MECHANICS OF BREATHING

NORMAL BREATHING

How Do We Breath?

- Inspiration is normally active
- Expiration is normally passive.

Muscles of Respiration

- Inspiratory muscles
  - Diaphragm.
  - External intercostals.
  - Accessory muscles.
    - Include sternomastoids, scalene muscles, and alae nasi.
- Expiratory muscles
  - Abdominal muscles.
  - Internal intercostals.

Figure 1: Respiratory Pressures

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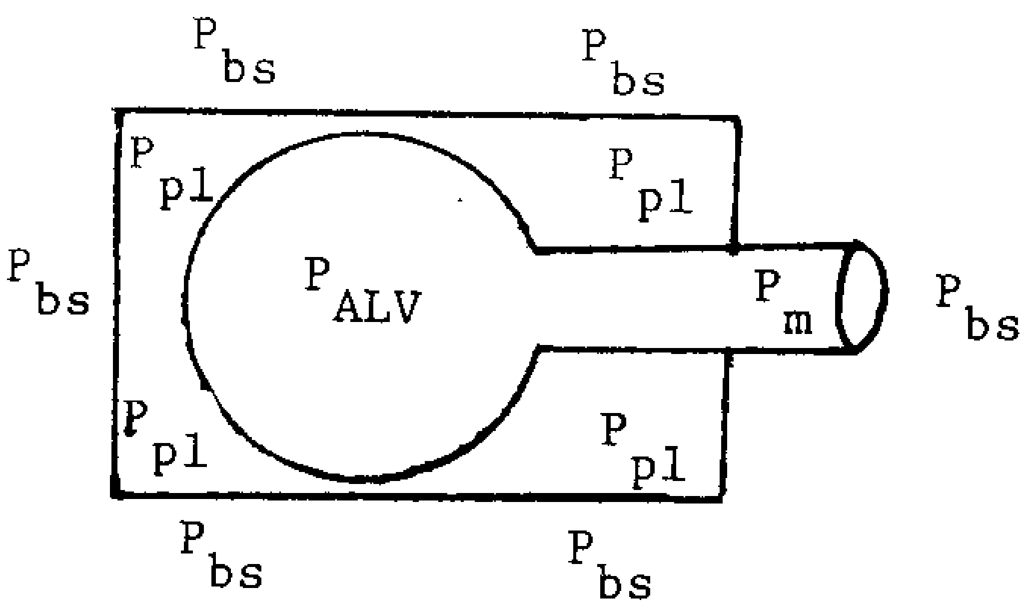


Important Respiratory Pressure Differences.

- **Airway pressure gradient:**

  $P_M - P_{ALV}$.

- **Transpulmonary pressure:**

  $P_{TP} = P_{ALV} - P_{Pl}$

- **Transchest wall pressure:**

  $P_{TC} = P_{Pl} - P_{bs}$

- **Transmural respiratory system pressure:**

  $P_{RS} = P_{ALV} - P_{bs}$

Balance of Static Forces

Increase <u>to</u> Inflate | **Increase <u>with</u> Inflation**

$$P_{RS} + P_{MUS} = P_{L} + P_{CW}$$

$$\uparrow P_{ALV} - P_{bs} \downarrow + \uparrow P_{MUS} = P_{L} + P_{CW}$$

	inspiratory muscle contraction	Lung elastic recoil	+	Chest wall elastic recoil

Outward Acting forces when positive

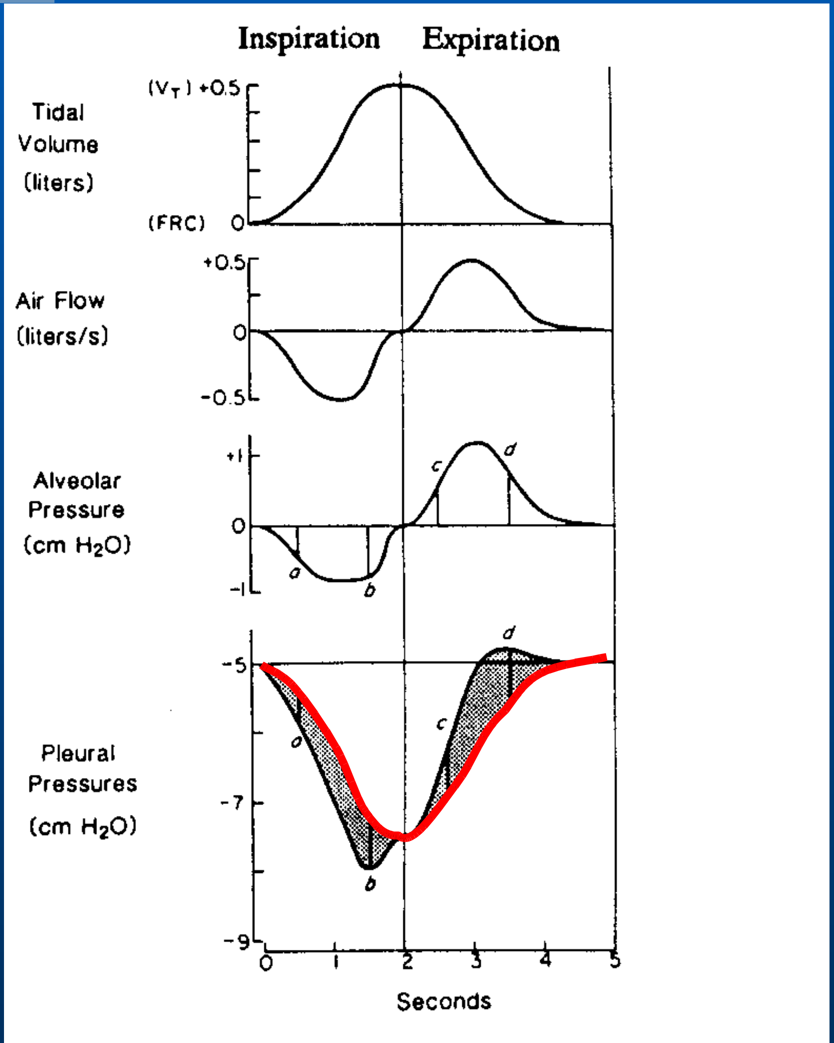
Inward acting forces when positive

Three Ways to Inflate the Lungs

- Increase alveolar pressure
  - Positive pressure respirators.
- Decrease body surface pressure
  - “Iron lungs”
- Activate inspiratory muscles
  - Normal way to breath.

Inflation Dynamics

- Transmural pressure must overcome:
  - Elastic recoil forces
  - Airway resistance to flow.

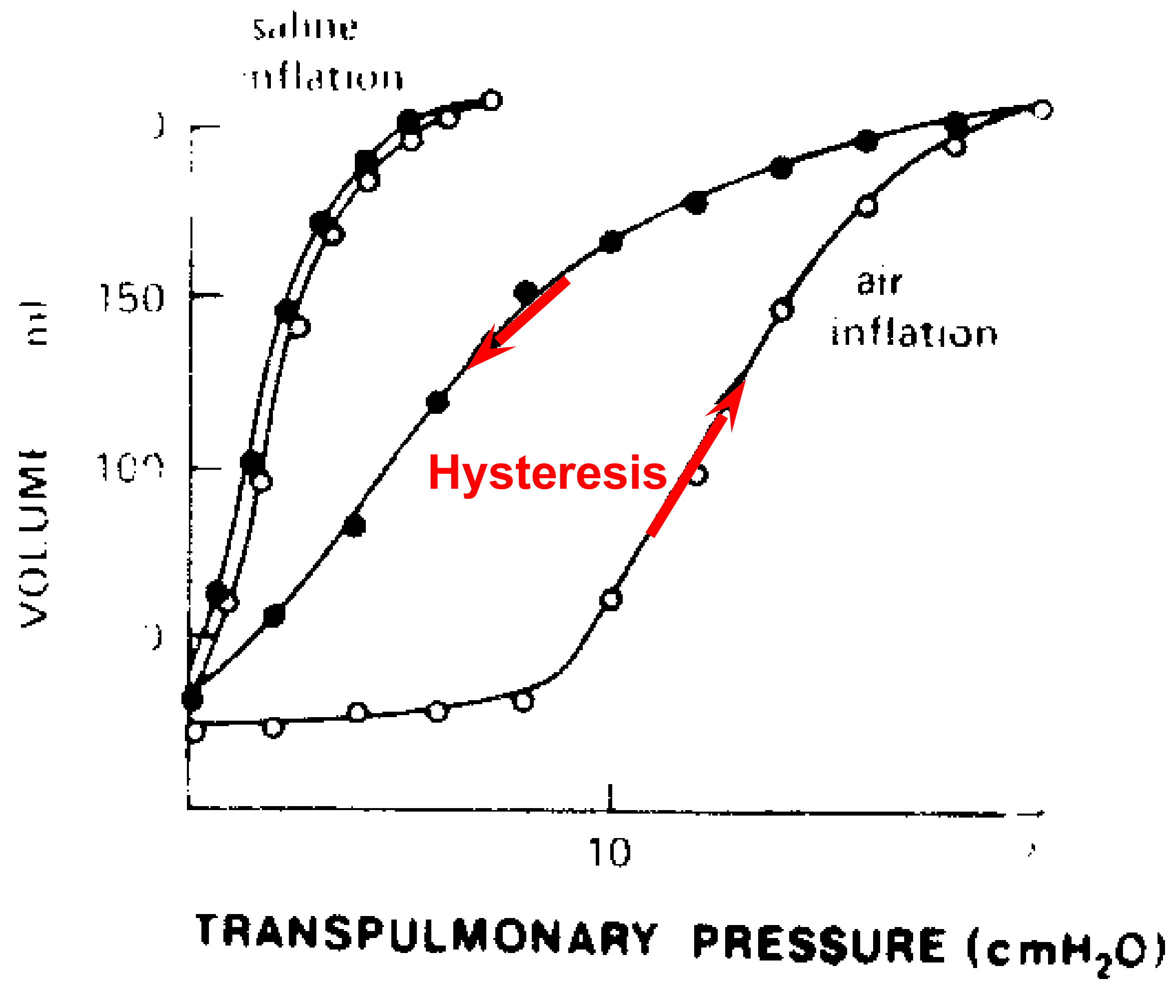


MECHANICS OF BREATHING

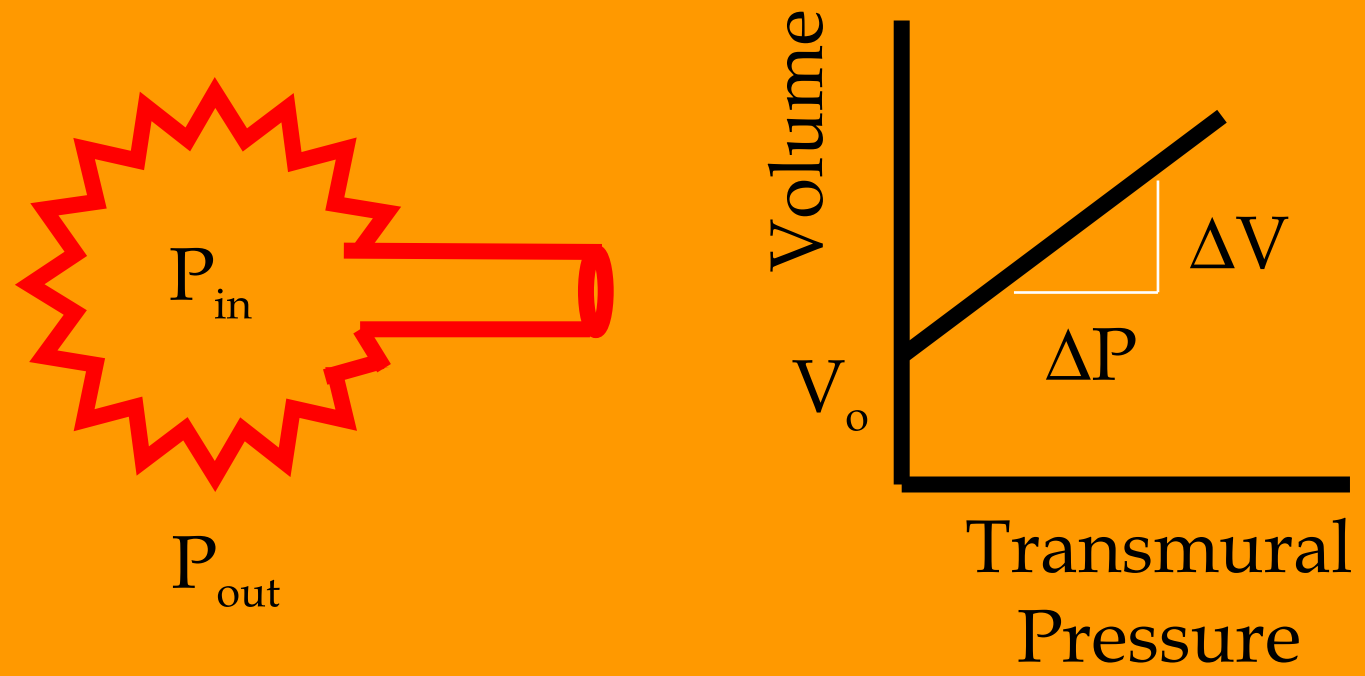
Part 2

ELASTIC CHARACTERISTICS OF THE LUNG

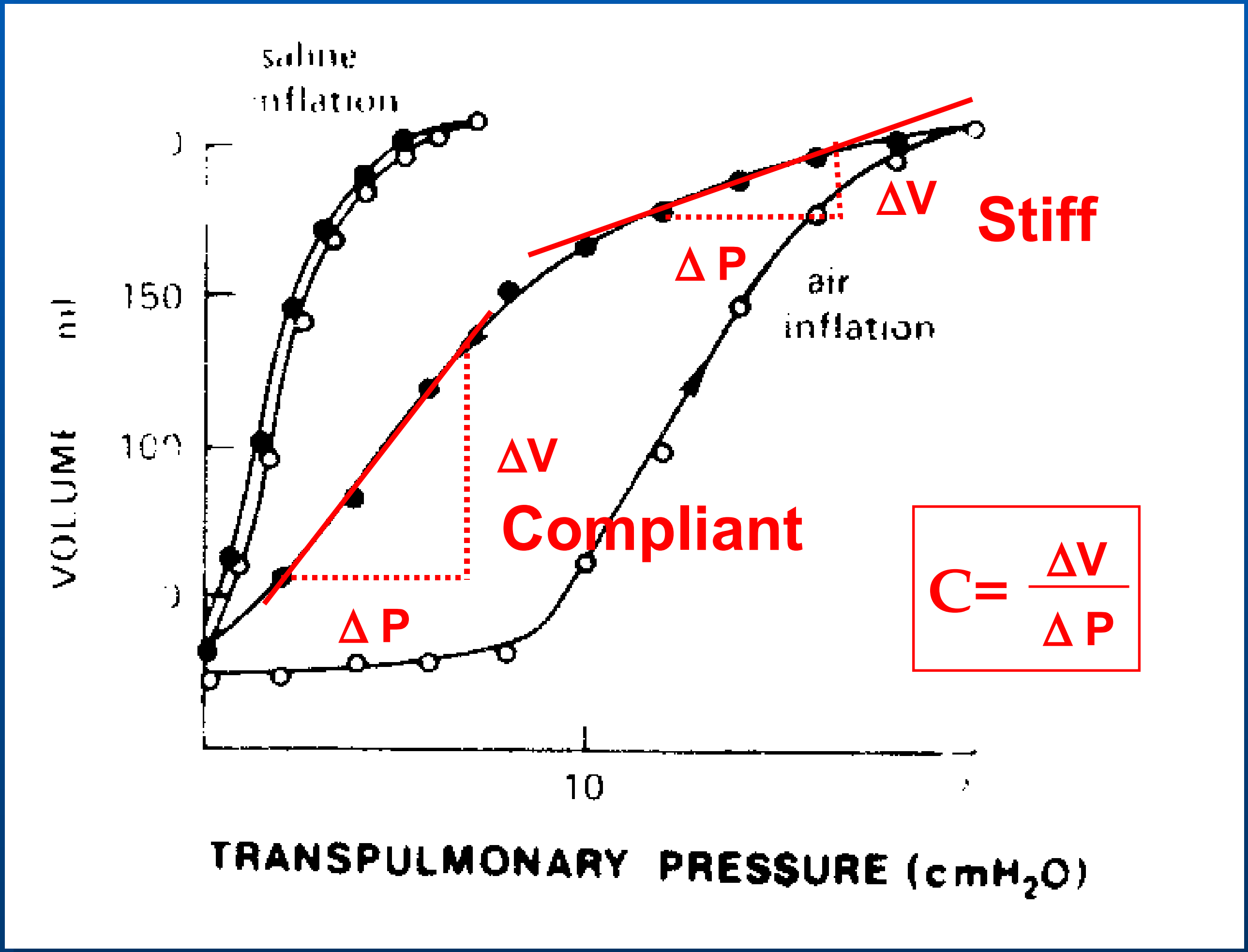
Inflation Hysteresis



Compliance



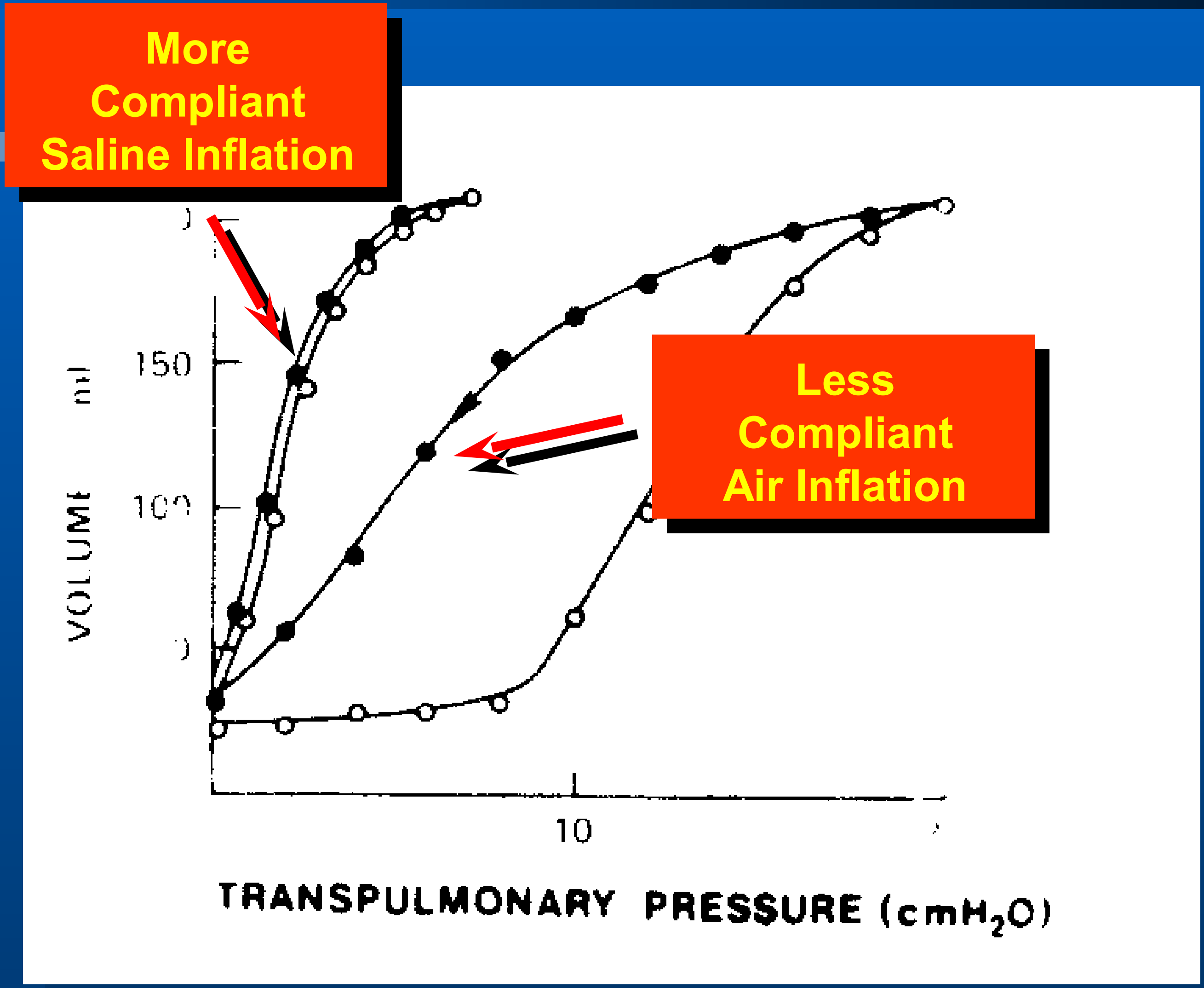
Lung Compliance vs. Volume



Two Major Forces affect Lung Compliance

- **Tissue elastic forces**
- **Surface tension forces.**

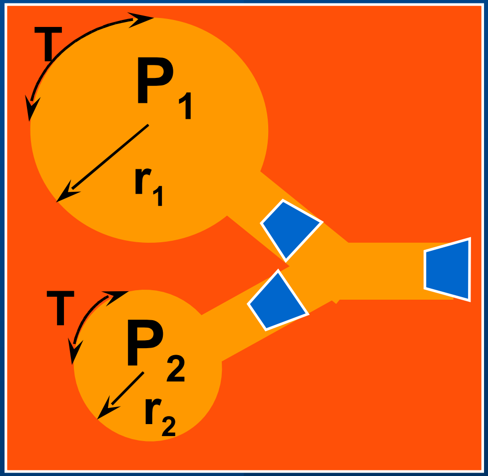
Air vs. Saline Inflation



Surface Tension.

- At every <u>gas-liquid interface</u> surface tension develops.
- Surface Tension is a liquid property
- LaPlace's Law:

$$P = \frac{2 \cdot T}{r}$$



$$T = \frac{P_1 \cdot r_1}{2} = \frac{P_2 \cdot r_2}{2}$$

If $r_1 > r_2$ Then, $P_2 > P_1$

<u>Result</u>: Small Bubble Collapses

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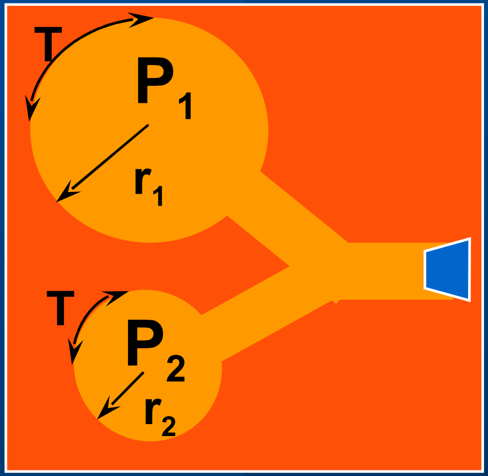

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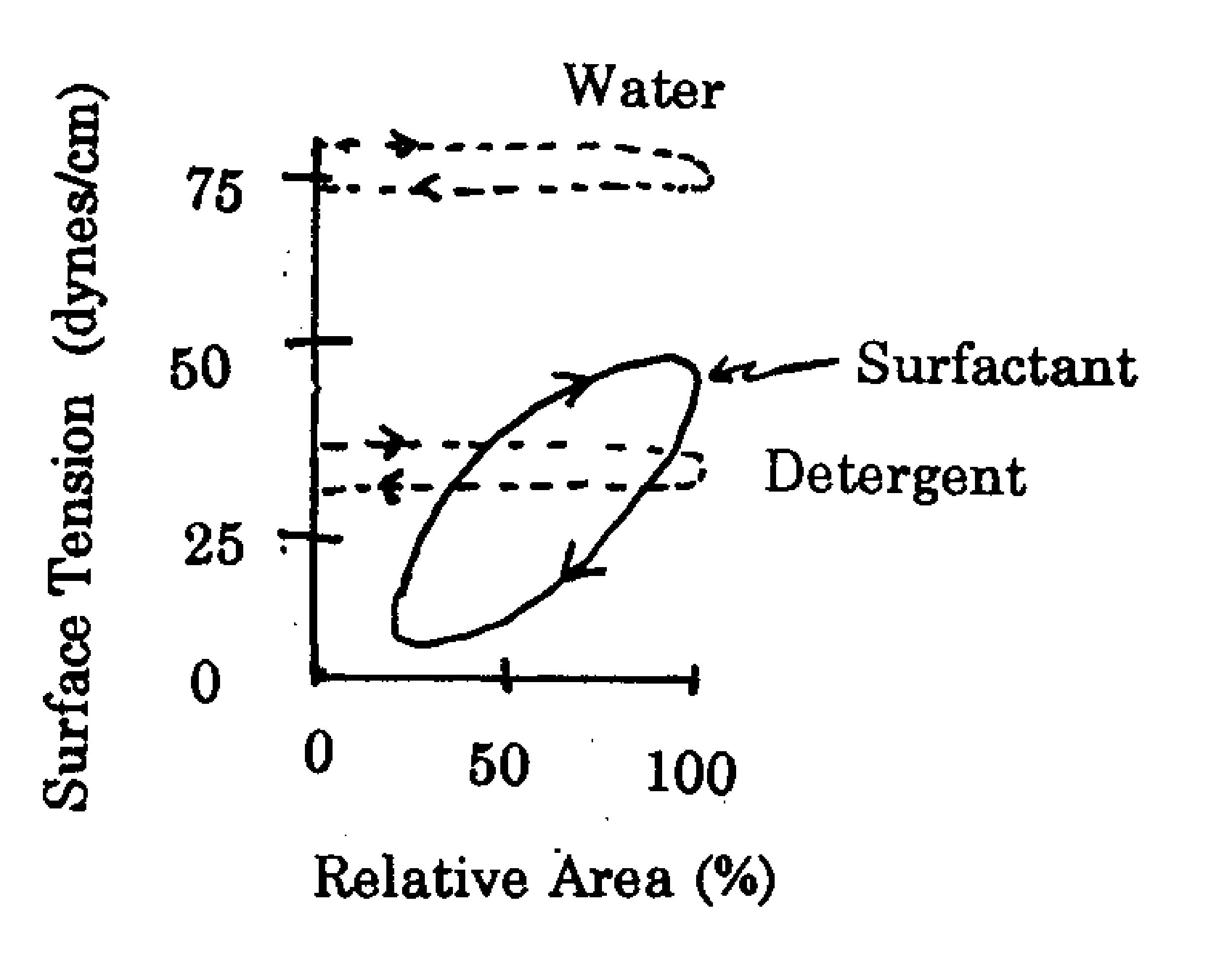
<u>Result</u>: Small Bubble Collapses

Surfactant

- Secreted by Type II alveolar cells
- Dipalmitoyl phosphatidyl choline
- Lines alveoli
- Unique surface tension properties:
  - Average surface tension low.
  - Surface tension varies with area:
    - Surface tension rises as area gets bigger
    - Surface tension falls as area gets smaller.

Figure 4: Surfactant



Physiological Importance of Surfactant

- Increases lung compliance (less stiff)
- Promotes alveolar stability and prevents alveolar collapse
- Promotes dry alveoli:
  - Alveolar collapse tends to "suck" fluid from pulmonary capillaries
  - Stabilizing alveoli prevents fluid transudation by preventing collapse.

Infant Respiratory Disease Syndrome (IRDS)

- **Surfactant starts late in fetal life**
  - **Total gestation: 39 wks**
  - **Surfactant: 23 wks ⟶ 32-36 wks**
- **Infants with immature surfactant (IRDS)**
  - **Stiff, fluid-filled lungs**
  - **Atelectatic areas (alveolar collapse)**
    - **Collapsed alveoli are poorly ventilated**
    - **Effective right to left shunt (Admixture)**
- **[lecithin]/[sphingomyelin] ratio ⟶ Gestational Maturity**

Dependent Lung

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- **Dependent Lung**—the lung in the lowest part of the gravitational field
  - base when in the upright position
  - dorsal portion when supine.

Gravity and Lung Inflation

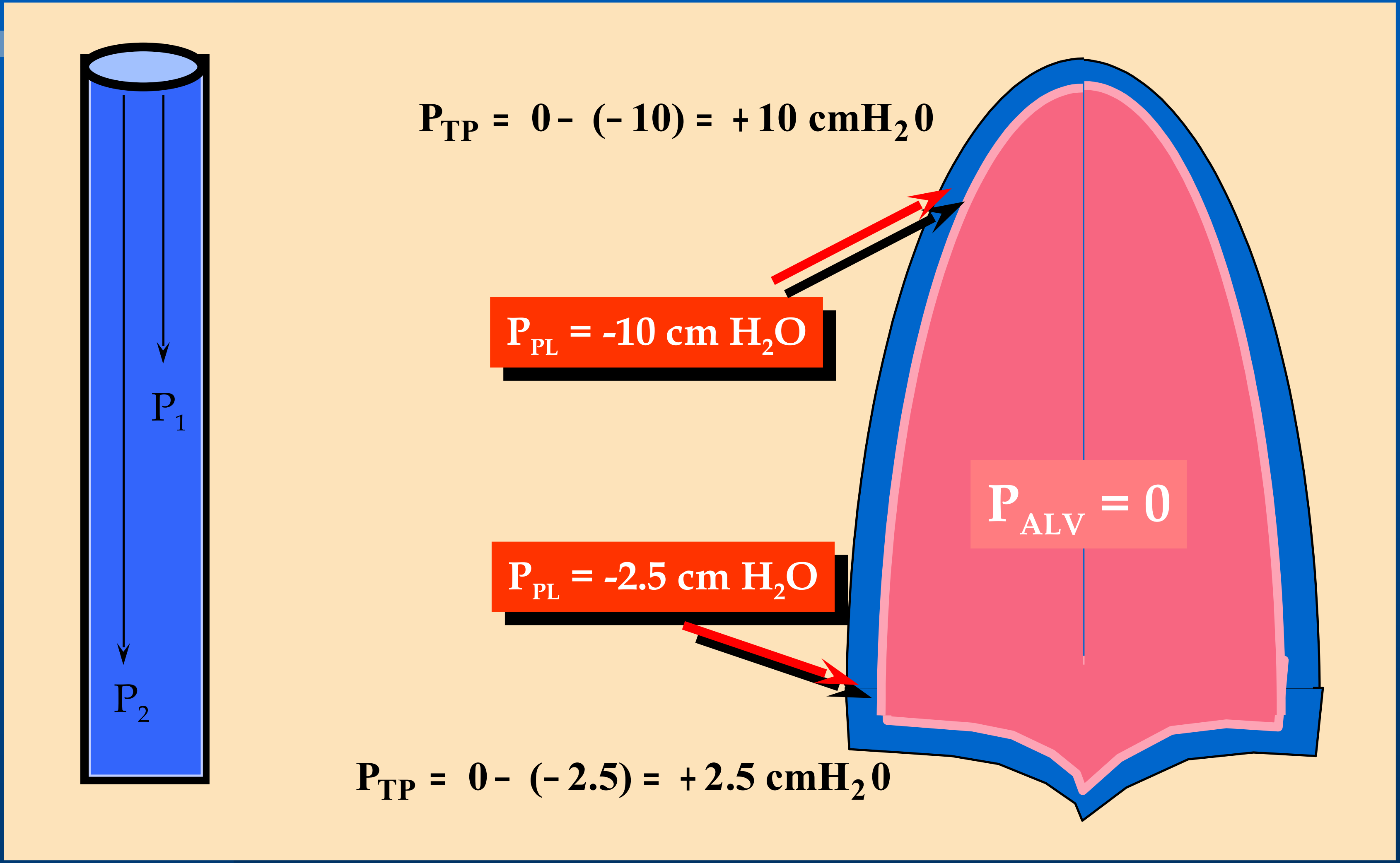
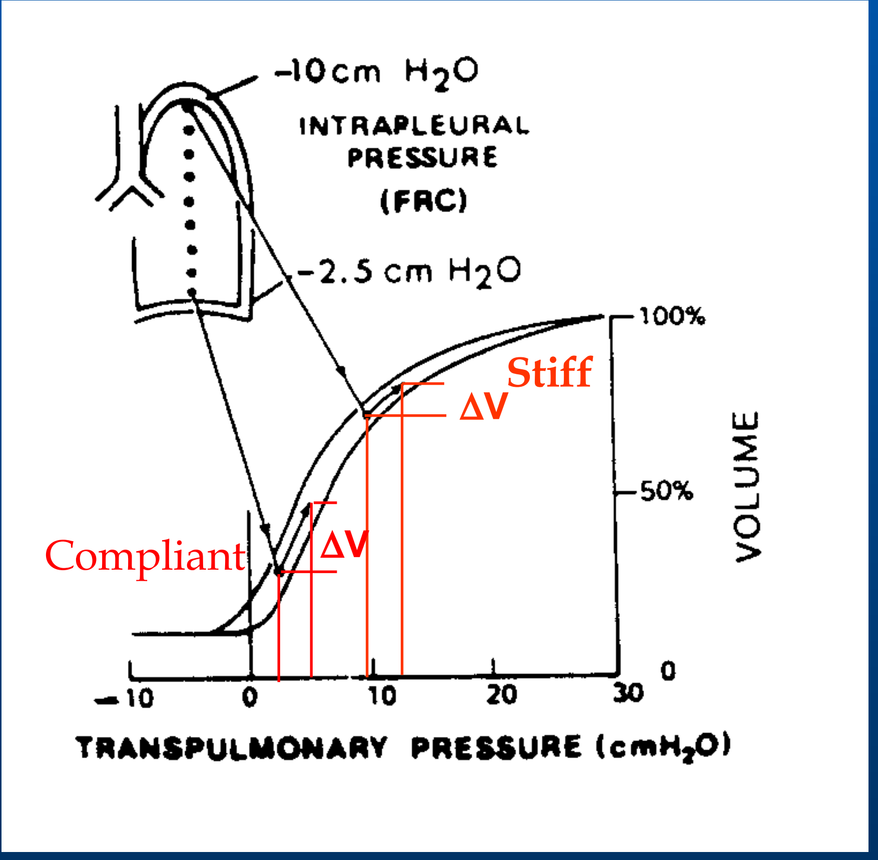


Figure 5: Regional Compliance Differences During Inflation



Regional Lung Volume vs. Regional Lung Ventilation

- In the upright posture:
  - Relative lung volume is greater at the apex
  - Lung is less compliant (stiffer) at the apex
  - Regional lung ventilation is greatest at the base

Time Constants for Emptying

- Important regional inhomogeneities:
  - regional differences in airway resistances
  - regional differences in elastic characteristics
- High resistance and high compliance cause slow emptying.

Time Constant $\propto$ RC

Specific Compliance

- $$\text{Specific Compliance} = \frac{\text{Compliance}}{\text{FRC}}$$
- Normalization allows comparison of tissue elastic characteristics
- Question: How would compliance differ in a child and an adult, both with normal lungs?

INTERACTIONS BETWEEN LUNGS AND CHEST WALL

General Principle

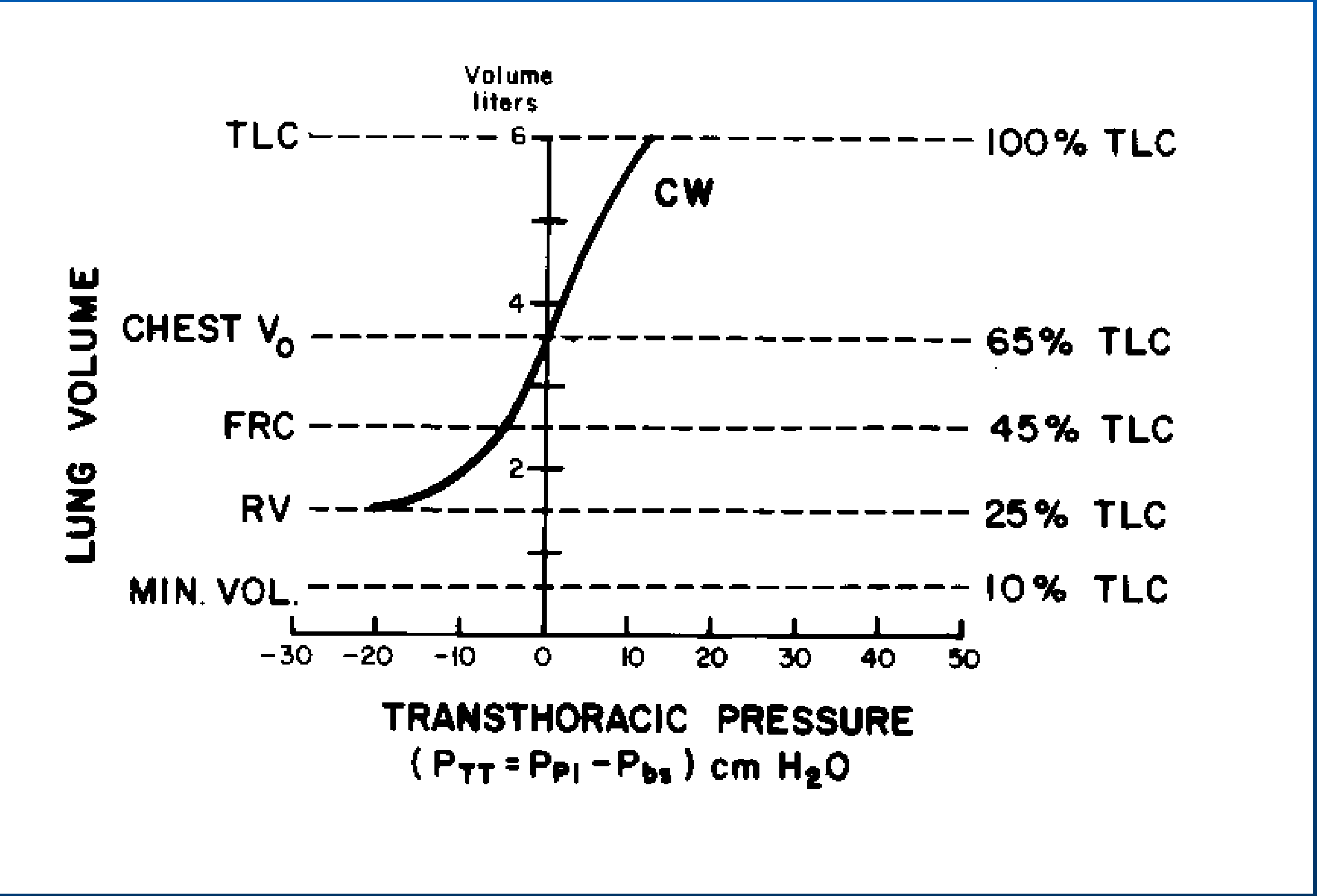
- The lungs and chest wall operate in series
- Lung and chestwall compliances add reciprocally:

$$\frac{1}{C_{Total}} = \frac{1}{C_{Chestwall}} + \frac{1}{C_{Lung}}$$

MECHANICS OF BREATHING

Part 3

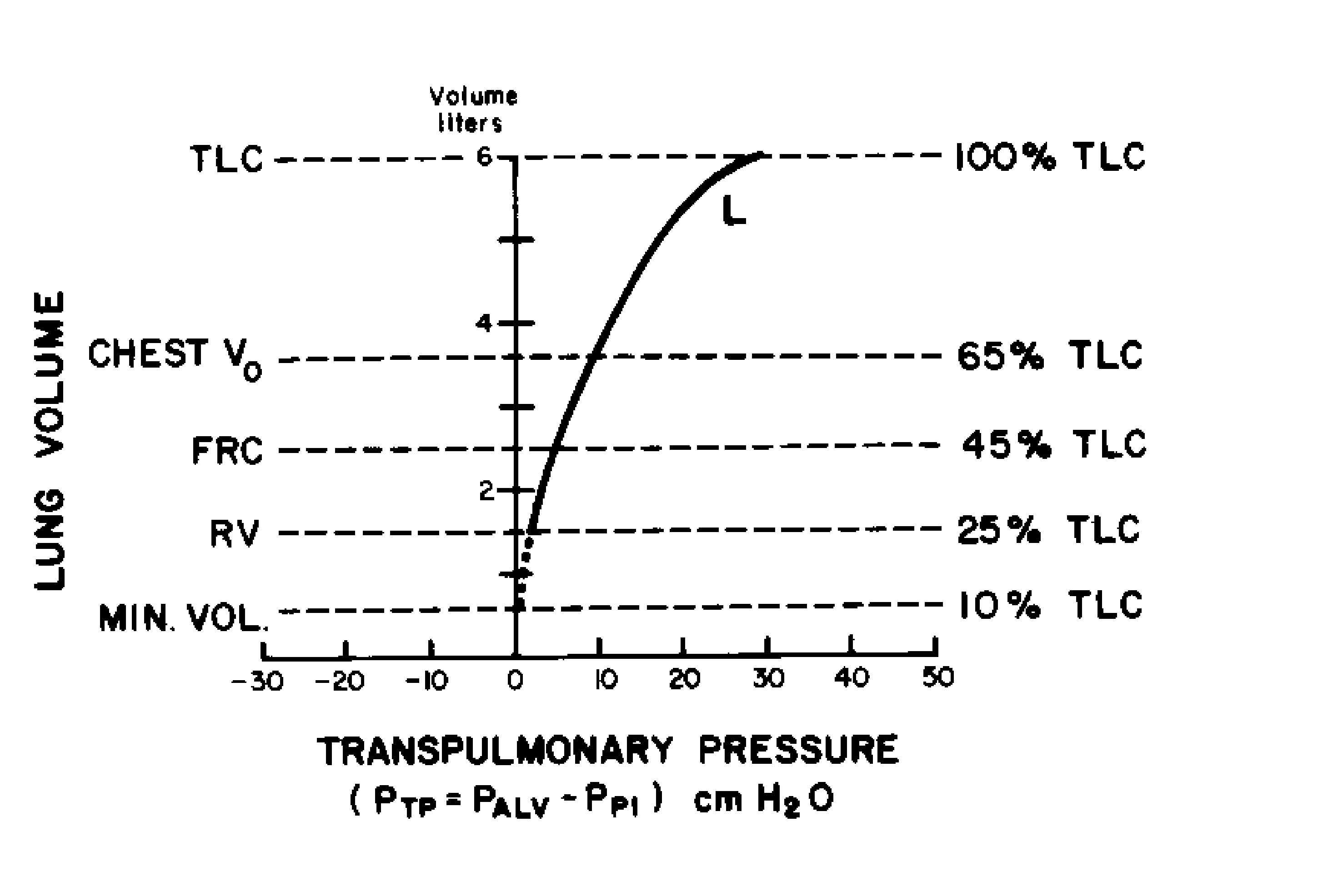
Figure 6: Chest Wall Mechanics



Chest Wall Mechanics Summary

- <u>Negative P_{TT} :</u> Found at RV and FRC.
  - Normal tidal breathing in this condition
  - chest wall below its unstressed volume
  - chest tends to spring out
- <u>Unstressed Volume:</u> 65% of TLC
  - No net recoil
- <u>Postive P_{TT}:</u> Above 65% of TLC
  - volumes above 65% TLC
  - Chest tends to collapse (spring in).

Figure 7: Lung Mechanics



Lung Mechanics Summary

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- Always above unstressed volume (minimal volume = 10% TLC).
- P_{TP} is positive from RV to TLC
- Lungs always tends to collapse.

Figure 8: Combined Mechanics

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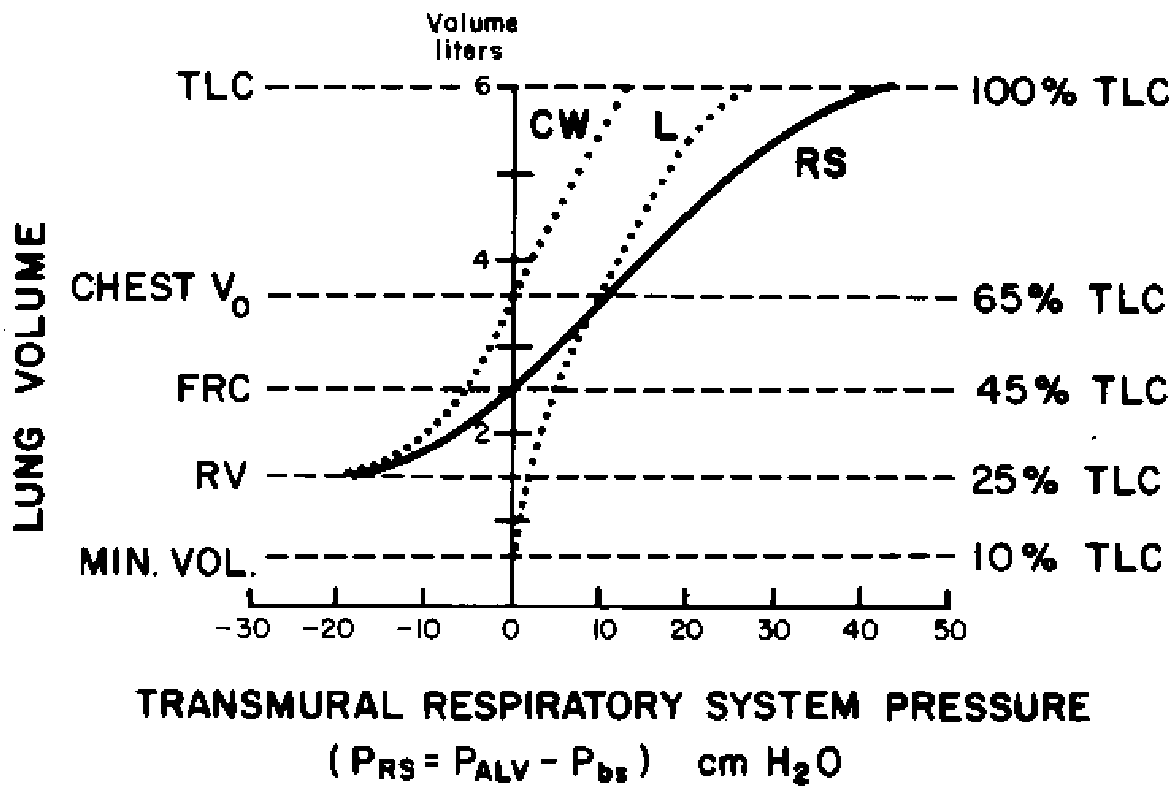

Combined Mechanics Summary

- Functional residual capacity
  - Respiratory system unstressed volume
  - Chest and lung recoil equal and opposite
- Pneumothorax
  - Uncouples lungs and chestwall
  - Lungs and chest wall move to their unstressed volume
    - lungs <u>always</u> recoil inward
    - chest wall springs outward below 65% TLC
    - chest wall springs inward above 65% TLC

Lung Compliance in Disease

- Diseases increasing compliance:
  - natural aging
  - emphysema.
- Diseases decreasing compliance (stiffer lung):
  - pulmonary fibrosis
  - edema (e.g. rheumatic heart disease)

Chestwall Compliance in Disease

- **Actually less compliant (stiffer):**
  - chest wall deformation (eg. kyphoscoliosis)
- **Functionally less compliant (stiffer):** (Abdominal cavity changes)
  - displacement of the diaphragm (eg. pregnancy)
  - ascites

AIRWAY RESISTANCE

Resistive Forces and Breathing

- Quiet breathing -- Air flow laminar
  - Resistance -- Poiseuille's Law
  - Pressure gradient proportional to flow.
- High airflow (e.g. exercise)
  - turbulence and eddy flow
  - Extra pressure gradient proportional to flow rate squared

Distribution of Airway Resistance

- Major portion larger airways
  - specifically medium size bronchi
- Small airways (< 2 mm)
  - Only 20% of total airway resistance
  - Resistance increases may foretell coming problems
  - FEF_{25-75} supposedly sensitive

Airway Resistance --Smooth Muscle

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- Bronchoconstrictors
  - Vagal tone
  - Histamine
- Bronchoconstrictors
  - Beta agonists ⟶ Bronchodilation
  - Anti-cholinergics

Airways and V/Q Matching

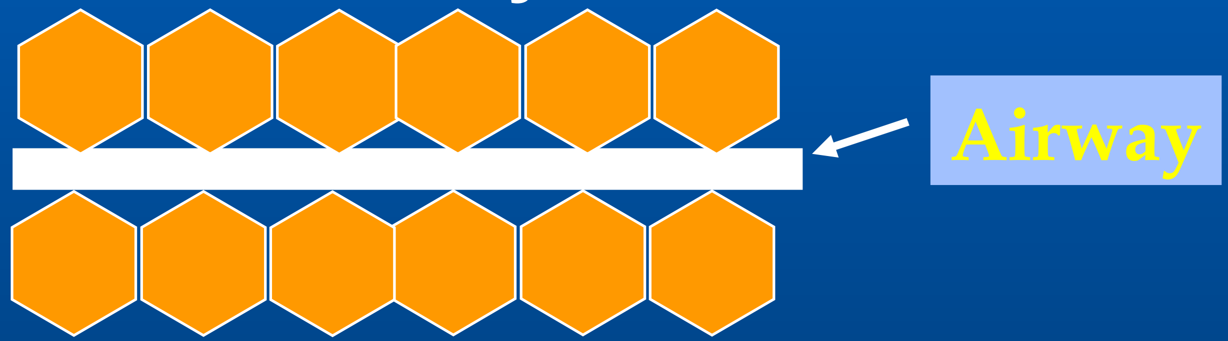
- ↑ P_ACO_2 ⟶ Bronchodilation
  - Find high P_ACO_2 in poorly ventilated regions
  - These airways tend to dilate.
  - Promotes homogeneous ventilation

Homeostatic Summary

- Low V/ Q units
  - Alveolar hypoxia
  - Alveolar hypercapnia
- Homeostasis
  - Alveolar hypercapnia tends to raise ventilation
  - Alveolar hypoxemia tends to lower blood flow
- Result: V/ Q tends back towards normal

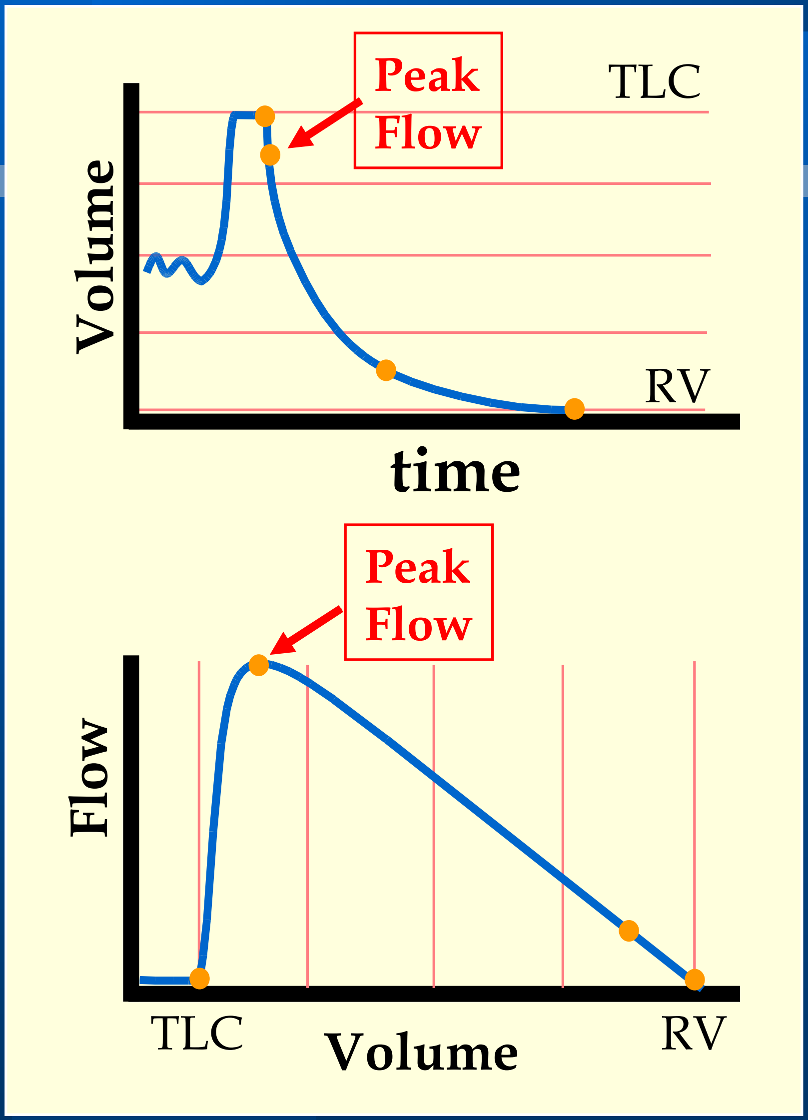
Airway Resistance -- Minimized by High Elastic Recoil

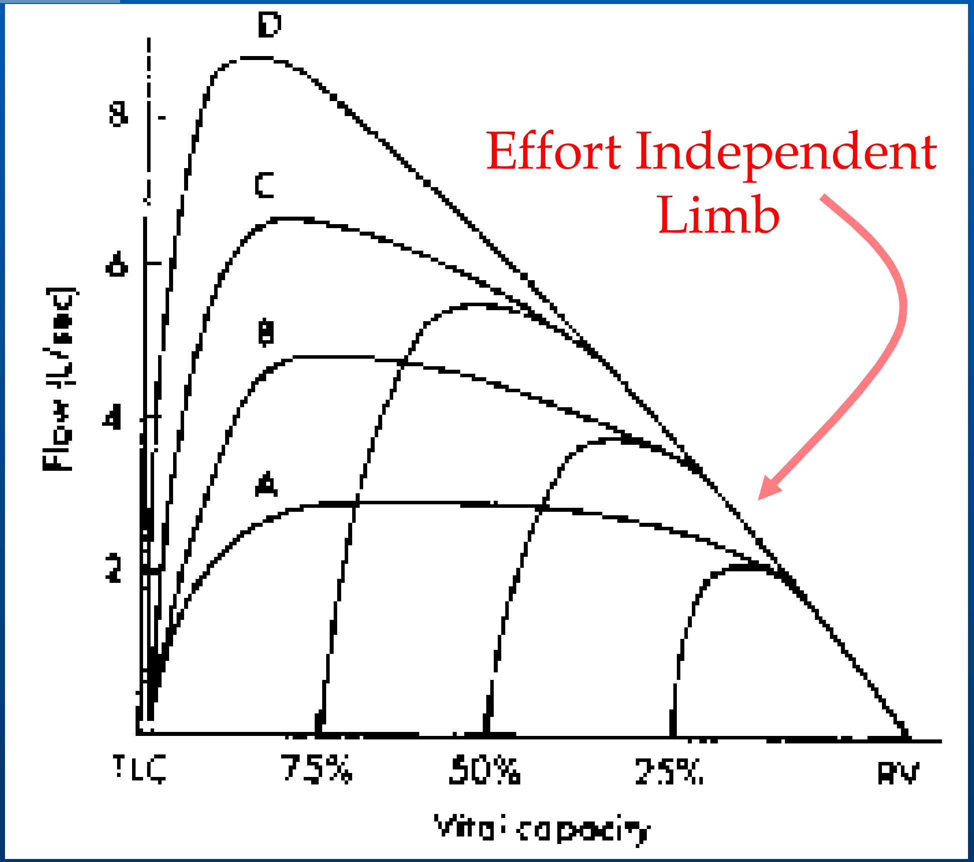
- Radial traction normally holds bronchi open



- Low elastic recoil forces causes less radial traction and higher airway resistances:
  - → Lower lung volumes
  - → Chronic obstructive disease (eg. Emphysema)

Maximum Forced Expiration

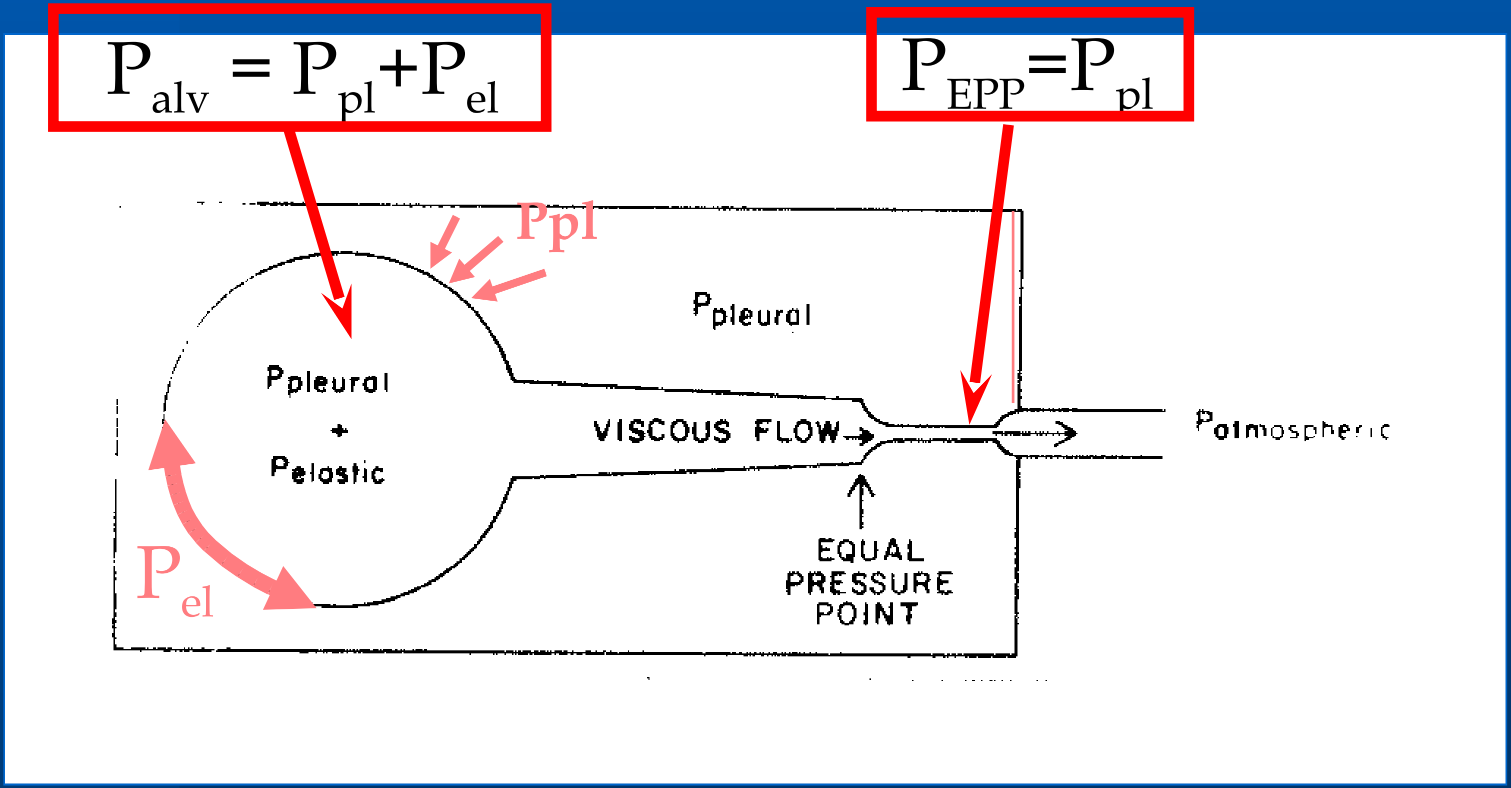




Summary of Forced Expiration

- Peak flow occurs early
- Envelope of effort-independence:
  - Flow depends only on elastic recoil.
  - Flow falls as expiration continues
- Envelope is eventually joined independent of:
  - Starting volume
  - Initial effort.

Figure 10: Flow Limitation and EPP



Mechanism of Flow Limitation Summary

- Force expiration: P_{PL} is positive outside the airways.
- Equal pressure point (EPP).
  - Point at which P_{airway} falls just enough to equal P_{PL}
  - Bronchi collapse
- Flow proportional to: $P_{ALV} - P_{EPP}$

Effort Independence of Flow-Volume Envelope

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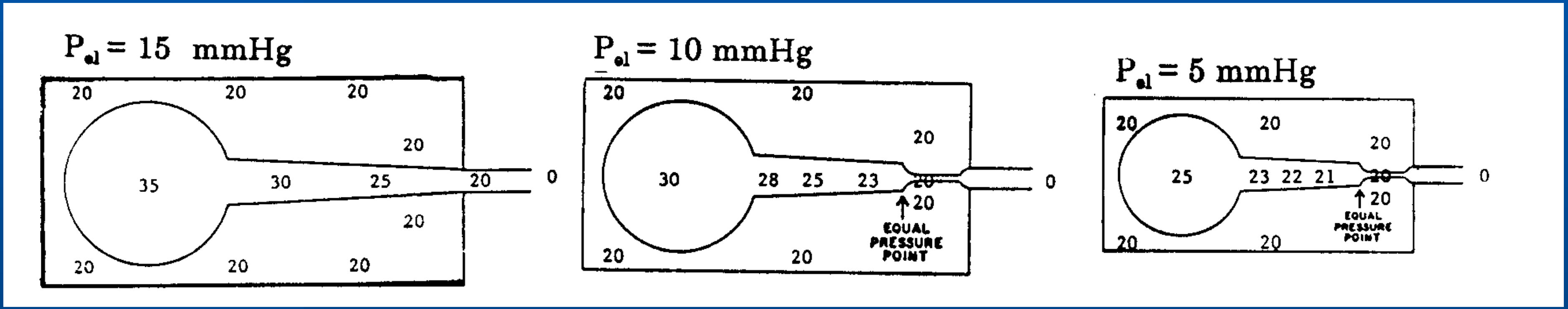
- Increased effort ⟶
  - Similar increases in P_{ALV} and P_{EPP}.
  - Pressure difference unchanged
  - Therefore, Flow unchanged.

Figure 11: Flow Limitation at Various Lung Volumes

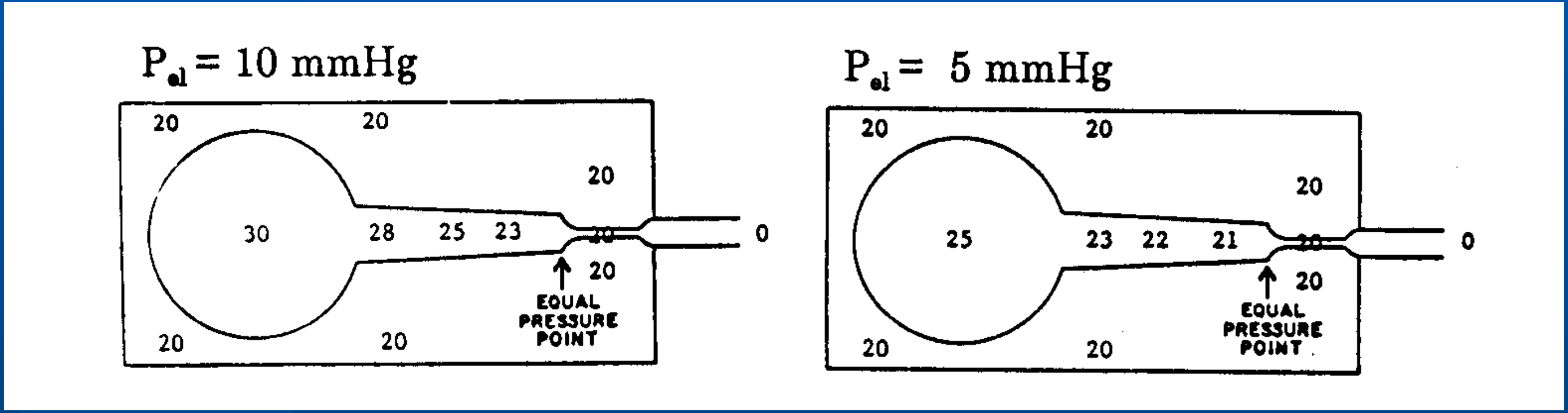


High Lung Volume

Medium Lung Volume

Low Lung Volume

Flow Limitation in COPD (Emphysema)

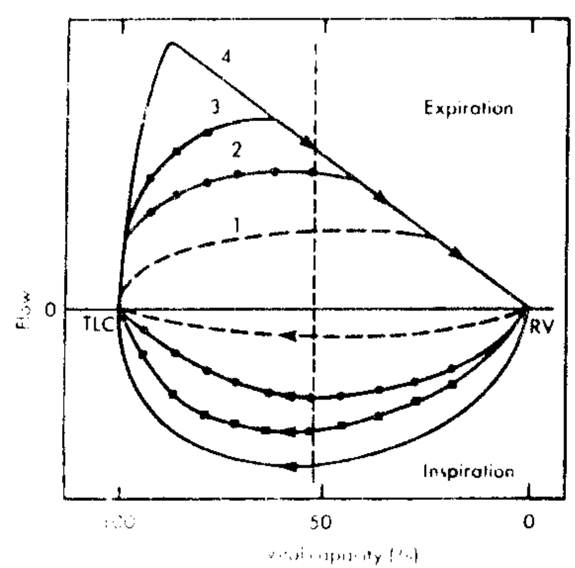


Normal Lung Medium Volume

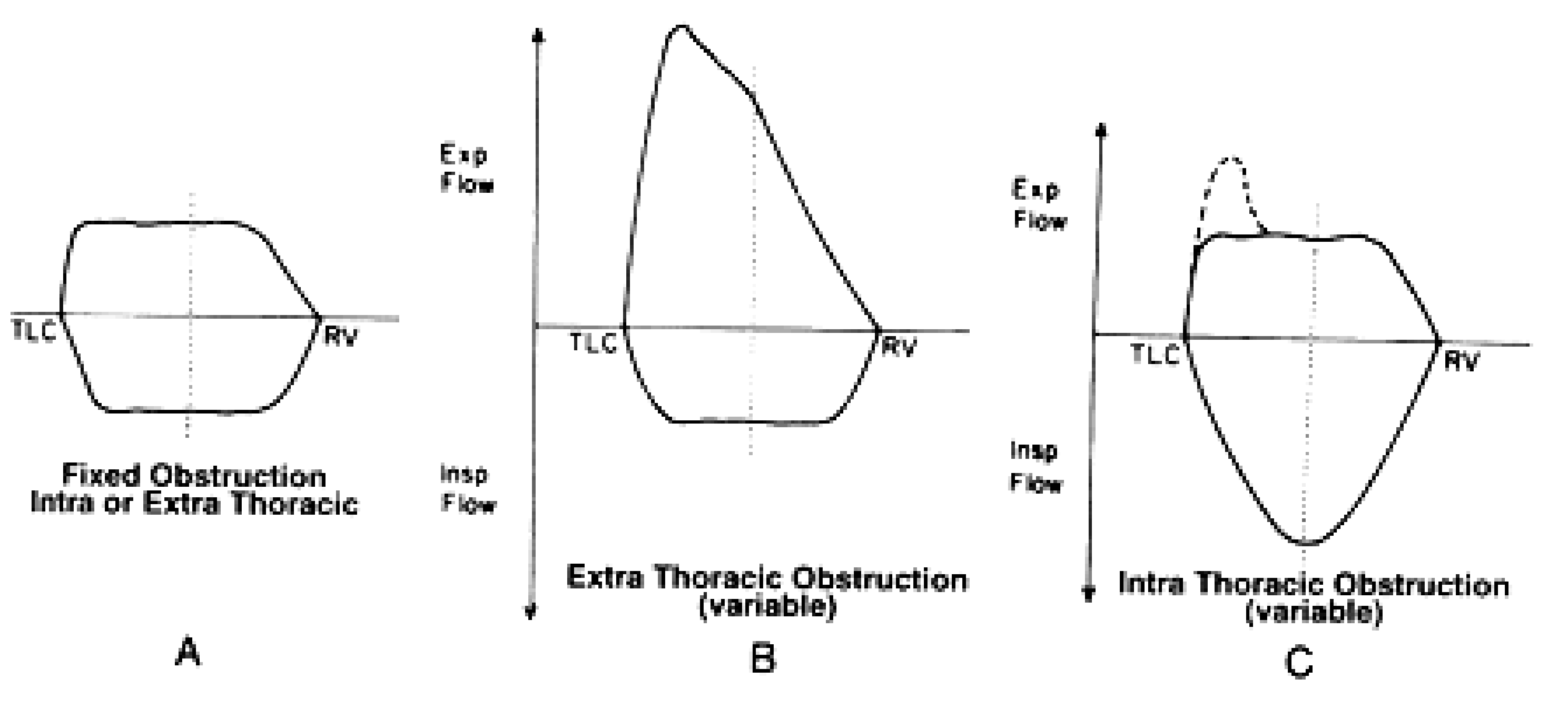
Emphysematous Lung Medium Volume

Forced Inspiration: is Effort-Dependent

- P_{PL} is Negative
- Airways are held open.



Clinical Flow-Volume Loops Obstruction



Reference

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