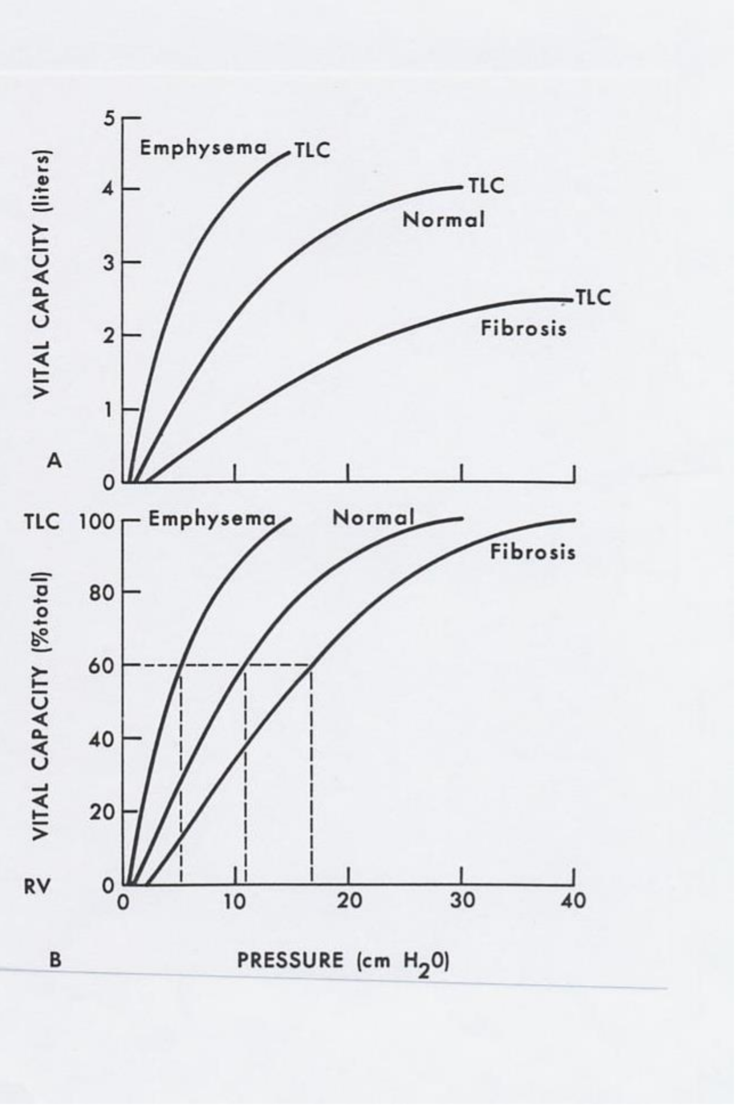
- Compliance is expressed as the volume change in the lungs for a unitary change in pressure, i.e. the slope of the pressure-volume curve.

$$Cl = \Delta V / (\Delta Palv - \Delta Ppl)$$

- The pressure required to maintain a given volume of gas inside the lungs increases as the volume increases, i.e. the slope decreases with increases in lung volume.

- Compliance of the lungs is also altered in diseases such emphysema and fibrosis.

Compliance



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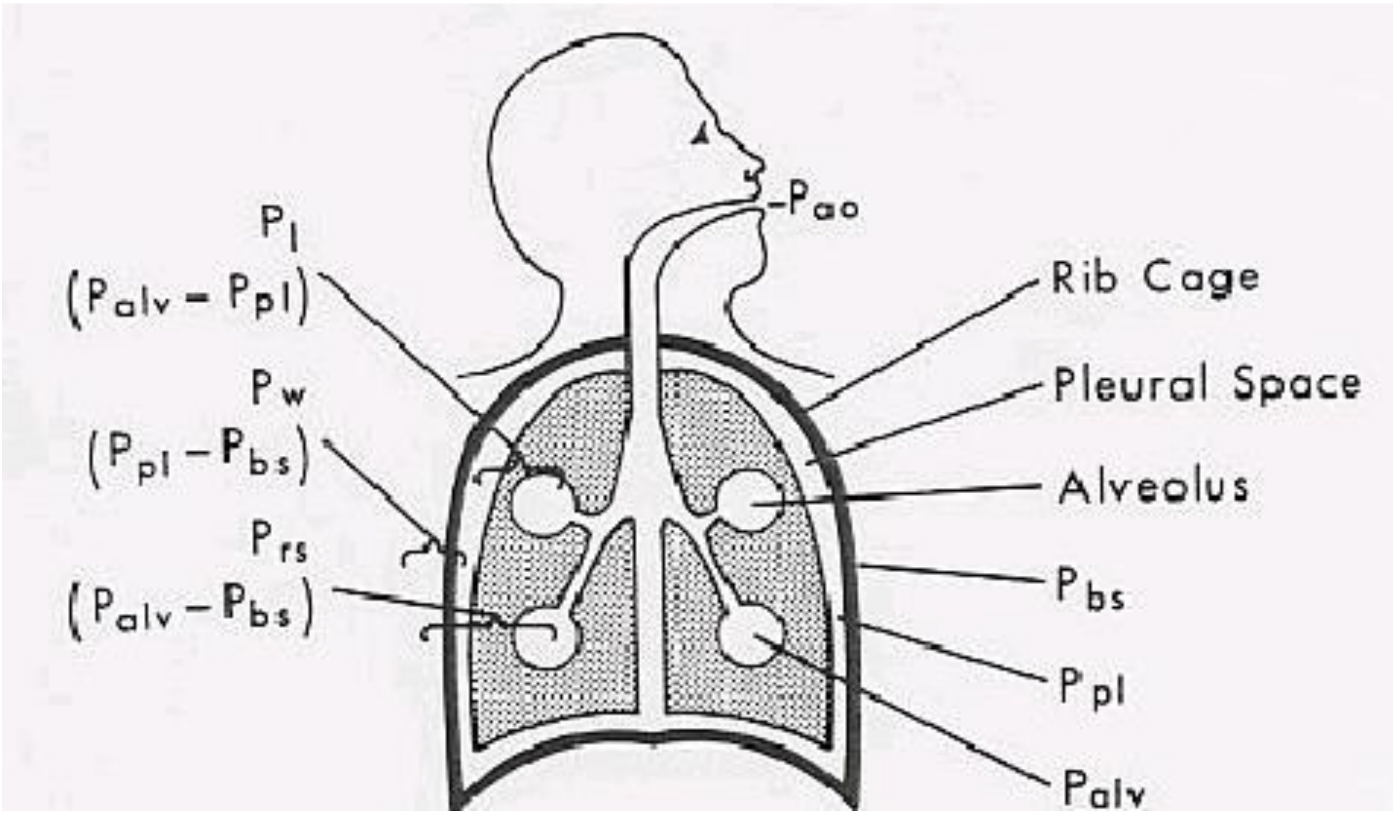
Compliance vs Elastance

- **Elastance= 1/compliance**

Compliance of the chest wall

- The tissues of the chest wall also have elastic properties that cause it to recoil either inward or outward, depending on its volume.

Elastic properties of the lungs and chest wall



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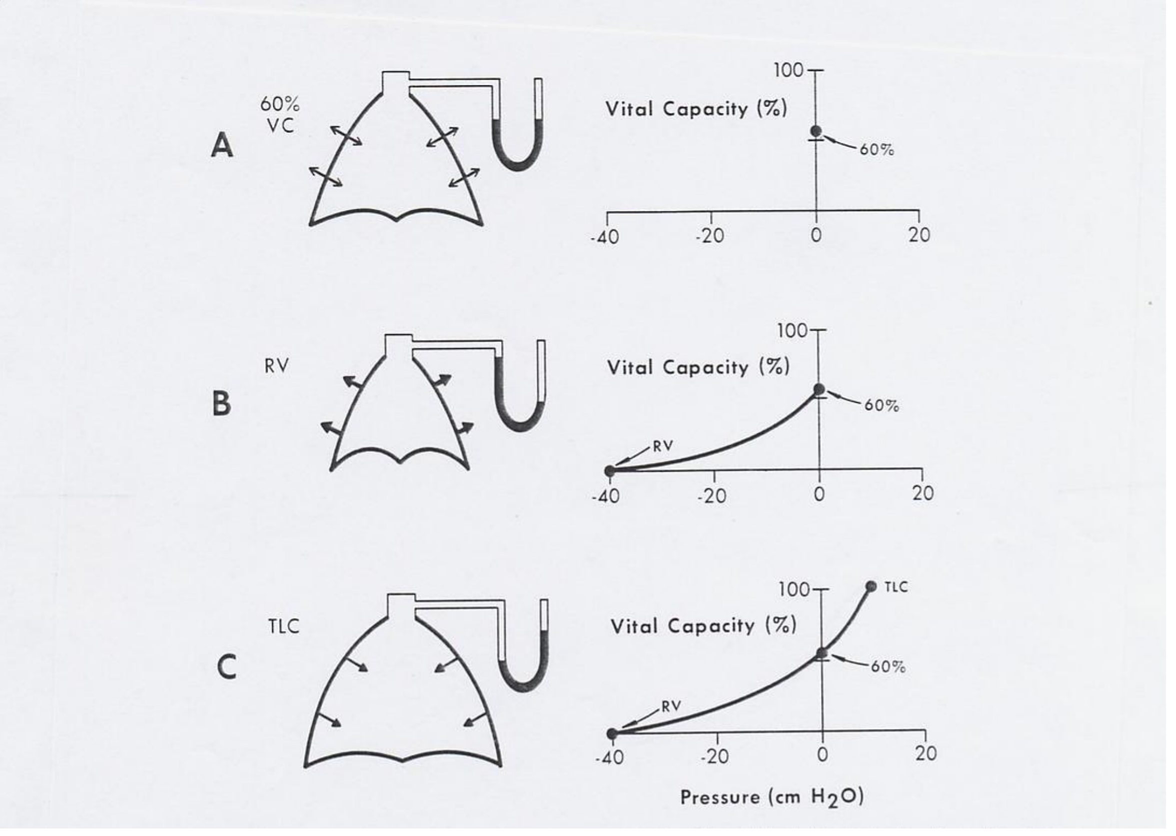
Compliance of the chest wall



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Compliance of the chest wall

The compliance of the chest wall is defined in terms of a change in thoracic volume ΔV (the change in volume of the thorax is the same as the change in volume of the lungs) and a change in pressure across the chest wall, ΔPpl.

Thus,

$$Cw = \Delta V / \Delta Ppl$$

Compliance of the respiratory system:

The pressure drop across the respiratory system:

Prs: Palv-Pbs

where Palv= Pl+Ppl and Pbs= Ppl-Pw

So Prs= Pl+Ppl-Ppl+Pw
=Pl+Pw

or

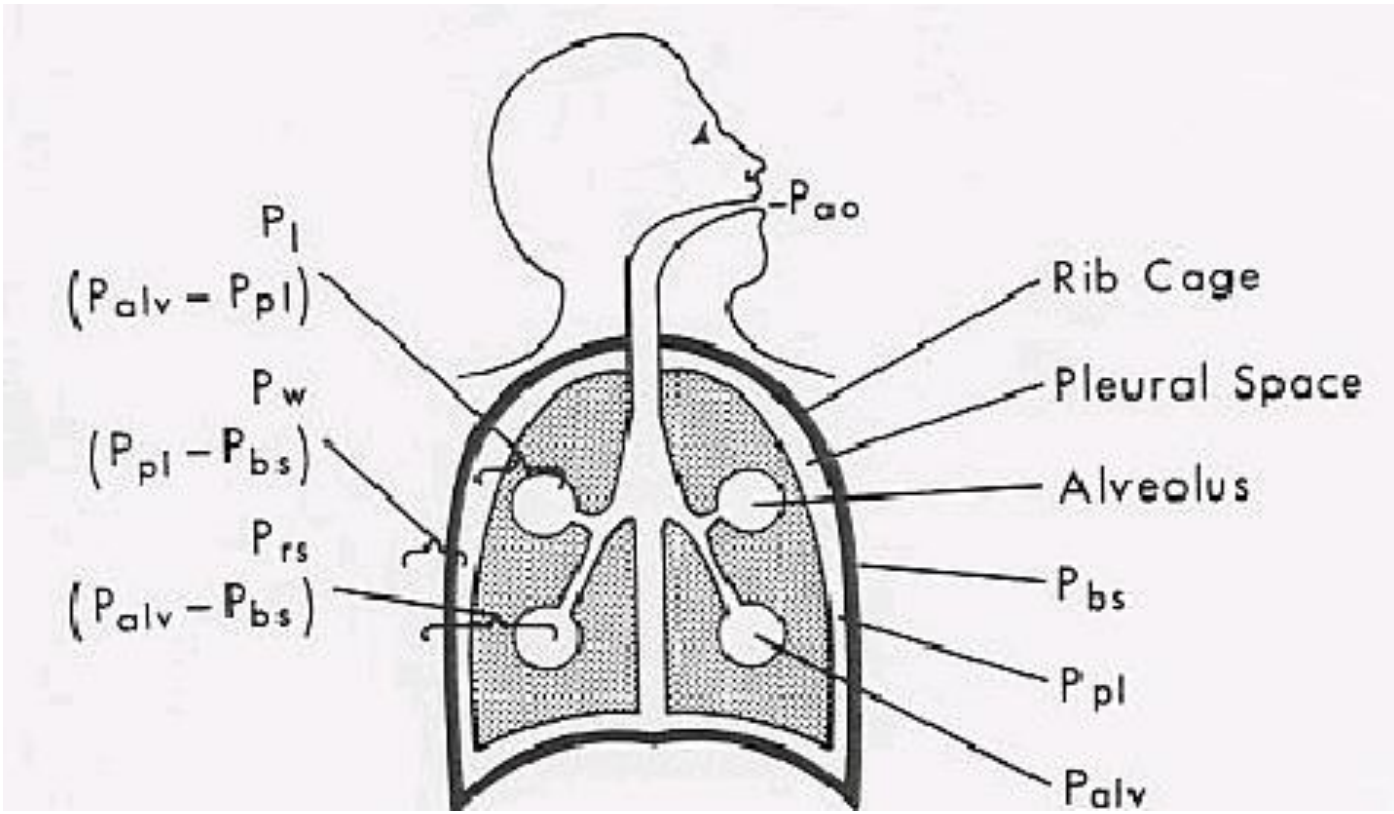
Prs is equal to the sum of the pressure drop across the lung and across the chest wall. Therefore, the compliance of the respiratory system, Crs, is related to the compliances of the lung and chest wall by

$Crs = \Delta V / \Delta Prs$

$Crs = \Delta V / \Delta(Pl+Pw)$

$1/Crs = 1/Cl + 1/Cw$

Elastic properties of the lungs and chest wall



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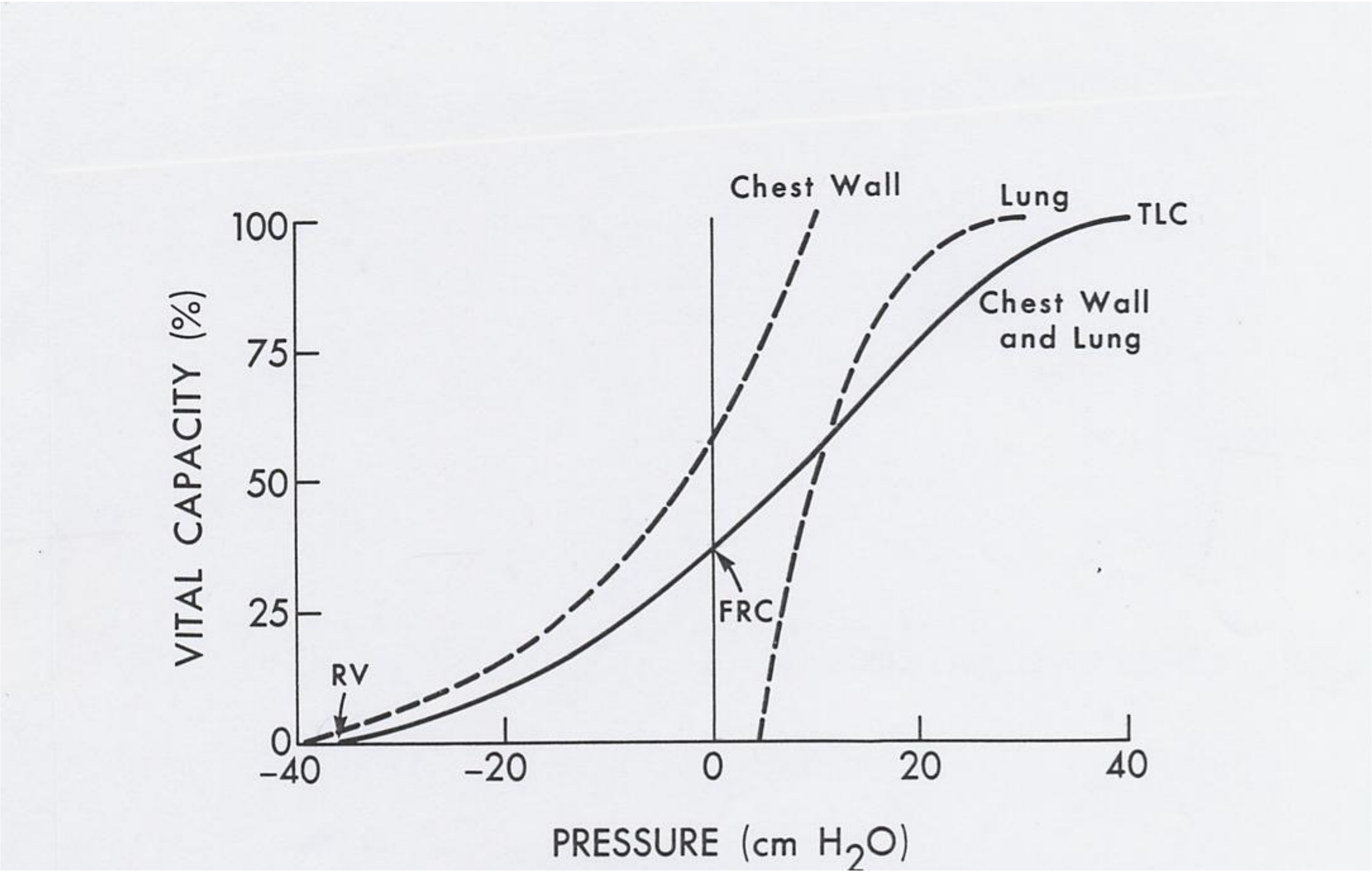
Volume-pressure relationships of chest wall and lung combined (solide line).



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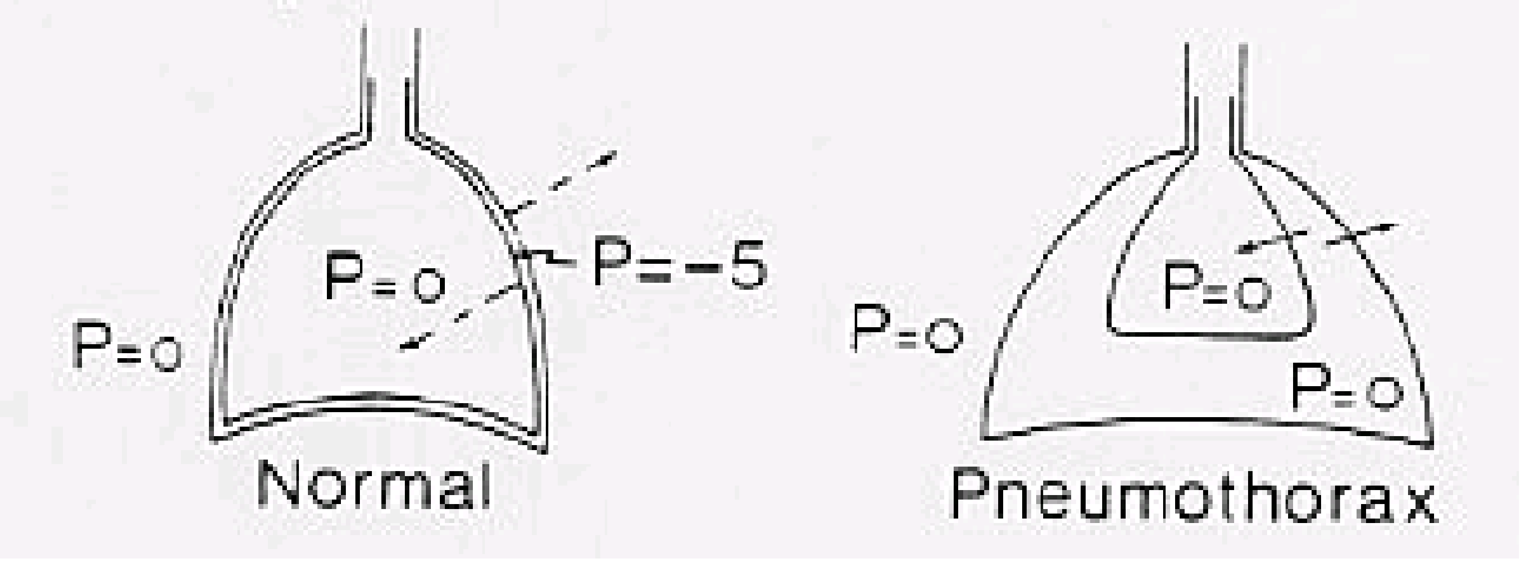
FRC

At FRC, Prs is zero because the system is at rest. This stable condition is caused by the inward recoil of the lungs (Pl is about +5 cmH_2O) which is balanced by the outward recoil of the chest wall (Pcw is about -5 cm H_2O). This means that, at FRC, the lungs are above their resting volume and the chest is below its resting volume (recall the concept of the pneumothorax).

Pneumothorax

The elastic properties of the respiratory system are best illustrated by what happens when the chest is opened during thoracic surgery, i.e. a pneumothorax. Air enters the pleural space because Ppl is less than atmospheric pressure. The lungs collapse to its resting position below RV, and the chest wall expands towards its resting position, at about 75% of total lung capacity. A traumatic or spontaneous pneumothorax may be a life-threatening emergency since the lungs are uncoupled from the chest wall.



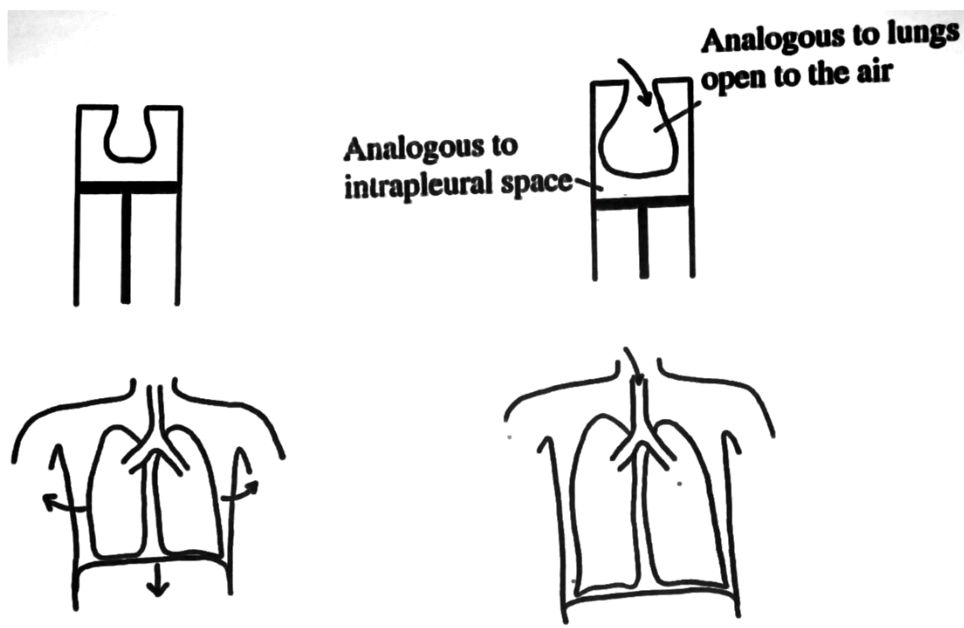
Lecture 7

D. Dynamics of a breath

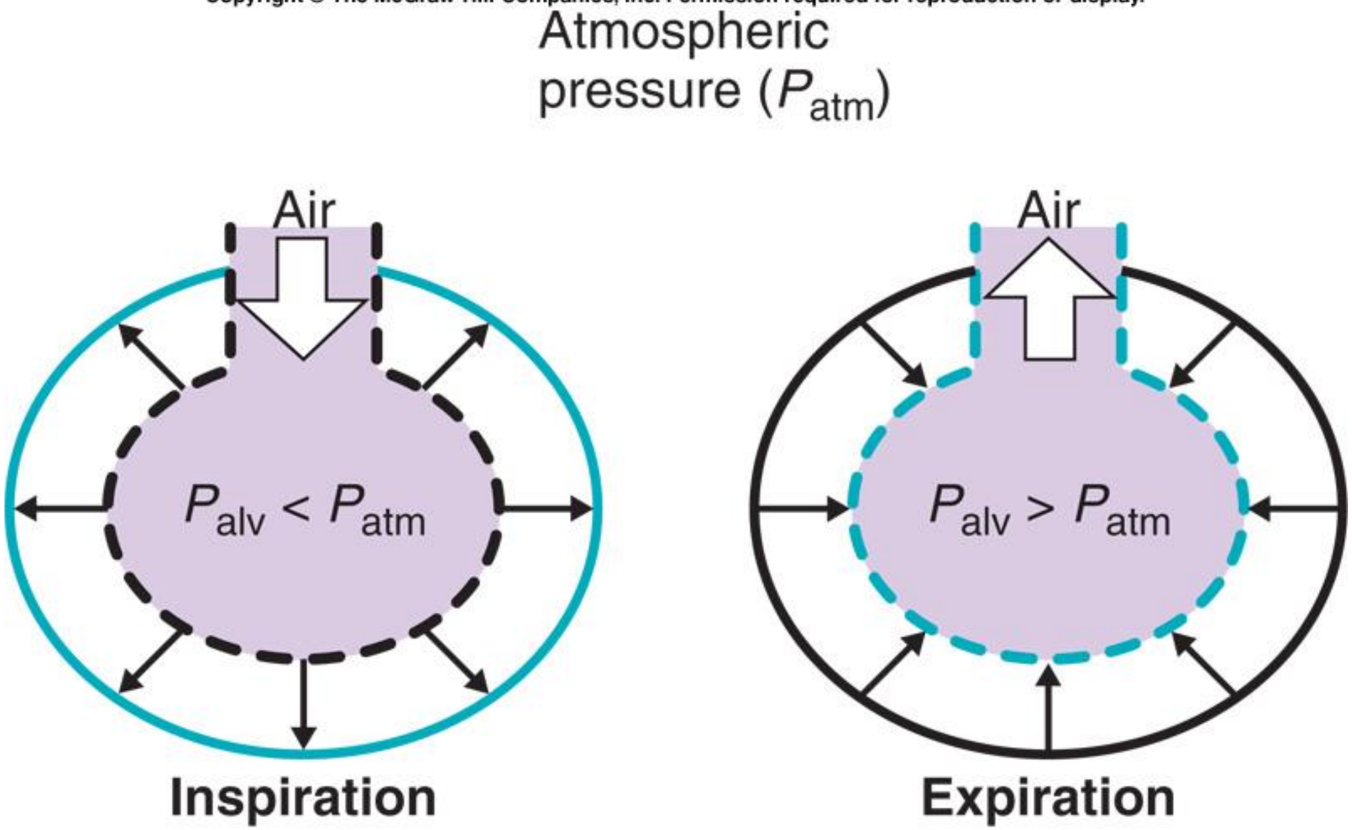
- The respiratory system may be regarded as a pump with elastic and flow-resistive properties.

- At rest, the lungs are at FRC and Ppl is negative due to the opposite forces acting on the lungs and chest wall.

- During inspiration, the diaphragm contracts and the chest wall is pulled open. This creates a more negative Ppl that causes expansion of the lungs.



Dynamics of a breath



Flow=

$$F = \frac{P_{alv} - P_{atm}}{R}$$

Dynamics of a breath

- As the lungs are pulled further away from their resting position (below RV), Ppl becomes even more subatmospheric.

- As the volume of the lungs is increased, gas in the lungs is decompressed. Palv drops below atmospheric pressure.

- The created negative pressure gradient between the alveoli and atmosphere generates air flow to the lungs.

- As inspiration proceeds, the lungs are filling up with air, and the pressure gradient and the air flow gradually decrease. At the end of inspiration air flow stops because Palv is equal to Patm (no pressure gradient).

Dynamics of a breath

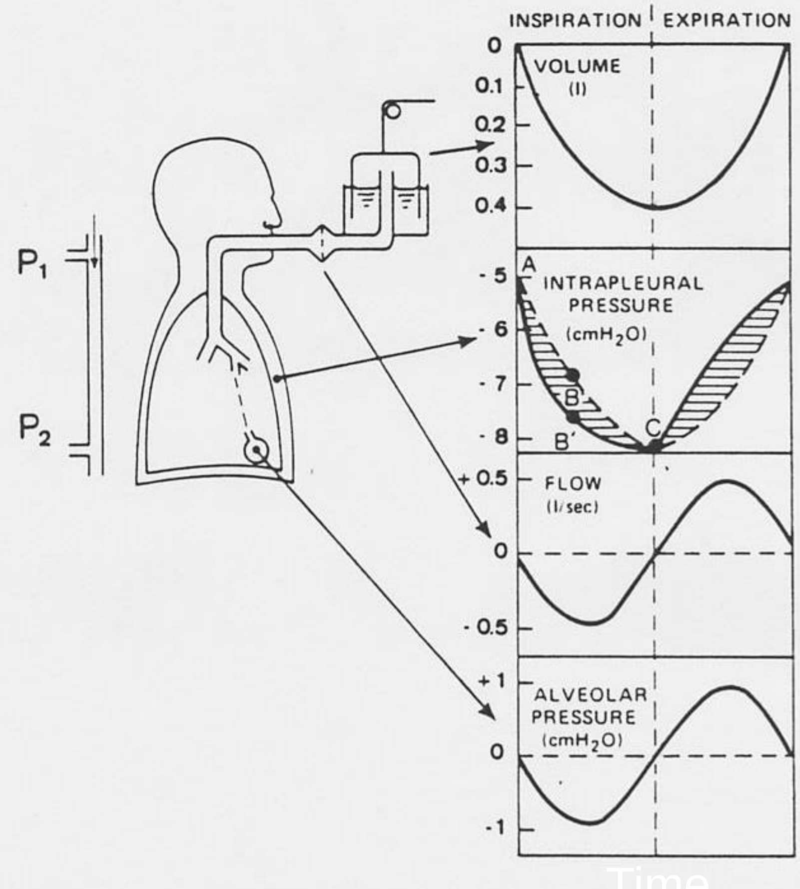


Figure 7.13. Pressures during the breathing cycle. If there were no airway resistance, alveolar pressure would remain at zero, and intrapleural pressure would follow the *broken line ABC,* which is determined by the elastic recoil of the lung. Airway (and tissue) resistance contributes the *hatched portion* of intrapleural pressure (see text).

(Reproduced from West: Respiratory Physiology- the essentials).

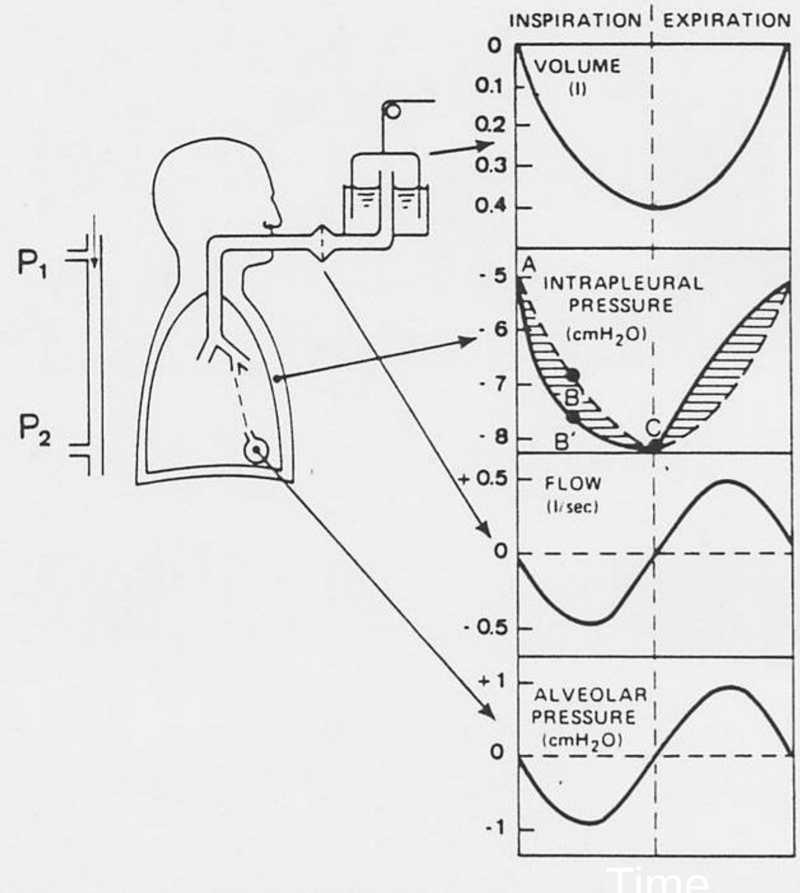
Dynamics of a breath

- At the onset of expiration, the diaphragm relaxes, elastic recoil of the respiratory system compresses the gas in the lungs, and Palv increases.

- The positive pressure gradient between the atmosphere and the lungs is reversed and air from the lungs is pushed out to the atmosphere.

- As lung volume decreases, Ppl slowly returns to its resting level. At the end of expiration, i.e. at FRC, air flow=0 ml/s and Palv=0 cmH_2O, and Ppl is about -5 cmH_20.

Dynamics of a breath



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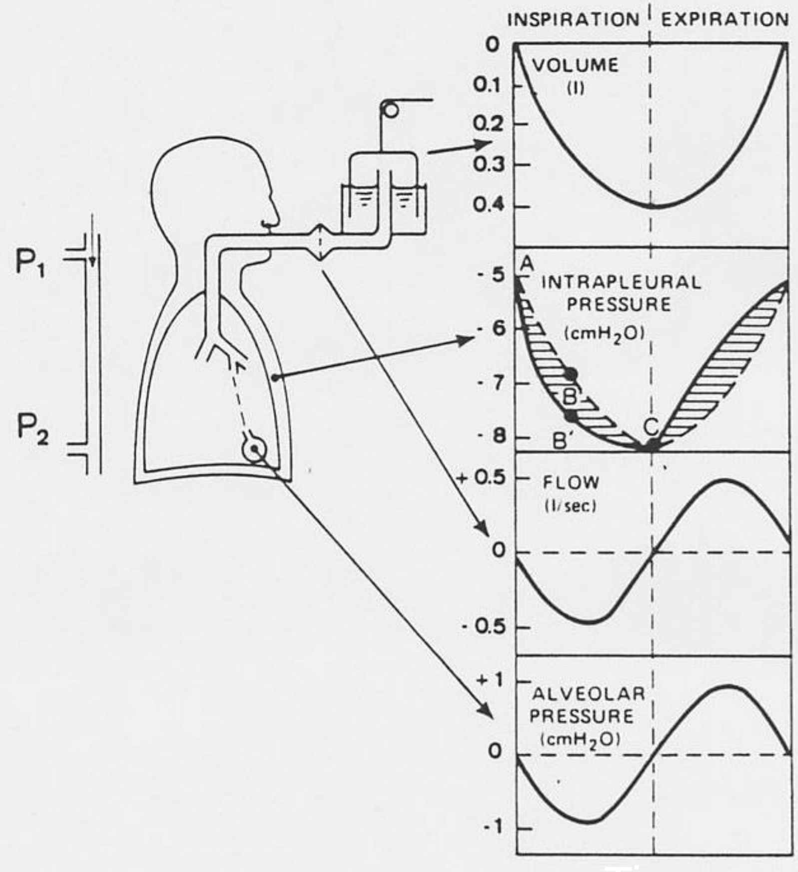
Dynamics of a breath

- The time course of changes in pleural pressure during inspiration and expiration depends on contraction of the diaphragm and airway resistance.

- The hatched area in the graph shows the amount of pleural pressure necessary to overcome airway (and tissue) resistance.

Dynamics of a breath



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E. Airway Resistance

•To have gas flow through the airways, Pao must be different from Palv.

•The resistance of the airways to gas flow (Raw) is the ratio of this pressure difference and the flow.

$$\mathbf{Raw = (Palv - Pao)/Flow}$$

where flow is equal to a change in volume per unit of time.

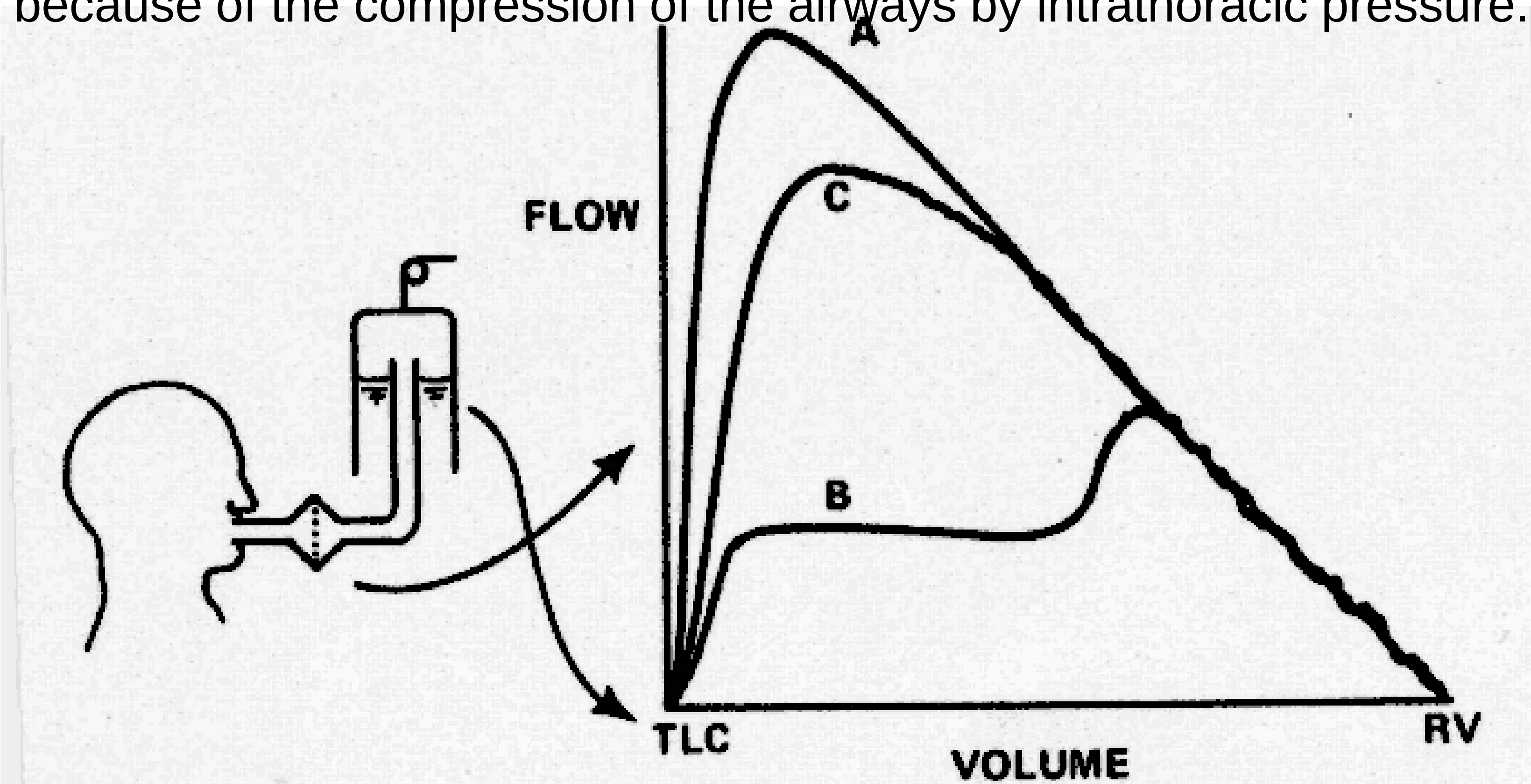
•A large diameter airway can carry a large flow for a given pressure difference and so has a smaller resistance than a small diameter airway.

•Airway resistance is therefore related to airway caliber and is an important determinant of lung function. In certain diseases (such as asthma) airway resistance can become very high making breathing difficult.

Dynamic compression of airways

- When a subject inspires to TLC and exhales to RV, during expiration, flow rises very rapidly to a high value and then declines over the rest of expiration.

- The descending portion of the flow-volume curve is independent of effort because of the compression of the airways by intrathoracic pressure.



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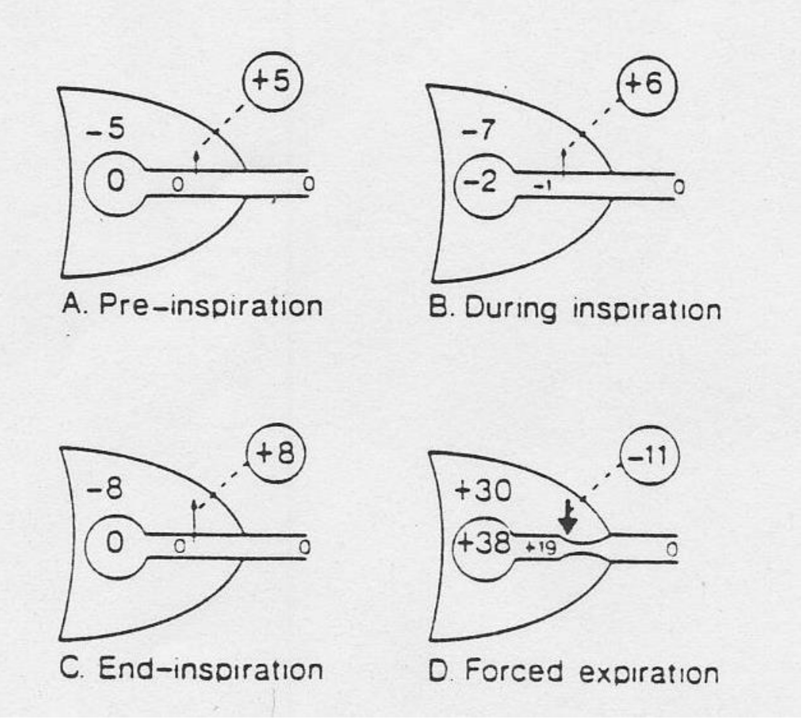
Forced expiration



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A) Before inspiration, Paw is 0 and Ppl is -5cm H_2O.
B) During inspiration, Ppl and Paw fall.
C) At the end of inspiration, Paw is 0 and the airway transmural pressure is 8cm H_2O.
D) During forced expiration, Ppl and Palv are increased.

Because of the pressure drop along the airways as flow begins, there is a point at which there is a positive pressure tending to close the airways.

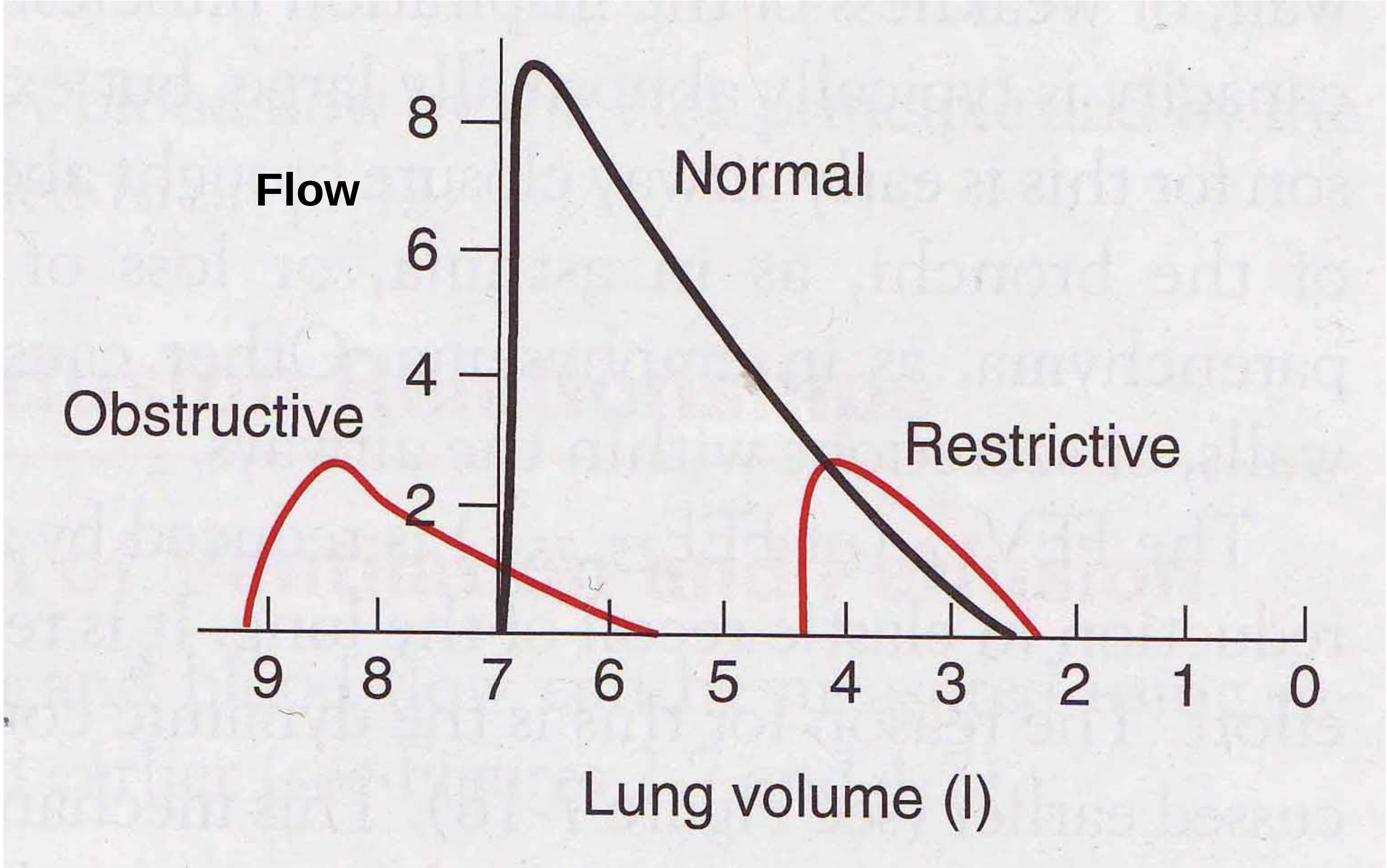

Figure 44b. In restrictive diseases (e.g. pulmonary fibrosis), the maximum flow rate and maximum volume exhaled are reduced. In obstructive diseases (e.g. emphysema), the flow rate is very low and a scooped out appearance is often seen. *(Reproduced from West: Respiratory Physiology- the essentials).*