VENTILATION PARAMETERS

A. Lung Volumes

1. Basic volumes: elements

a. Tidal Volume (V_T, TV): volume of gas exchanged each breath; can change as ventilation pattern changes

b. Inspiratory Reserve Volume (IRV): maximum volume that can be inspired, starting from the end inspiratory position (potential volume increase at the end of inspiration)

c. Expiratory Reserve Volume (ERV): maximum volume that can be expired, starting from the end expiratory position (potential volume decrease at the end of expiration)

d. Residual Volume (RV): volume remaining in the lungs and airways following a maximum expiratory effort (note: lungs cannot empty completely because of (1) stiffness when compressed and (2) airway collapse and gas trapping at low lung volumes)

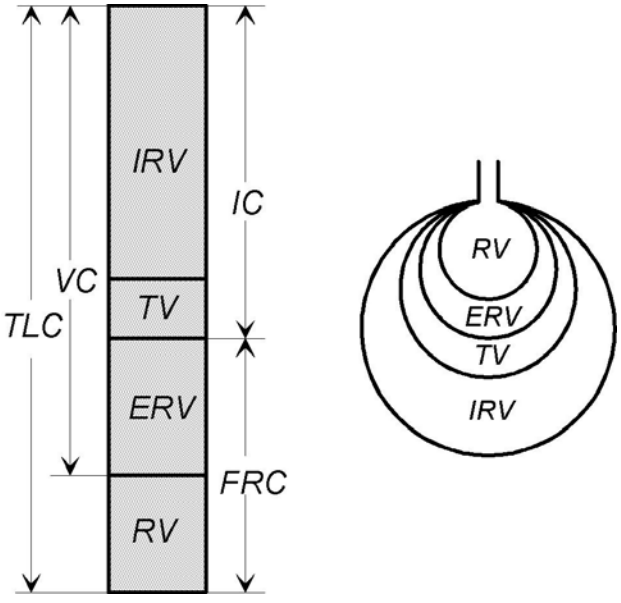
2. Capacities: combined volumes

a. Vital Capacity (VC): maximum volume of gas that can be exchanged in a single breath
VC = TV + IRV + ERV

b. Total Lung Capacity (TLC): maximum volume of gas that the lungs (and airways) can contain
TLC = VC + RV = TV + IRV + ERV + RV

c. Functional Residual Capacity (FRC): volume of gas remaining in the lungs (and airways) at the end expiratory position
FRC = RV + ERV

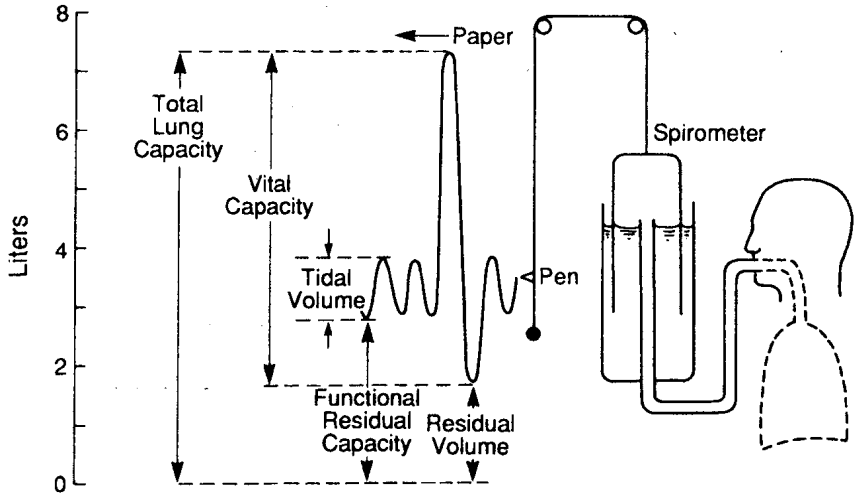
d. Inspiratory capacity (IC): maximum volume of gas that can be inspired from the end expiratory position
IC = TV + IRV



VENTILATION PARAMETERS (continued)

A. Lung Volumes (continued)

3. Measurement of volumes: Spirometer/Spirometry



4. Typical Values (young male of average size)

TV	= 0.5 L (10% TLC)	VC	= 4.8 L (≈ 5 Liters; 80% TLC)
IRV	= 3.0 L (50% TLC)	TLC	= 6.0 L
ERV	= 1.3 L (20% TLC)	FRC	= 2.5 L
RV	= 1.2 L (20% TLC)	IC	= 3.5 L

Note: "normal" values depend upon age, sex, and size

Note: the above percentages for TV, IRV, and ERV are for a person at rest breathing normally; RV, VC, and TLC do not depend on whether the person is at rest or is breathing more vigorously

B. Ventilation

1. frequency or respiration rate (f or RR): breaths per unit time

typical value at rest: 12/min (but much individual variation)

2. ventilation rate: total volume inspired or expired per unit time (written as V' or V-dot); sometimes called Minute Volume (MV) when measured per minute; to avoid ambiguity, usually measured as volume expired, V_E'

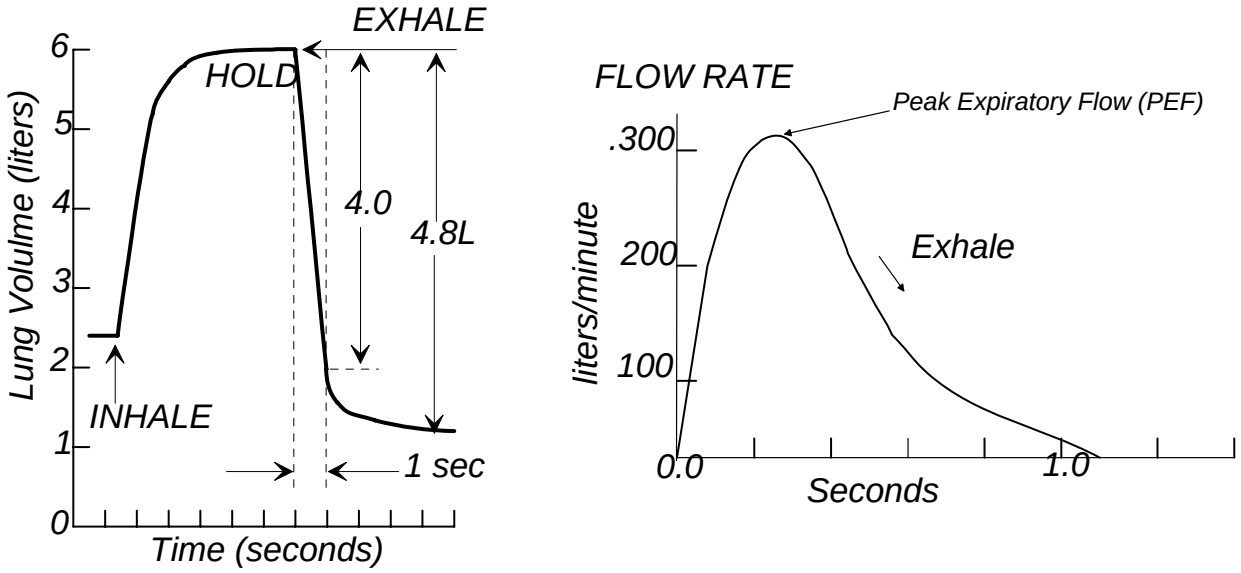
MV or V_E' = f × TV

typical value at rest: MV or V_E' = 12/min × 0.5L = 6 L/min

VENTILATION PARAMETERS (continued)

B. Ventilation (continued)

3. maximum air flow rate, single breath



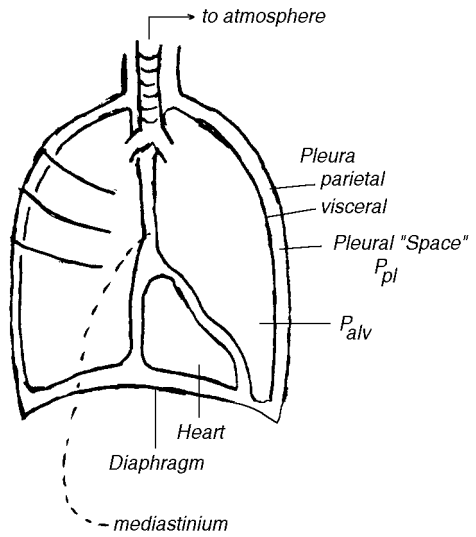
a. peak velocity (e.g. peak expired flow rate) normal value 400-600 liters/minute

b. timed vital capacity: volume of gas that can be expired from the lungs with maximum effort in a given time (usually 1 second; "one-second forced expired volume", FEV_1)

1) usually expressed as a fraction of the total volume expired in a maximum effort, the Forced Vital Capacity (FVC)
2) normal value of FEV_1 / FVC $\geq$ 80%

PHYSIOLOGICAL ANATOMY

A. Lungs and Thoracic Cavity

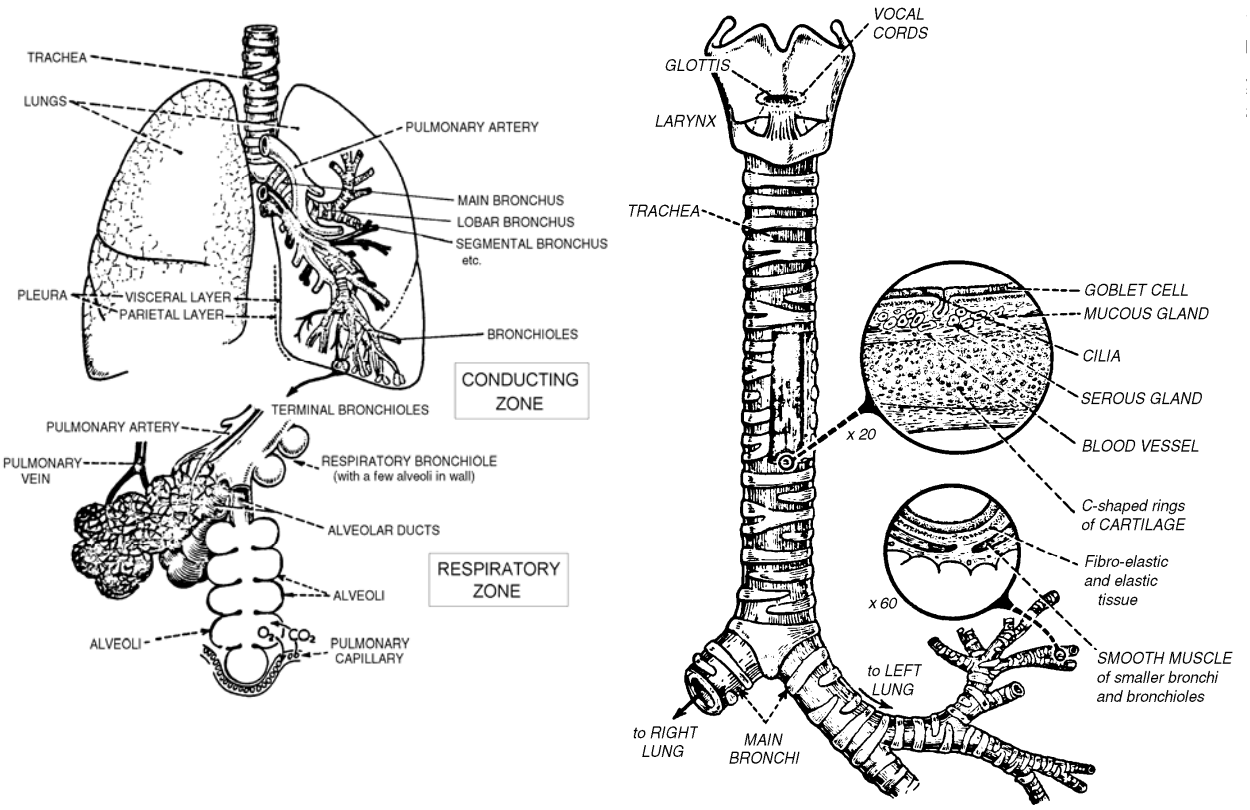


P_{alv} = intra-alveolar pressure; pressure within the alveoli; positive on expiration, negative on inspiration, and zero (same as atmospheric) when no air movement

P_{pl} = intrapleural pressure; pressure in the intrapleural space (small, fluid-filled region); generally negative because the lungs are "naturally" smaller than the chest wall; the negative pressure helps to keep the airways open and keep the lungs from collapsing

Note: pressures in the respiratory function are generally measured relative to atmospheric pressure; positive pressure means greater than atmospheric and negative means less than atmospheric pressure; also, pressures in respiration are generally measured in cmH_2O (1mmHg = 1.36 cmH_2O)

PHYSIOLOGICAL ANATOMY (continued)



B. Gas Exchange

1. Airways are divided into those in the Conducting Zone (role: air flow) and the Respiratory Zone (alveoli; role: gas exchange with pulmonary capillary blood)

C. Airways

1. Role of secretions and cilia: Trap (secretions) and remove (cilia) inspired particulate matter

   The larger inspired particles tend to deposit on the airway walls, and thus are eventually removed from the airways by ciliary action (velocity 1-2 mm/min mouthward)

   Note: Smallest particles may reach the terminal bronchioles and some may remain in lungs

2. Role of smooth muscle: adjust airway diameter and thus control airflow resistance and ventilation distribution

SEQUENCE FOR AIR MOVEMENT

A. Air Movement (volume & ventilation rate)depends on

1. Force of respiratory muscle contraction
2. Elastic recoil of the lung and chest wall (*Compliance*)
3. Resistance to rate of lung volume change (*Flow Resistance*)

RESPIRATORY MUSCLE CONTRACTION

A. Inspiration (inhalation)

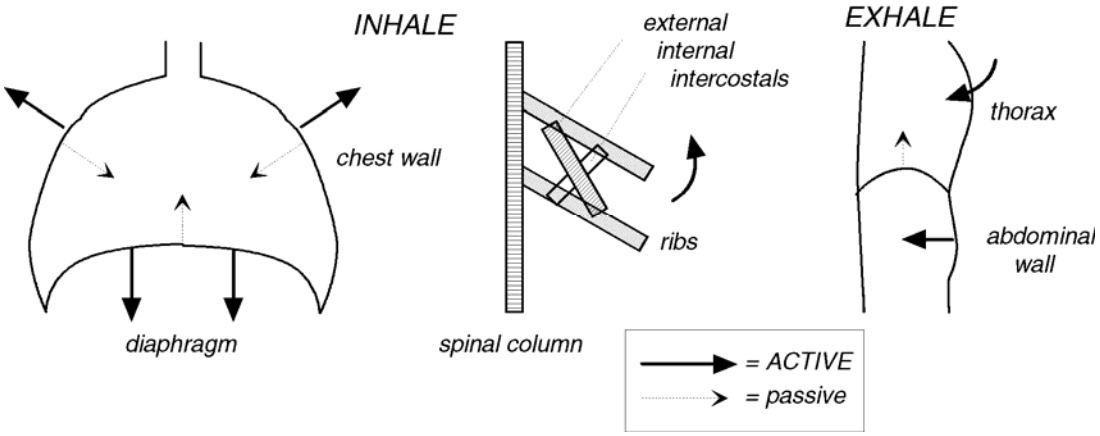
1. active process (requires skeletal muscle contraction)

2. Diaphragm

   a. descends upon contraction, pulling air into the lungs
   b. responsible for about 2/3 of inspired volume in quiet breathing

3. Intercostal muscle contraction, particularly external intercostals

   a. raise rib cage, thus increasing chest anterior-posterior dimension



B. Expiration (exhalation)

1. Quiet breathing

   a. passive
   b. due to elastic recoil upon relaxation of inspiration muscles
   c. normal breathing at rest

2. Forced expiration

   a. intercostal muscles, particularly internal intercostals (lower rib cage, decreasing anterior-posterior thoracic distance)
   b. abdominal muscles (increase abdominal pressure, forcing diaphragm up)

C. Force Magnitude

1. Quiet breathing
   a. low pressures (few cmH_2O) due to high compliance & low airway resistance

2. Maximum respiratory effort
   a. inspiration: $\cong$ -100 cmH_2O
   b. expiration: $\cong$ +100 cmH_2O

   Note: Maximum respiratory effort requires extreme work and interferes with cardiac output, particularly venous return

   Valsalva maneuver: maximum expiratory effort while holding the glottis closed; develops maximum expiratory pressure

COMPLIANCE

A. Compliance (elastance)

1. Definition: $C = \Delta V / \Delta P$

B. Basis of Compliance (or Stiffness)

1. Total system stiffness (S_t) is the sum of the lung stiffness (S_L) and chest wall stiffness (S_{cw})

   $S_t = S_L + S_{cw}$

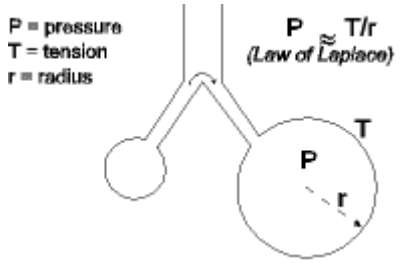
2. Chest Wall Stiffness: due to elasticity of tissue; normally responsible for one-half of the total system stiffness

3. Lung Stiffness: contributing factors

   a. elasticity of lung tissue

   b. surface tension

      1) due to air-liquid interface in the alveoli
      2) important because of large alveolar surface area
      3) leads to
         a) high stiffness (low compliance)
         b) alveolar instability, with small alveoli emptying into large alveoli; can cause atelectasis -- alveolar collapse
         c) movement of interstitial fluid into the alveoli
      4) effects greatly reduced by a surfactant substance secreted by lung type 2 alveolar cells



   c. role of surfactant

      1) lower surface tension to about 1/3 of plasma (increase lung compliance)
      2) lower surface tension more in small alveoli (increase alveolar stability)
      3) helps keep alveoli “dry”

FLOW RESISTANCE

C. Determinants of flow resistance [R]

1. Airway Resistance (major factor), which depends mainly upon airway diameter, as controlled by the following:

   a. bronchial smooth muscle contraction

   b. bronchial secretion: narrows lumen if accumulates faster than removed by cilia (or coughing)

   c. autonomic nervous system, through its effects on (a) and (b) above:

parasympathetic (muscarinic)	bronchoconstriction increase secretion	$R_{aw} \Uparrow$
sympathetic (β_2)	bronchodilation decreased secretion (?)	$R_{aw} \Downarrow$

   d. volatile irritants: generally stimulate secretion; may also cause bronchoconstriction (note sensory endings in airways)

   e. airway inflammation: stimulate secretion, can lead to tissue edema and swelling (brochiolitis)

   f. tracheal and bronchial reflexes

   g. temperature: e.g. inspiring cold air can cause smooth muscle contraction

   h. agents acting directly on bronchial smooth muscle
      1) bronchoconstrictors: histamine, acetylcholine
      2) bronchodilators: epinephrine & other beta-2 agonists, atropine, CO_2

   i. pressure across the airway wall (lumen pressure minus intrapleural pressure); tends to collapse airways if intrapleural pressure > 0

      flow limiting segment in expiration: upon increasing expiratory effort, the increase in P_{pl} tends to reduce airway diameter, so that flow does not increase proportionally to effort

   j. supporting tissue in airway wall: resists (i) above

   k. lung volume: bronchioles become smaller as lung volume decreases; not usually major factor

2. Tissue viscosity also contributes to resistance to lung volume change, but the effect is not major (only about 20% of total resistance)

PATHOPHYSIOLOGY OF RESPIRATORY VENTILATION

A. Physiological Classification

CAUSE	EXAMPLE	PATHOPHYSIOLOGY
Muscle Excitation		Inadequate muscle excitation
	Polio CNS depression	
Elastic Force		Increased stiffness (or Compliance decrease)
chest wall	Skeletal deformity (e.g. kyphoscoliosis)	
lung tissue	Fibrosis (e.g. silicosis, asbestosis, black lung)	
surface tension	Hyaline membrane disease (e.g. respiratory distress syndrome of the newborn	
space occupying lesion	Thoracic cancer	
Airway Resistance		Increased airway resistance
upper airway	Aspirate solid object Laryngospasm	
lower airway: acute	Asthma	
lower airway: chronic	COLD or COPD (Chronic Obstructive Lung Disease or Chronic Obstructive Pulmonary Disease)	chronic bronchitis emphysema (degenerative disease of lung tissue)

B. Clinical Classification

1. Restrictive
   a. associated with reduced total lung capacity
   b. due to increased stiffness
   c. diagnosed from TLC⇓ or C⇓

2. Obstructive
   a. associated with reduced air velocity
   b. due to increased airway resistance
   c. diagnosed from R⇑ or FEV_1/VC⇓ or Peak Exp. Flow Rate ⇓

3. CNS Disease
   a. reduced muscle stimulation by the nervous system
   b. reduced muscle strength
   c. reduced muscle strength can be diagnosed from maximum