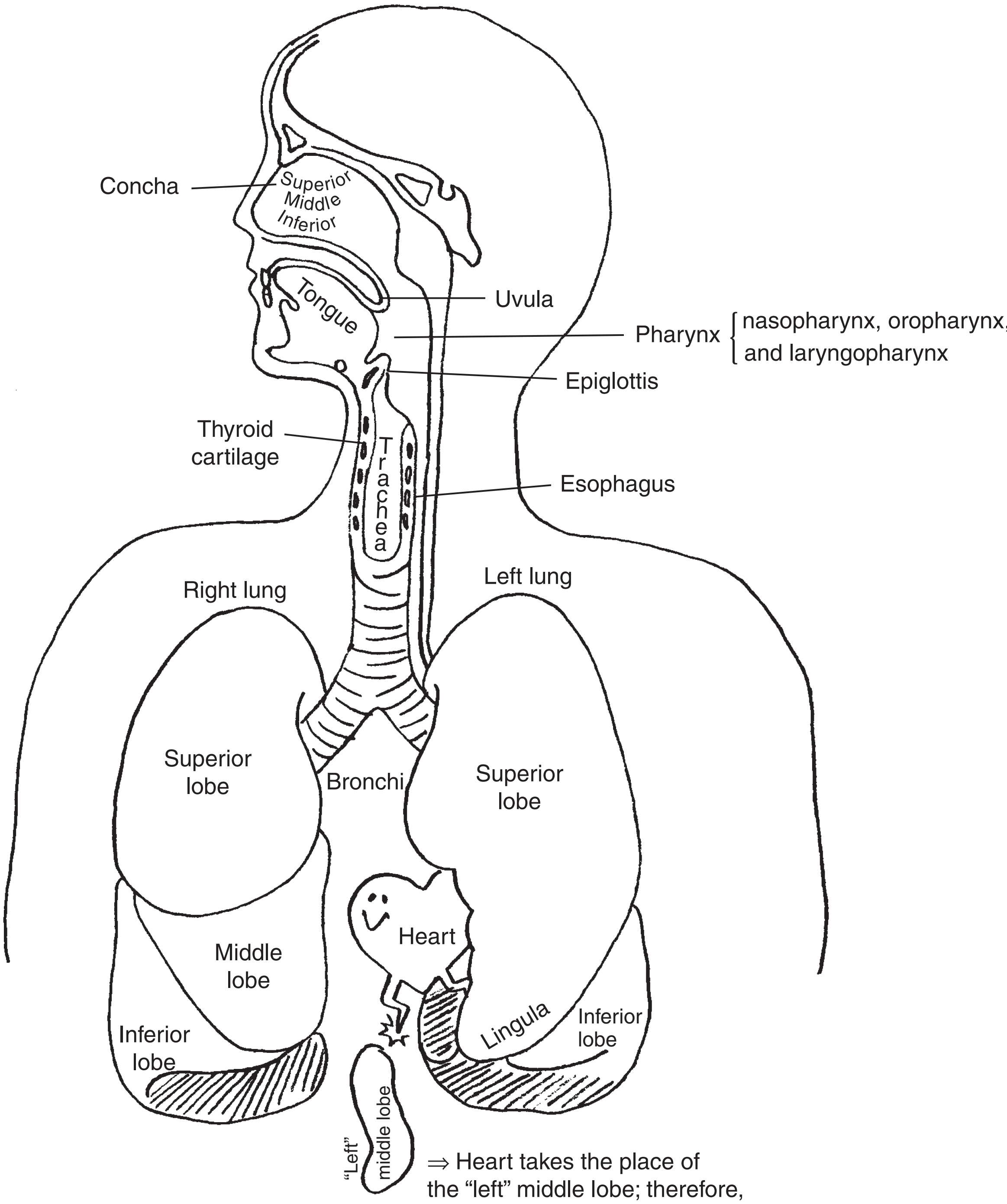
NOTES

RESPIRATORY TRACT

- The respiratory tract conducts air to the lungs where gaseous exchange occurs. It is separated into air-conducting and respiratory (where gas exchange occurs) divisions.
- Upper respiratory tract includes the nasal cavity, pharynx, and larynx. The lower respiratory tract includes the trachea, bronchi, and bronchial tree.
- Beginning at the larynx, the respiratory tract is cartilaginous; the cartilage is then replaced by smooth muscle beginning at the bronchioles.
- The conchae are bony structures in the nasal cavity that increase the surface area, increase moisture, and warm the air that is conducted through the nasal passages.
- The pharynx consists mostly of skeletal muscle (the constrictor muscles) and fibrous tissue. It resides posterior and inferior to the nasal cavity and posterior to the oral cavity. It ends at the larynx and esophagus.
- The larynx produces sound for speech. The epiglottis covers the laryngeal opening during swallowing to prevent aspiration.
- The lobes of the lungs are encased in visceral pleura that eventually reflect off the lungs to become the parietal pleura that lines the inner wall of the thorax. The visceral and parietal pleura are separated only by a serous fluid. The potential space between these two pleura is called the “pleural cavity.”

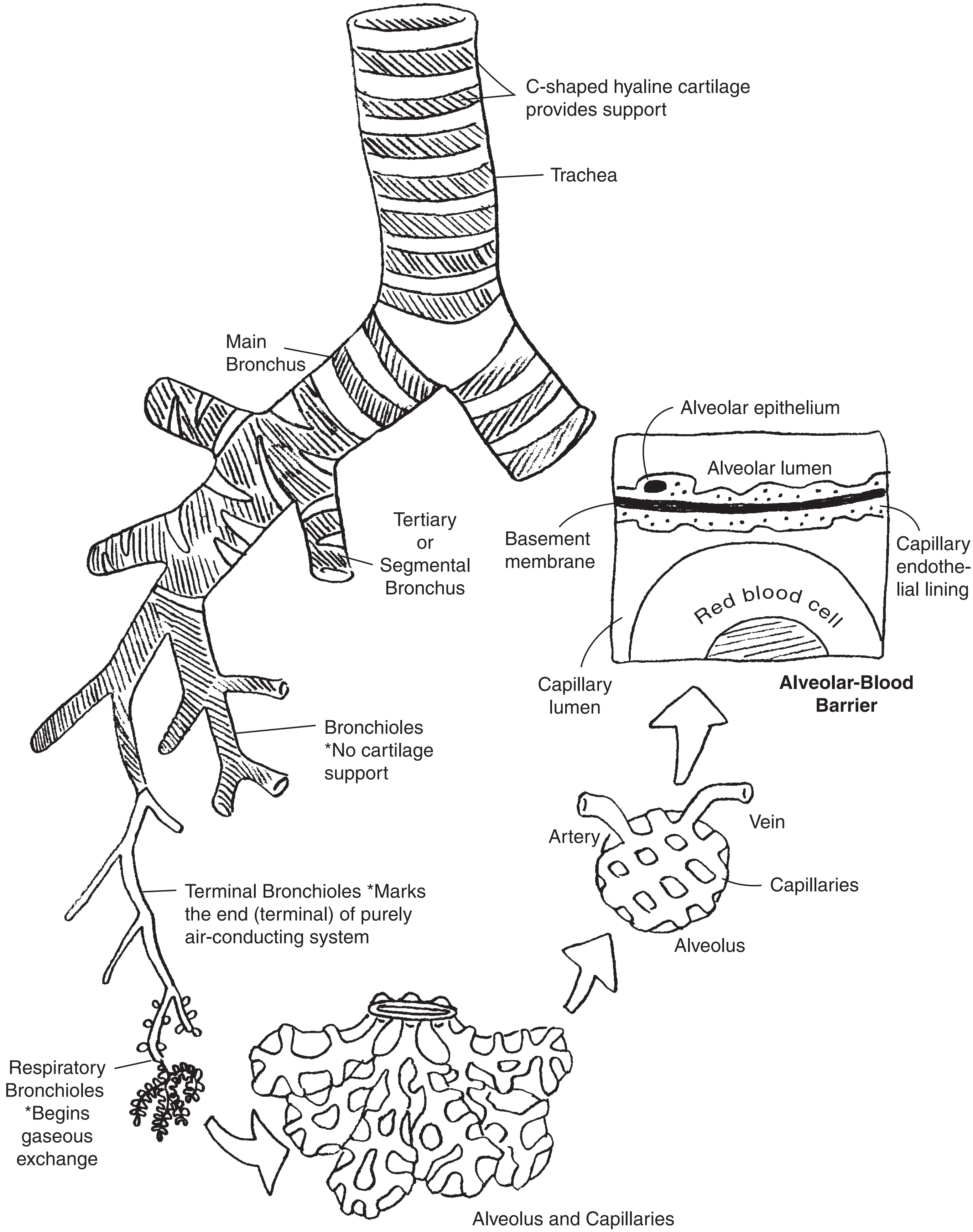


⇒ Heart takes the place of the "left" middle lobe; therefore, there is no left middle lobe as there is on the right.

NOTES

LOWER RESPIRATORY TRACT

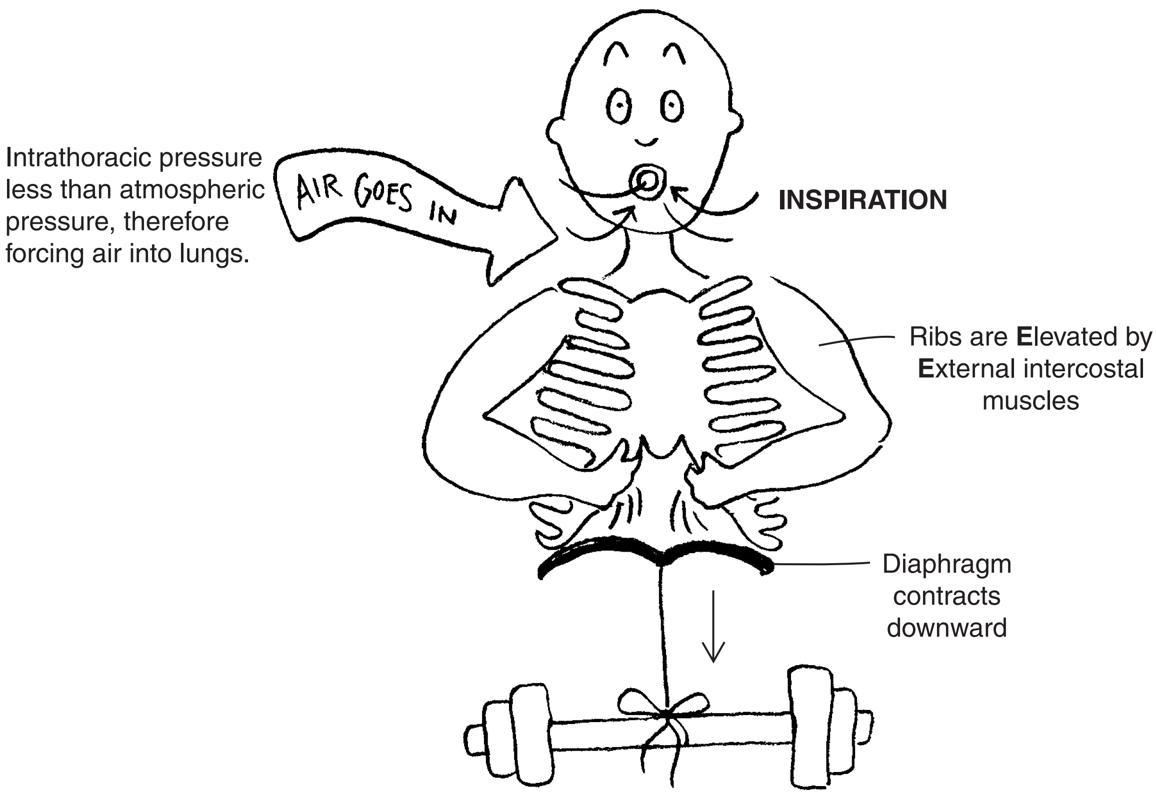
- The lower respiratory tract consists of the trachea, bronchi, and bronchial tree. The lungs are divided into separate bronchopulmonary segments each served by its own segmental bronchus, artery, vein, and lymphatics.
- The segmental or tertiary bronchus branches into bronchioles that consist of smooth muscle rather than cartilage.
- The bronchioles then branch into even smaller terminal bronchioles that mark the end of the purely air-conducting system.
- The terminal bronchioles then branch into the respiratory bronchioles that contain occasional alveolar sacs on their walls. The respiratory bronchiole terminates as an alveolar duct that opens into alveolar sacs where gaseous exchange occurs in the alveolar cells.
- The alveolar air cells are made of simple squamous epithelium. Each alveolus is surrounded by capillaries that originate in the pulmonary arterioles and, in turn, mark the beginning of pulmonary venules.
- Gas exchange (oxygen for carbon dioxide) occurs via the alveolar-blood barrier. This barrier consists of the capillary endothelial lining, basement membrane, and alveolar epithelium.

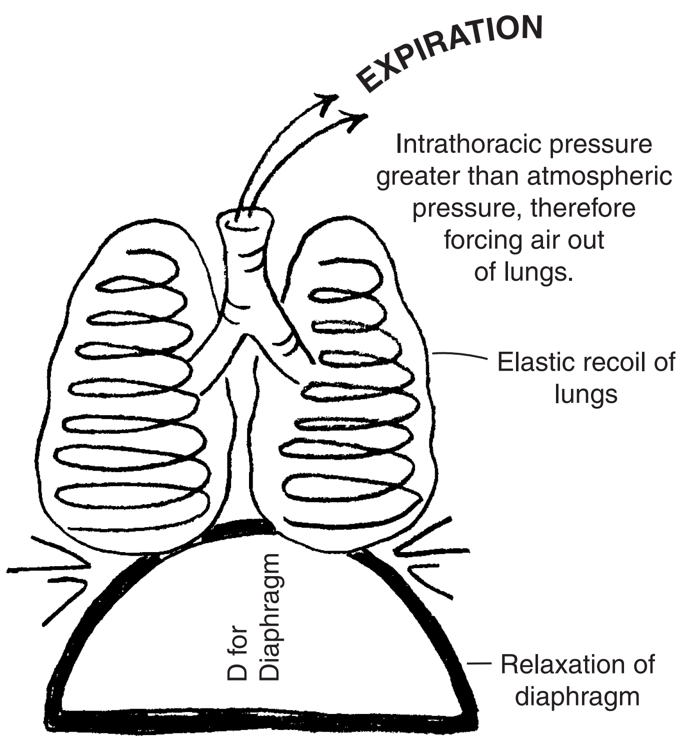

C-shaped hyaline cartilage provides support
Trachea
Main Bronchus
Tertiary or Segmental Bronchus
Alveolar epithelium
Alveolar lumen
Basement membrane
Capillary endothelial lining
Red blood cell
Capillary lumen
Alveolar-Blood Barrier
Bronchioles *No cartilage support
Artery
Vein
Capillaries
Alveolus
Terminal Bronchioles *Marks the end (terminal) of purely air-conducting system
Respiratory Bronchioles *Begins gaseous exchange
Alveolus and Capillaries

NOTES

MECHANICS OF RESPIRATION

- Respiration consists of inspiration and expiration. Air movement occurs secondary to the inverse relationship of pressure and volume (if one goes up, the other must go down).
- 500 mL of air is moved with each breath.
- The flattening contraction of the diaphragm is responsible primarily for most of the inspiratory effort and secondarily for contraction of the external intercostal muscles that elevate the ribs. These actions collectively increase the intrathoracic volume that causes a decrease in pressure. At this point the internal thoracic pressure is lower than the outer atmospheric pressure, which forces air to enter the respiratory tract.
- Expiration provides the relaxation of the diaphragm and external intercostals. The contraction of the internal intercostals and the natural elastic recoil of the lungs also aid in exhalation. Collectively, these actions decrease the intrathoracic volume and thus increase the pressure. At this point the intrathoracic pressure is greater than the external atmospheric pressure, which forces air to exit the respiratory tract.

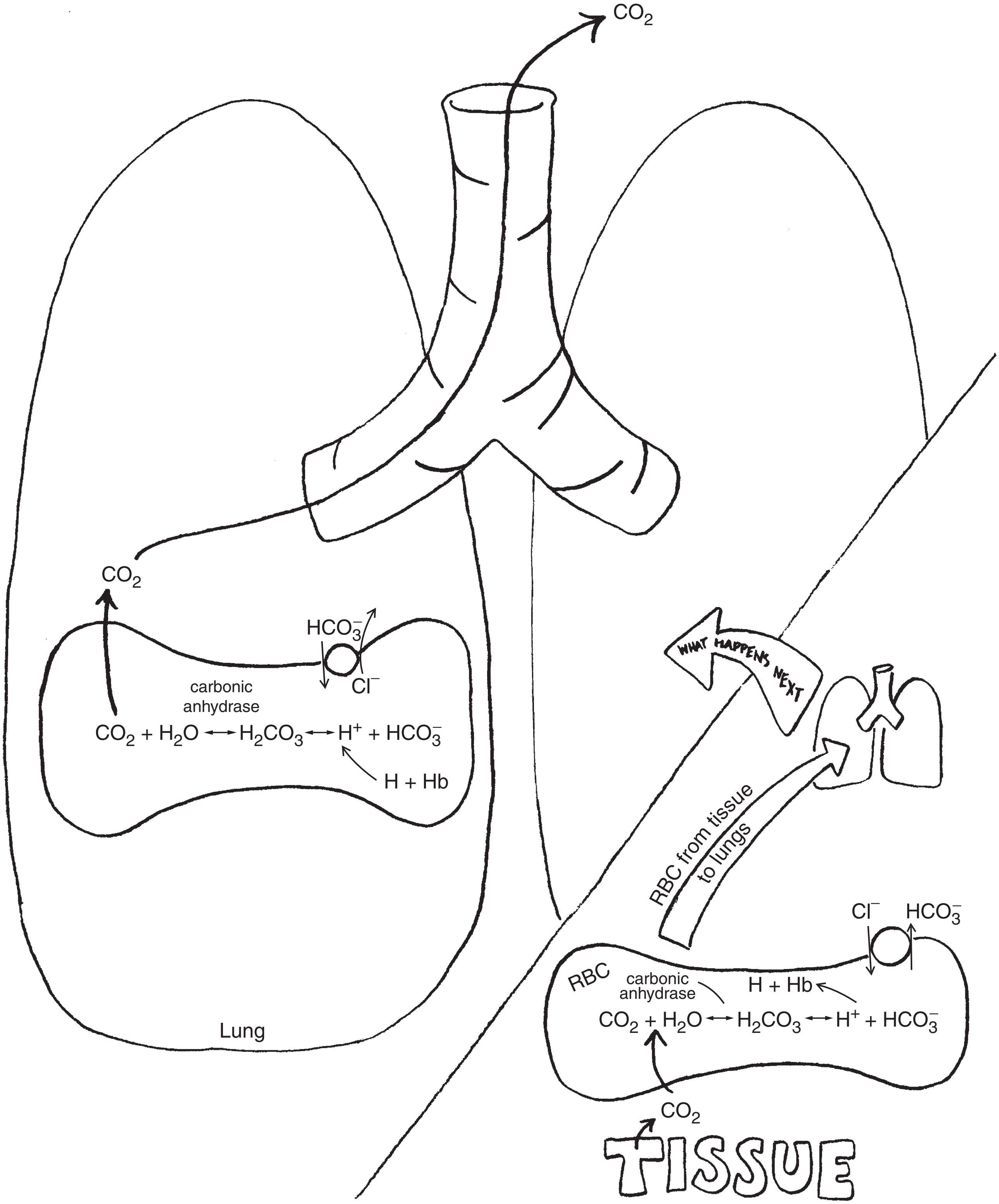

Intrathoracic pressure less than atmospheric pressure, therefore forcing air into lungs.
AIR GOES IN
INSPIRATION
Ribs are **E**levated by **E**xternal intercostal muscles
Diaphragm contracts downward


EXPIRATION
Intrathoracic pressure greater than atmospheric pressure, therefore forcing air out of lungs.
Elastic recoil of lungs
D for Diaphragm
Relaxation of diaphragm

NOTES

CO_2 TRANSPORT

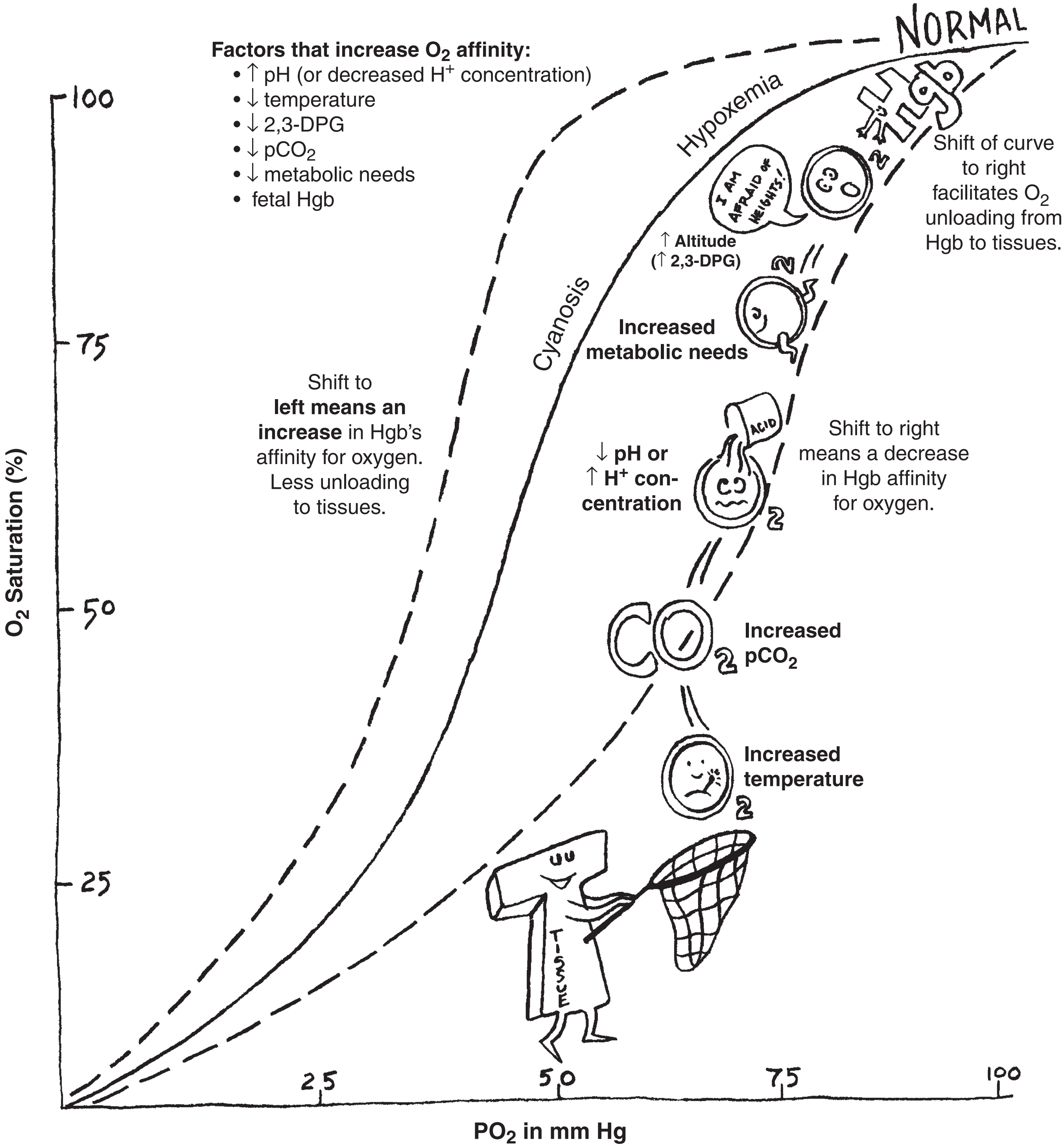
- Transported in venous blood in three forms:
  - HCO_3^- → hydration of CO_2 in RBCs; 90%
  - carbaminohemoglobin → CO_2 bound to hemoglobin
  - dissolved CO_2
- HCO_3^- transport of CO_2
  - CO_2 from tissues diffuses into RBCs → CO_2 combines with H_2O → forms H_2CO_3, which dissociates into H+ and HCO_3^-
  - chloride shift causes HCO_3^- to exit the RBC in exchange for Cl^- ion. This allows the HCO_3^- to be transported in the plasma to the lungs where reverse reactions occur (see illustration) allowing CO_2 to be exhaled.
  - H^+ ion from the dissociation of H_2CO_3 is buffered by deoxyhemoglobin in the RBC.


CO_2
CO_2
HCO_3^-
Cl^-
carbonic anhydrase
$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
H + Hb
Lung
WHAT HAPPENS NEXT
RBC from tissue to lungs
Cl^-
HCO_3^-
RBC
carbonic anhydrase
H + Hb
$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$
CO_2
TISSUE

NOTES

HEMOGLOBIN-OXYGEN DISSOCIATION CURVE

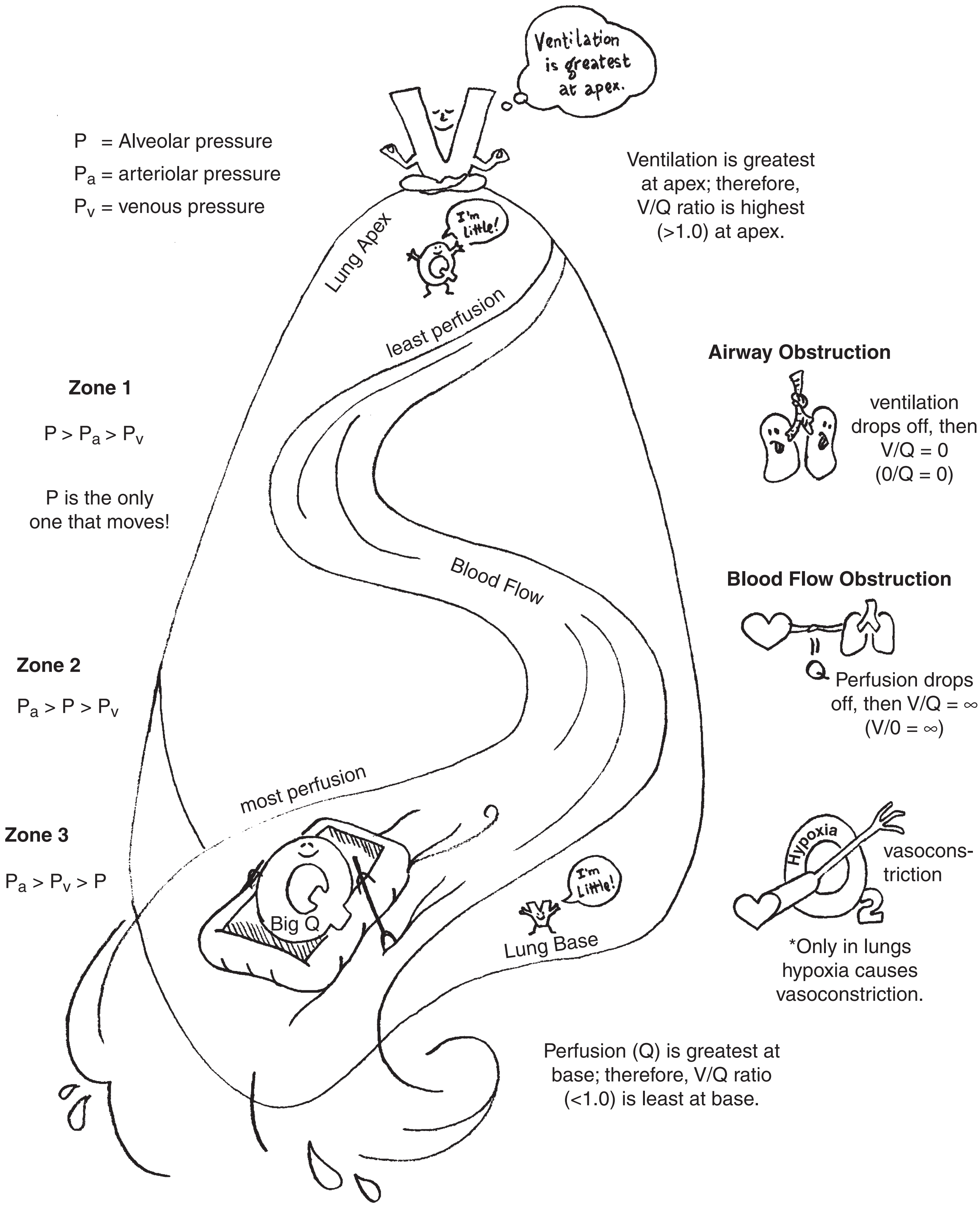
- Dalton's law of partial pressure: partial pressure = total pressure × fractional gas concentration
- In dry air the partial pressure is:
  - PO_2 = 760 mm Hg (atmospheric pressure) × 0.21 (fractional concentration of oxygen)
    = 160 mm Hg
- The air we inhale is humidified in the nasal cavity and trachea, resulting in a need to correct the PO_2.
  - PO_2 = (760 mm Hg – 47 mm Hg partial pressure of H_2O) × 0.21
    = 150 mm Hg
- Alveolar air is approximately 100 mm Hg → decreased secondarily to diffusion of oxygen to pulmonary arterial blood
- Arterial blood partial pressure of oxygen is approximately 100 mm Hg because the pulmonary capillary blood equilibrates with the alveolar air
- Diffusion rates of oxygen and carbon dioxide depend on pressure gradients through the alveolar-blood barrier
- Oxygen is carried in the blood as a dissolved form and bound to hemoglobin (Hgb)
- Adult hemoglobin (four subunits → $\alpha_2\beta_2$) dramatically increases the blood's capacity to carry oxygen; Hgb contains an iron element (heme) that—when in the ferrous state (Fe_2^+)—binds oxygen; when in the methemoglobin state (Fe_3^+) does not bind oxygen.
- Fetal hemoglobin (four subunits → $\alpha_2\beta_2$) possesses a higher affinity for oxygen than adult hemoglobin because it does not bind as well to 2,3-DPG; the oxygen from the mother's blood will therefore more readily transfer to the fetus' blood during pregnancy
- When bound to oxygen hemoglobin forms oxyhemoglobin; the hemoglobin-oxygen dissociation curve illustrates the percentage of hemoglobin saturated with oxygen at a specific partial pressure of oxygen in the blood
  - Hgb is 100% saturated at a PO_2 of 100 mm Hg
  - Hgb is 75% saturated at a PO_2 of 40 mm Hg
  - Hgb is 50% saturated at a PO_2 of 25 mm Hg (also known as the P_{50}—the point at which oxygen binds to two of the four heme groups of the hemoglobin)
- Sigmoid shape of curve secondary to positive cooperativity property of hemoglobin; each successive oxygen molecule bound to hemoglobin increases the affinity for the next oxygen molecule to bind; hemoglobin will therefore have the highest affinity for the fourth and final oxygen molecule
- The flat portion of the curve illustrates that a large deficit of hemoglobin's ability to carry oxygen or a change in atmospheric concentration of oxygen may be tolerated before it becomes a problem
- Shifts to right on the curve mean a decrease in the affinity of Hgb for oxygen; unloading of oxygen to tissues is increased; examples: decrease in pH, increase in temperature, and increase in 2,3-DPG)
- Shifts to the left indicate an increase in the affinity of Hgb for oxygen; unloading of oxygen to tissues is decreased; the opposite circumstances apply here: increase in pH, decrease in temperature, and decrease in 2,3-DPG)
- Carbon monoxide decreases the oxygen content in blood by directly competing for sites on the hemoglobin molecule; hemoglobin's affinity for CO is 200 times that of oxygen


NORMAL
Factors that increase O_2 affinity:
• ↑ pH (or decreased H^+ concentration)
• ↓ temperature
• ↓ 2,3-DPG
• ↓ pCO_2
• ↓ metabolic needs
• fetal Hgb
Hypoxemia
Cyanosis
Hgb
I AM AFRAID OF HEIGHTS!
Shift of curve to right facilitates O_2 unloading from Hgb to tissues.
↑ Altitude (↑ 2,3-DPG)
Increased metabolic needs
Shift to left means an increase in Hgb's affinity for oxygen. Less unloading to tissues.
ACID
↓ pH or ↑ H^+ concentration
Shift to right means a decrease in Hgb affinity for oxygen.
Increased pCO_2
Increased temperature
TISSUE
100
75
50
25
O_2 Saturation (%)
25
50
75
100
PO_2 in mm Hg

NOTES

V/Q MISMATCH

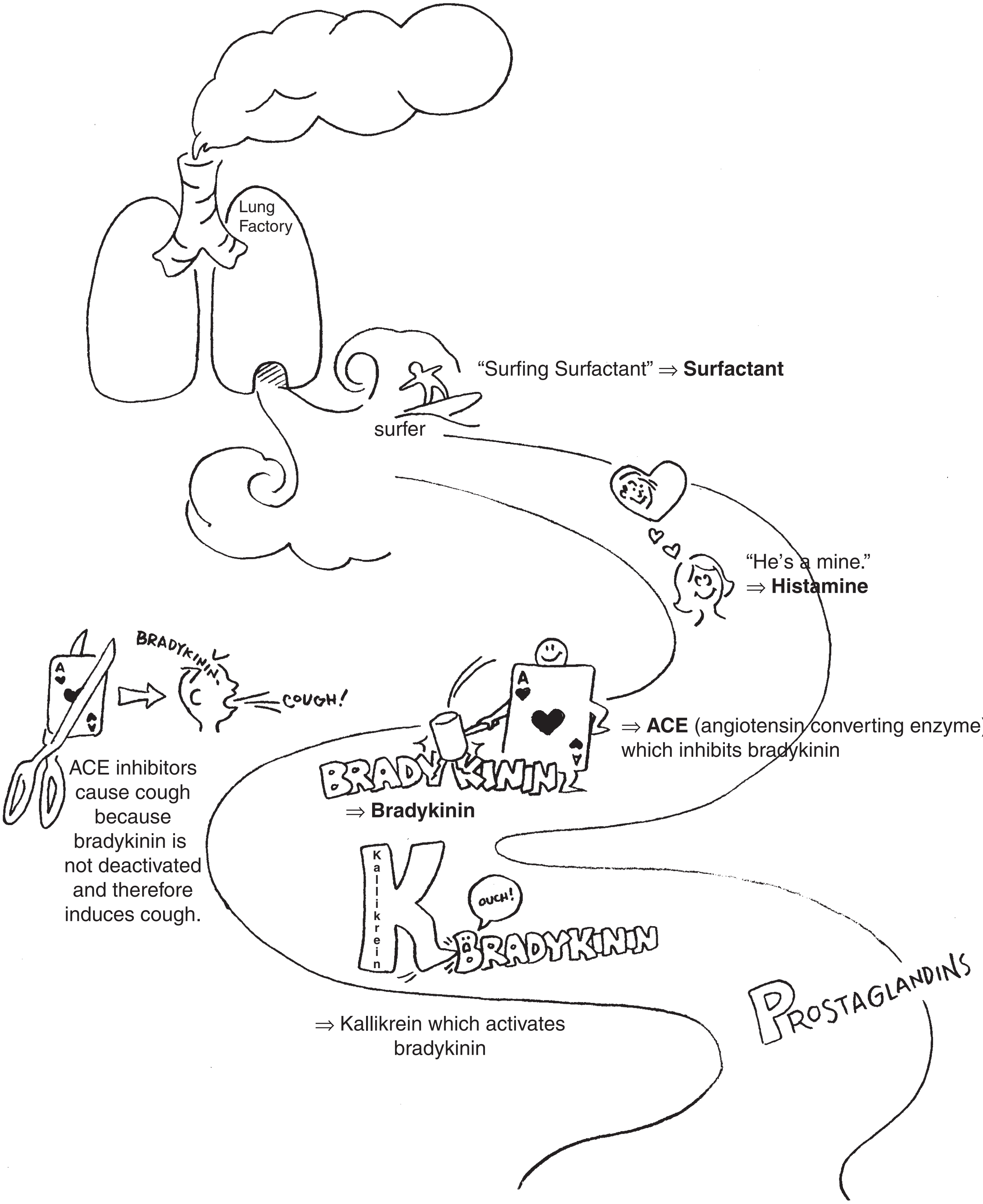
- V/Q ratio → ratio of alveolar ventilation (V) to pulmonary blood flow (Q)
- Normally equal to 0.8
- In airway obstruction the ventilation decreases; therefore no gas exchange, resulting in a V/Q ratio equal to 0 (0/Q = 0)
- In blood flow obstruction the perfusion of the lung is decreased; V/Q ratio therefore equals infinity (∞) (V/0 = ∞)
- Ratios vary according to anatomical locations in lung:
  - at apex, perfusion is the least secondary to gravity and ventilation is the greatest; the V/Q ratio is therefore highest (>1.0) at the apex; gas exchange is more efficient
  - at the base, perfusion is the greatest secondary to gravity and ventilation is the least; the V/Q ratio is therefore lowest (<0.8) at the base; gas exchange is less efficient.


Ventilation is greatest at apex.
P = Alveolar pressure
P_a = arteriolar pressure
P_v = venous pressure
Ventilation is greatest at apex; therefore, V/Q ratio is highest (>1.0) at apex.
I'm little!
Lung Apex
least perfusion
Airway Obstruction
ventilation drops off, then V/Q = 0 (0/Q = 0)
Zone 1
$P > P_a > P_v$
P is the only one that moves!
Blood Flow
Blood Flow Obstruction
Q
Perfusion drops off, then V/Q = ∞ (V/0 = ∞)
Zone 2
$P_a > P > P_v$
most perfusion
Zone 3
$P_a > P_v > P$
Hypoxia
vasocons-triction
Big Q
I'm Little!
Lung Base
*Only in lungs hypoxia causes vasoconstriction.
Perfusion (Q) is greatest at base; therefore, V/Q ratio (<1.0) is least at base.

NOTES

WHAT PRODUCT DO THE LUNGS MAKE?

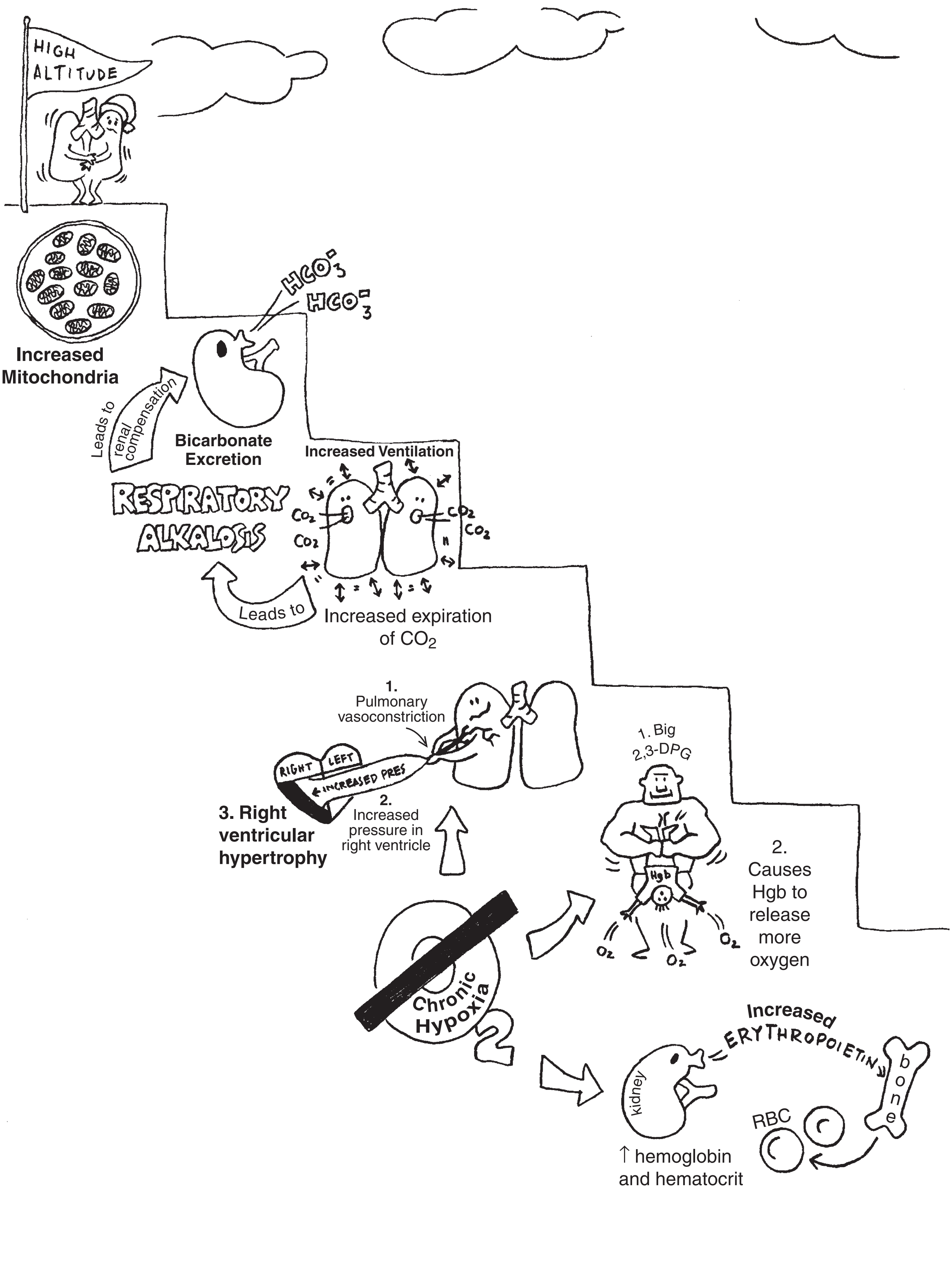
- Surfactant: reduces surface tension in alveoli and prevents their collapse
- Histamine
- Angiotensin converting enzyme: ACE converts angiotensin I to angiotensin II; it also inactivates bradykinin; therefore, when ACE inhibitors are used to control blood pressure, bradykinin is in its active form; a side effect would be a cough
- Kallikrein: activates bradykinin
- Prostaglandins: important in augmenting inflammatory reactions


Lung Factory
"Surfing Surfactant" ⇒ **Surfactant**
surfer
"He's a mine."
⇒ **Histamine**
BRADYKININ
COUGH!
ACE inhibitors cause cough because bradykinin is not deactivated and therefore induces cough.
⇒ **ACE** (angiotensin converting enzyme) which inhibits bradykinin
BRADYKININ
⇒ **Bradykinin**
Kallikrein
OUCH!
BRADYKININ
⇒ Kallikrein which activates bradykinin
PROSTAGLANDINS

NOTES

CHANGES THAT OCCUR AT HIGH ALTITUDE

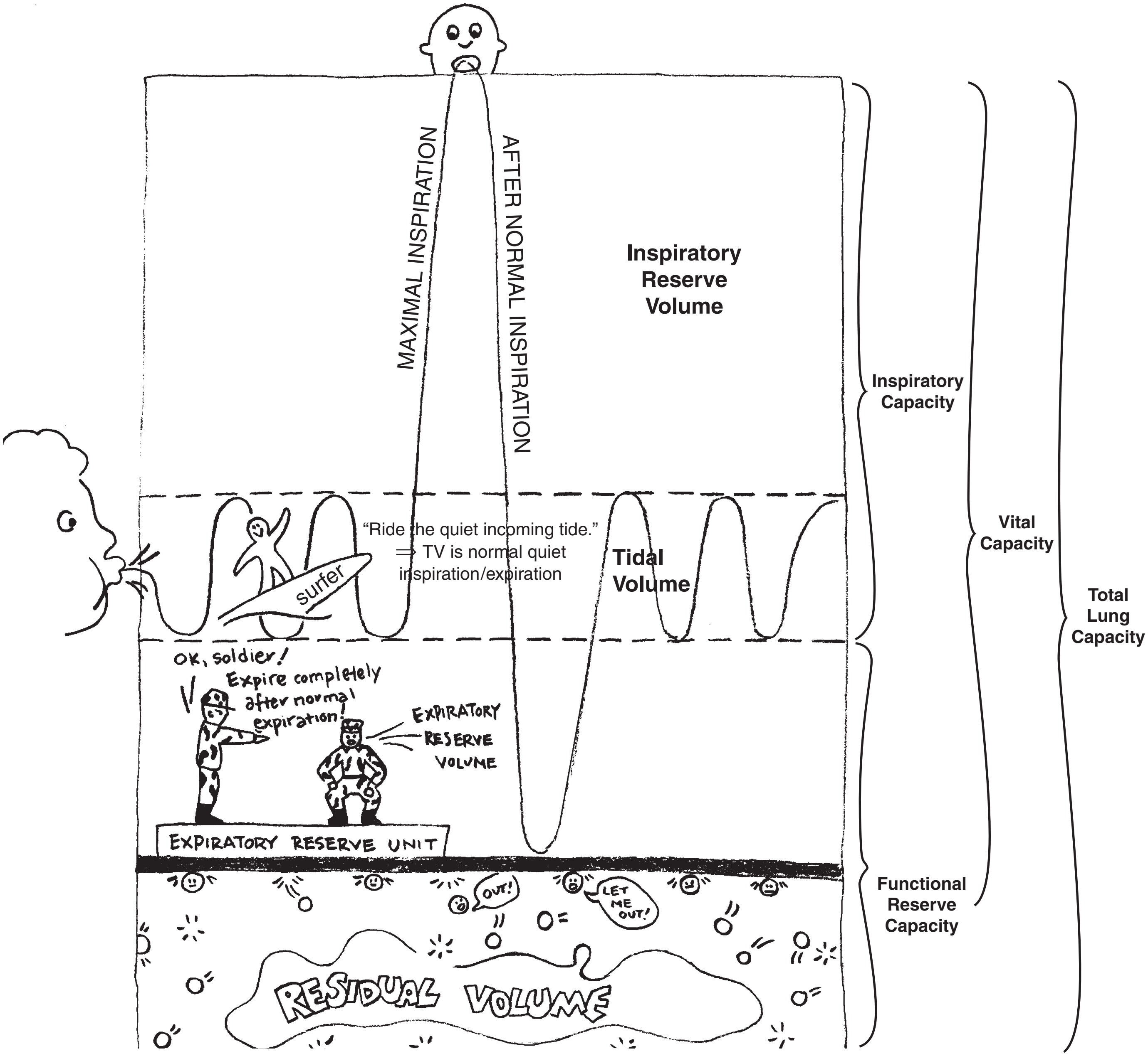
- Increased ventilation → leads to an increase in CO_2 expiration → respiratory alkalosis results → leads to renal compensation in the form of increased bicarbonate excretion
- Hypoxia causes three responses:
  - pulmonary vasoconstriction → leads to increased pressure in pulmonary artery → increased pressure in right ventricle; therefore → leads to right ventricular hypertrophy
  - increased 2,3-DPG causes increased unloading of oxygen from Hgb to tissues
  - increased erythropoietin results in increased RBC production; therefore → increased Hgb and hematocrit


HIGH ALTITUDE
Increased Mitochondria
HCO3-
HCO3-
Leads to
renal compensation
Bicarbonate Excretion
Increased Ventilation
RESPRATORY ALKALOSIS
CO2
CO2
CO2
CO2
Leads to
Increased expiration of CO2
1. Pulmonary vasoconstriction
RIGHT
LEFT
INCREASED PRES
2. Increased pressure in right ventricle
3. Right ventricular hypertrophy
1. Big 2,3-DPG
Hgb
O2
O2
O2
2. Causes Hgb to release more oxygen
Chronic Hypoxia
Increased ERYTHROPOIETIN
kidney
bone
RBC
↑ hemoglobin and hematocrit

NOTES

LUNG VOLUMES

- Total lung capacity
- Vital capacity
- Inspiratory capacity
- Functional reserve capacity
- Inspiratory reserve volume
- Tidal volume
- Expiratory reserve volume
- Residual volume


MAXIMAL INSPIRATION
AFTER NORMAL INSPIRATION
Inspiratory Reserve Volume
Inspiratory Capacity
Vital Capacity
Total Lung Capacity
"Ride the quiet incoming tide."
⟹ TV is normal quiet inspiration/expiration
surfer
Tidal Volume
OK, soldier!
Expire completely after normal expiration!
EXPIRATORY RESERVE VOLUME
EXPIRATORY RESERVE UNIT
OUT!
LET ME OUT!
RESIDUAL VOLUME
Functional Reserve Capacity