Respiratory Physiology

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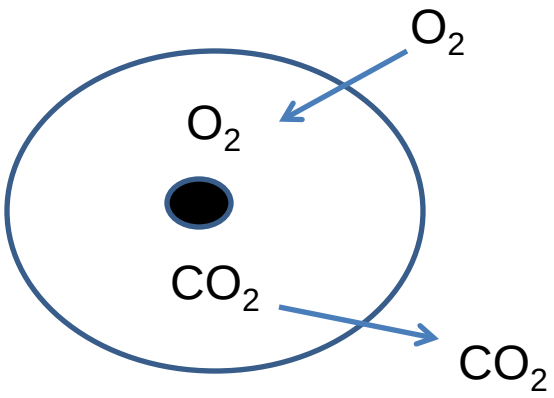
Respiration is the process by which an organism meets its requirement of O_2 and eliminates CO_2.

Unicellular organisms



Multi-cellular organisms

1. Blood circulatory system
2. Respiratory system

(a) Blood circulatory system to carry:

(1) O_2 to the tissue cells (with the help of Hb) and

(2) CO_2 liberated from metabolism in the tissue cells to the lungs.

(b) Respiratory system to load the blood with O_2 from the atmosphere and to remove excess CO_2 from the blood into the atmosphere.

The respiratory system consists of

(1) a gas exchanging organ, the lungs and

(2) a pump that ventilates the lungs:

The pump consists of

- the **chest wall**
- the **respiratory muscles** that increase or decrease the size of the thoracic cavity
- the **neurons in the brain and spinal cord** that control the respiratory muscles

External respiration (Pulmonary ventilation)

Internal respiration (Cell respiration)

(1) External respiration

- refers to exchange of O_2 and CO_2 between the external environment and the body as a whole.
- involves **pulmonary ventilation** and gas exchange in the lungs.

Primary function of the respiratory system

- Gas exchange
- delivering oxygen from the environment to the tissues and removing carbon dioxide from the tissues

(2) **Internal respiration** (**cell respiration**)

refers to

- exchange of O_2 and CO_2 between the internal environment and cells
- consumption of O_2 (for production of ATP in the mitochondria)
- formation and liberation of CO_2 by cells
- O_2 is required for production of energy (ATP) by the respiratory chain enzymes of mitochondria (**oxidative phosphorylation**)

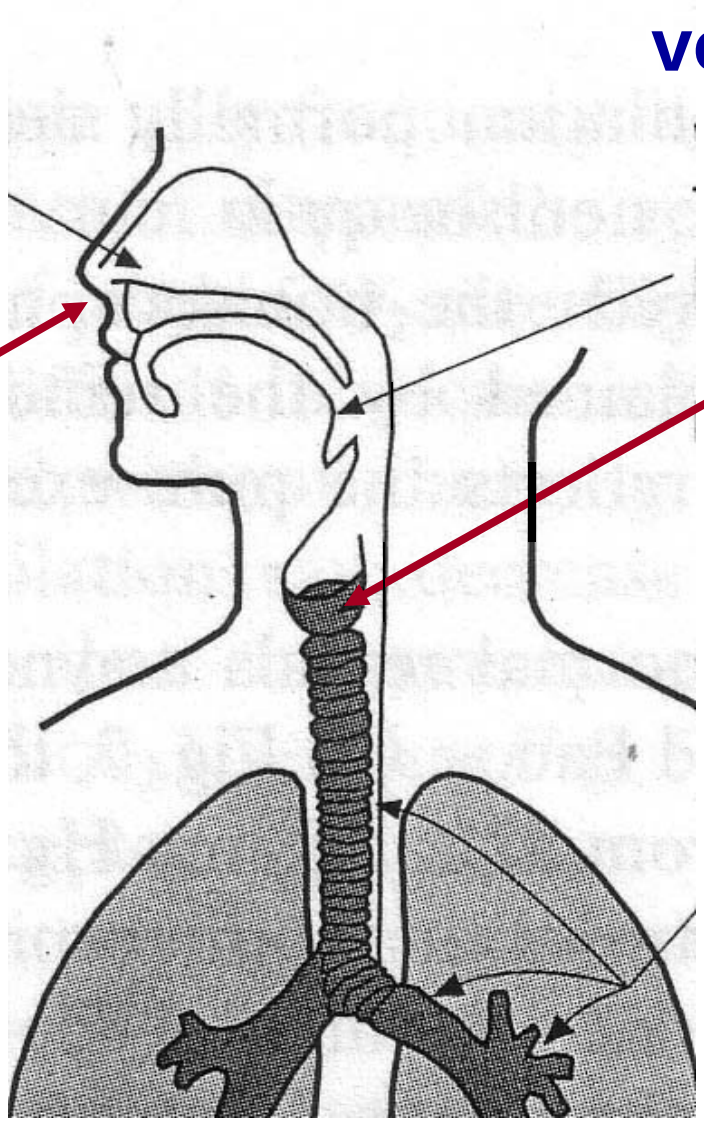
Rate of Ventilation or Breathing (Respiratory rate)

- At birth: 40 - 60 times/min
- First year: 25 - 35 times/min
- 2 - 4 years: 20 - 30 times/min
- 5 - 14 years: 20 - 25 times/min

Normal adult: 10 – 18 times/min

Upper respiratory tract

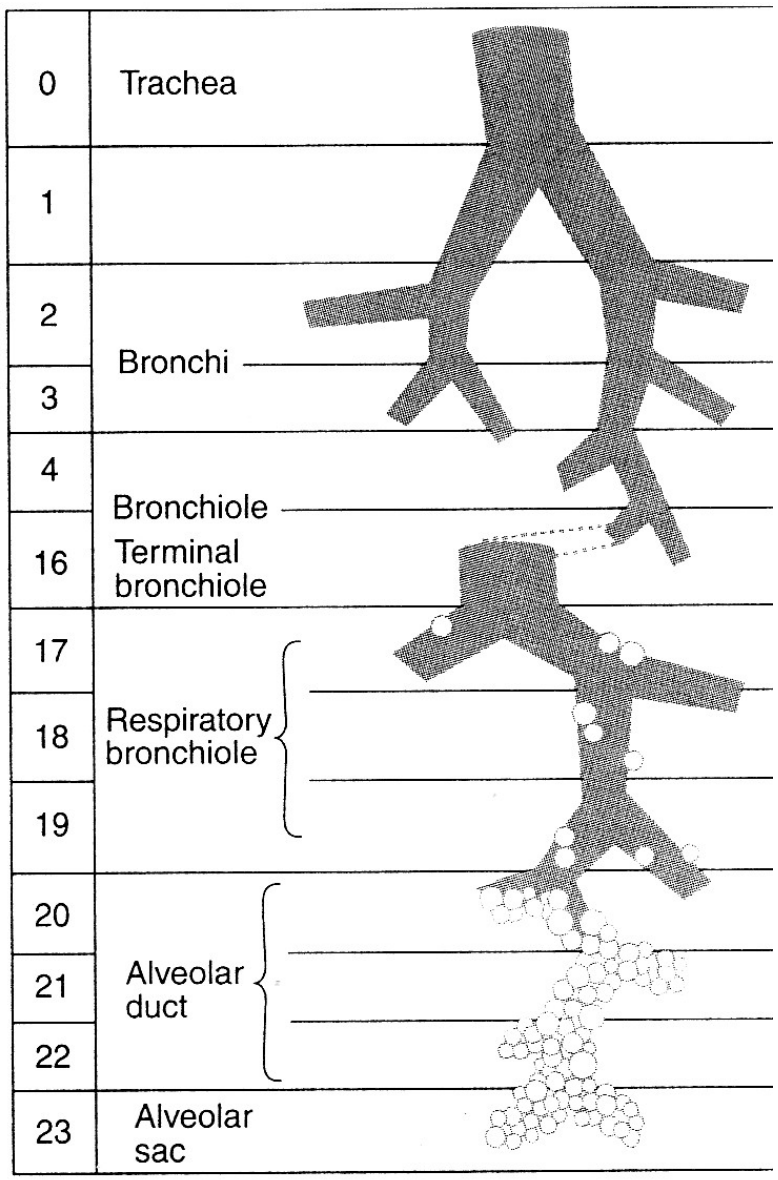
from anterior nares to vocal fold



Functions of URT

- **warm the inspired air**
- **humidified the insp air**
- **remove large particles in the insp air**

Lower respiratory tract



Air conduction

Gas exchange

Upper respiratory tract

Conducting Zone

from anterior nares to terminal bronchioles

Lower respiratory tract

Exchange zone

from respiratory bronchiole to alveolus

Velocity of airflow

Lower respiratory tract (Lungs)

is a series of branching tubes

Leading from the trachea

to smaller terminal air sacs at the ends of the airways

called alveoli.

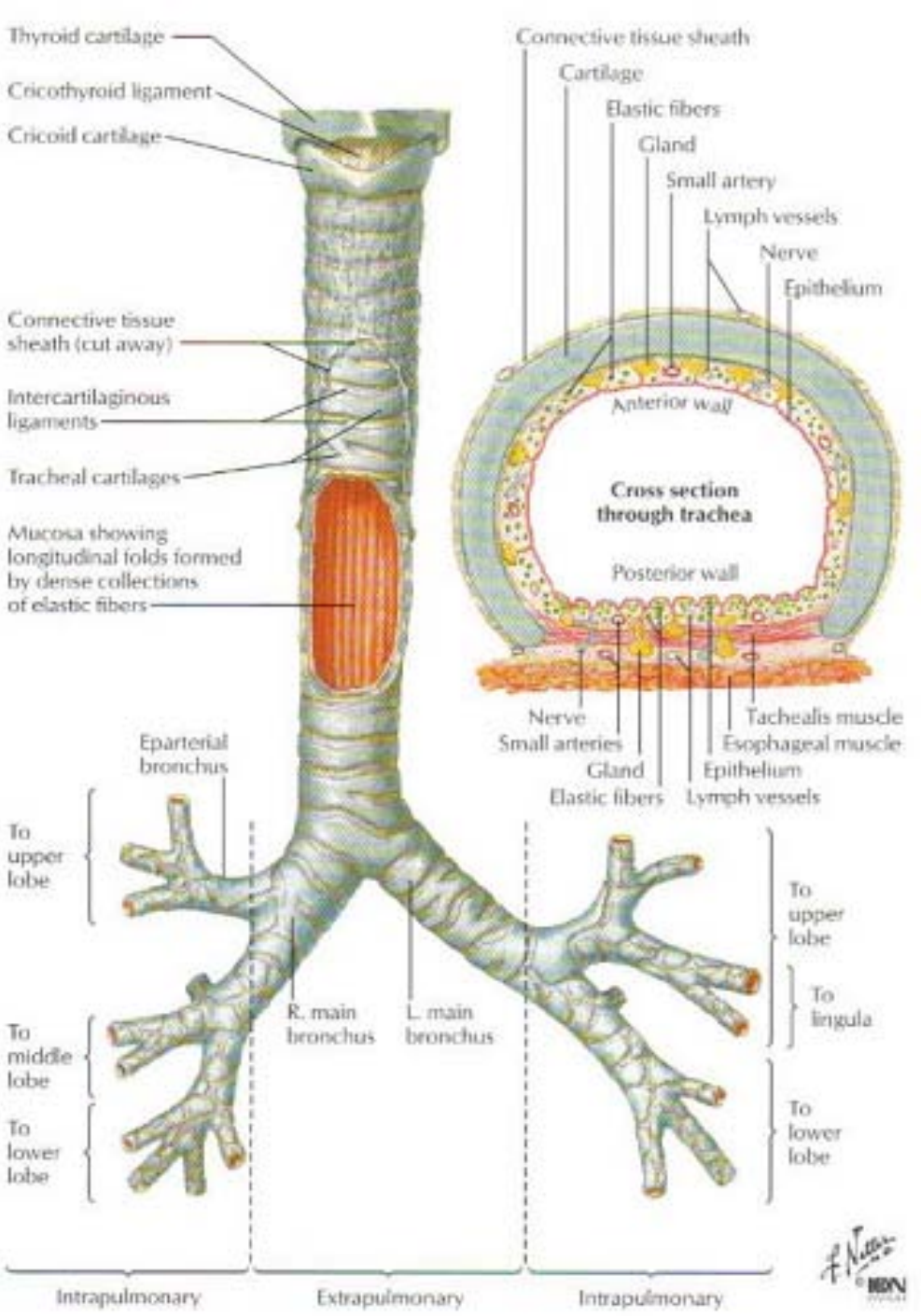
Trachea

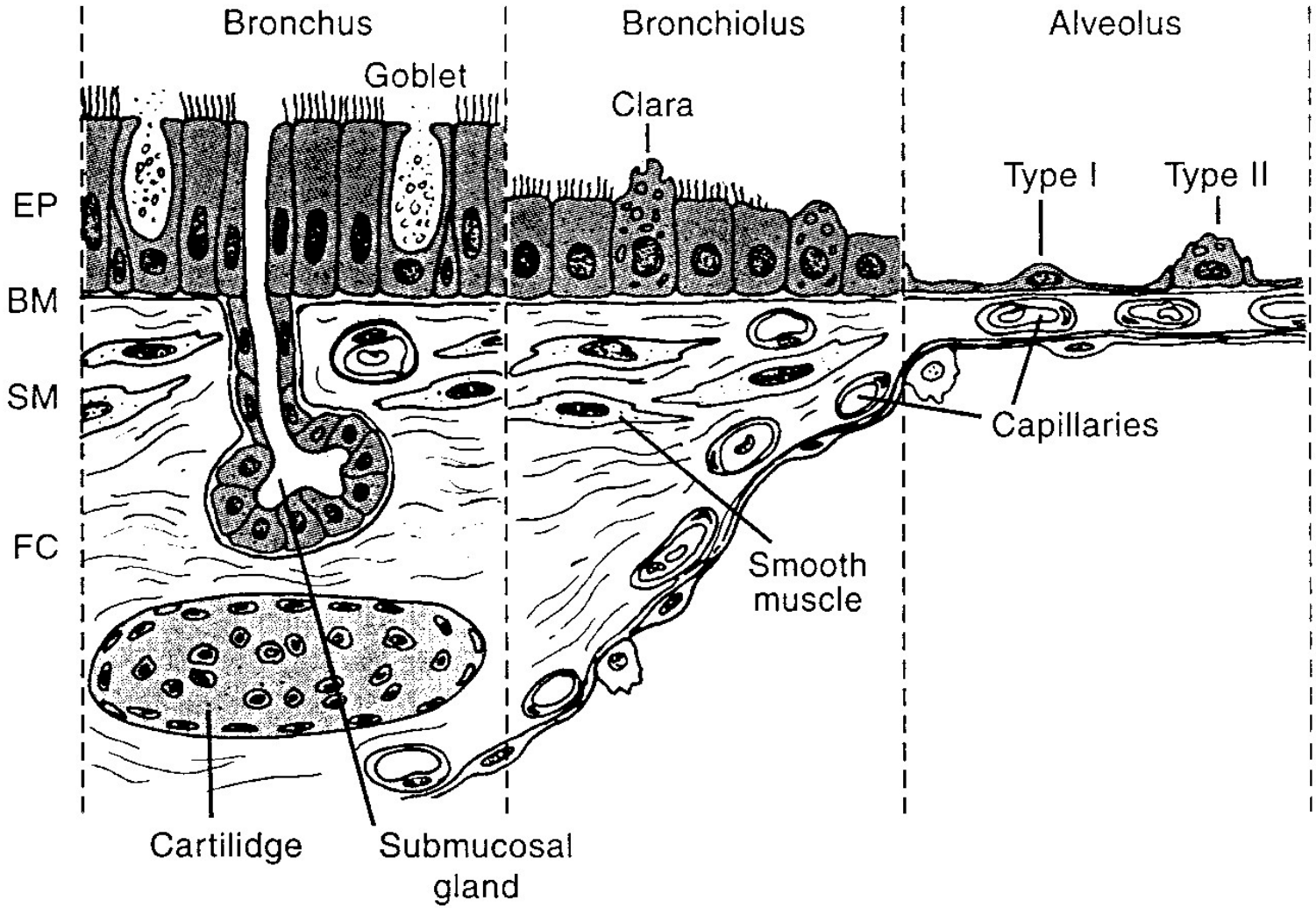
- lined by ciliated epithelium

- mucous and serous glands

- cartilage

- little smooth muscles




Bronchus
Bronchiolus
Alveolus
Goblet
Clara
Type I
Type II
EP
BM
SM
FC
Capillaries
Smooth muscle
Cartilidge
Submucosal gland

BRONCHIAL TONE

Bronchial tone: a partially contracted state of the bronchial smooth muscle

Functions

- helps to maintain an even distribution of ventilation
- protects the bronchi during coughing
- aids ventilation

CONTROL OF BRONCHIAL TONE

- **Neural control (autonomic nervous system)**
  (1) Parasympathetic cholinergic discharge
  (2) Stimulation by irritants
  (3) Sympathetic noradrenergic discharge
  (4) Non-cholinergic and non-adrenergic discharge

- **Chemical control**
- **Physical control**
- **Circadian variation**

Neural control of bronchial tone

(a) Parasympathetic cholinergic discharge

Ach + muscarinic receptor

↓

contraction of bronchial and bronchiolar muscle

(bronchoconstriction)

irritants and chemicals + irritant receptors in airway

↓

reflex bronchoconstriction (cholinergic pathway)

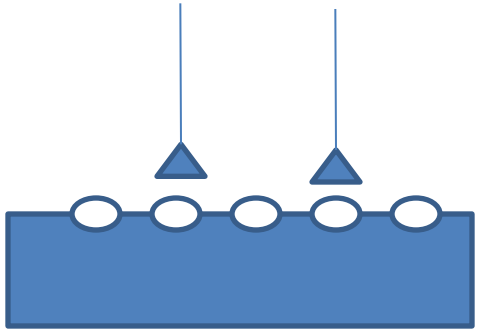
CONTROL OF BRONCHIAL TONE

(b) Sympathetic noradrenergic discharge

NA or adrenaline + β_2-adrenergic receptors

↓

relaxation of bronchial smooth muscle
(bronchodilation)

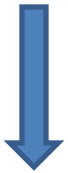


- **Most of the receptors are not innervated.**

- **Response to circulating adrenalin and inhaled β-agonist**

CONTROL OF BRONCHIAL TONE

(c) Noncholinergic, nonadrenergic innervation



VIP (vasoactive intestinal peptide)

bronchodilation

VIP has been found to be deficient or absent in large number of patient with bronchial asthma.

CONTROL OF BRONCHIAL TONE

(2) Humoral factors: bronchoconstriction

- histamine
- substance P
- adenosine

VD

- some prostaglandins

VD/VC

- some leukotrienes

VC

CONTROL OF BRONCHIAL TONE

(3) Physical factors

- Cooling the airways: bronchoconstriction

- Physical exercise - asthmatic attacks
  by lowering airway temperature

CONTROL OF BRONCHIAL TONE

(4) Circadian variation

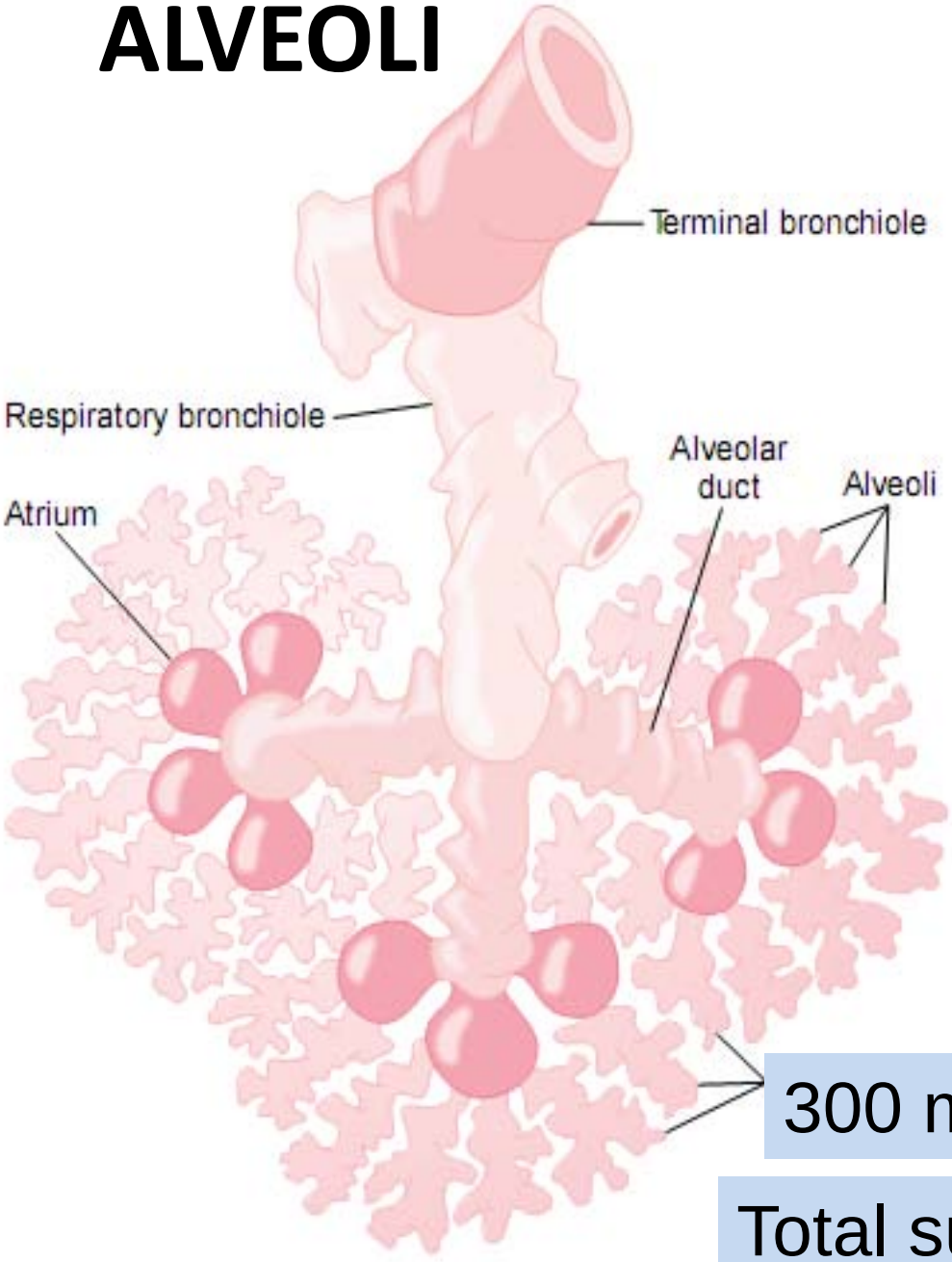
- a daily rhythm called *circadian rhythm* in bronchial tone

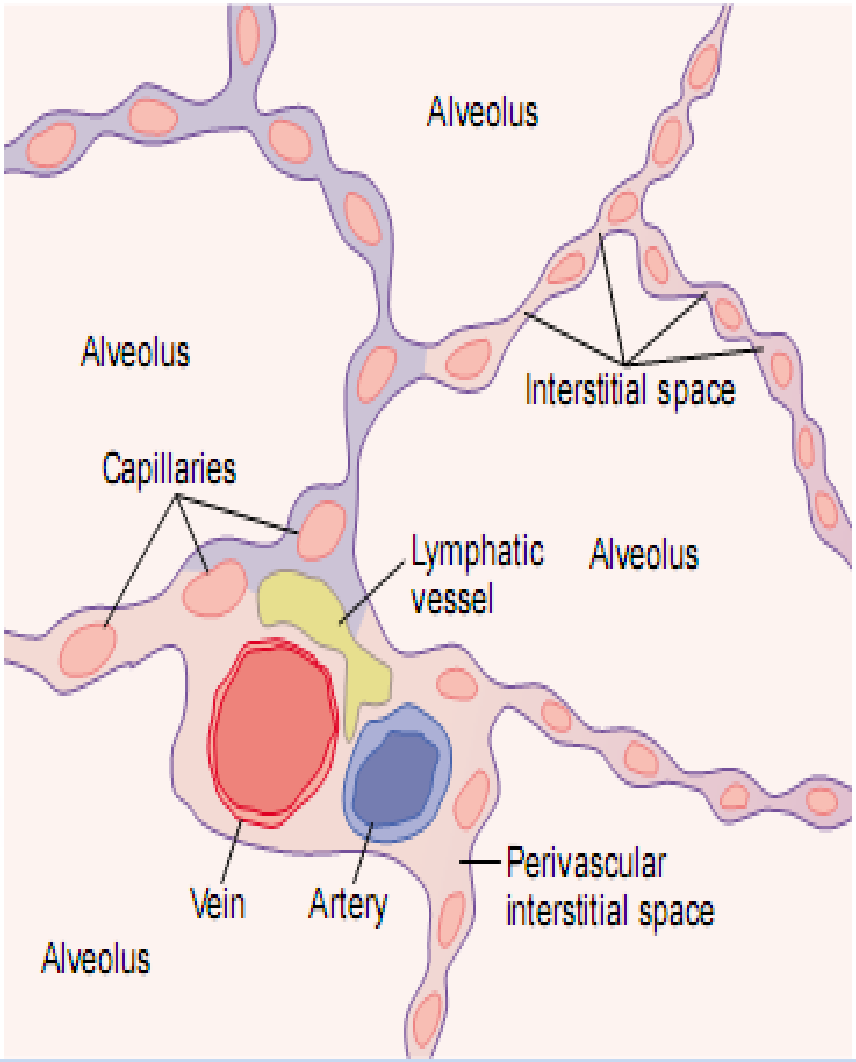
- maximal constriction at about 6:00am

- maximal dilation at about 6:00pm

- asthmatic attacks are more severe in the early morning hours.

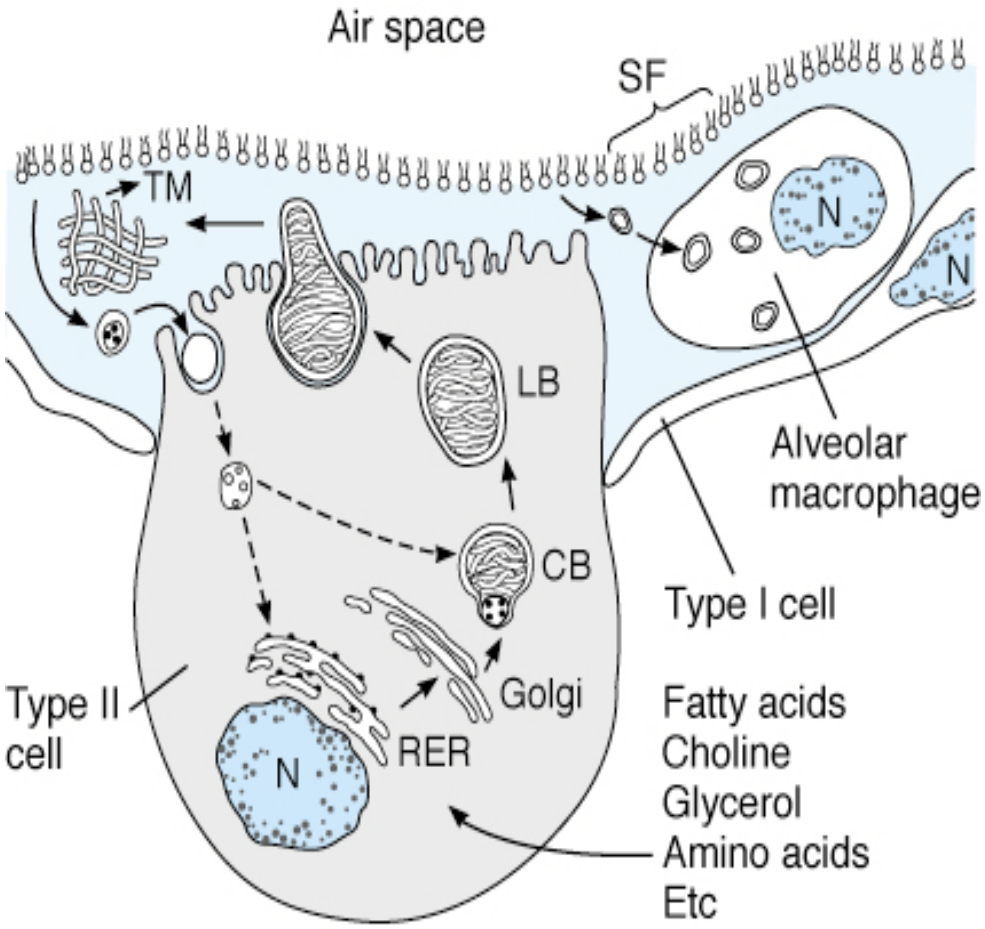
ALVEOLI





300 million alveoli in both lungs

Total surface area: 70m^2



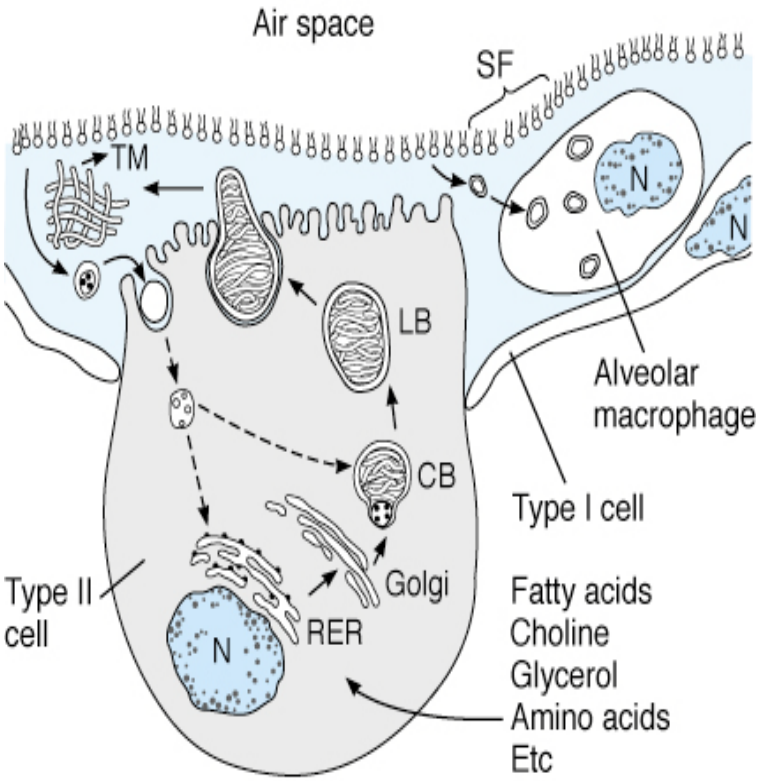
Epithelial lining cells

- 2 types of

(a) **Type I cells**: primary lining cells

(b) **Type II cells**: thicker and secrete surfactant,

Surfactant



- a lipid surface tension lowering agent
- is present in the thin film of fluid lining the alveoli
- a mixture of phospholipid (DPPC) and proteins
  (SP-A, SP-B, SP-C and SP-D)
- phospholipid: head (hydrophillic)
  tail (hydrophobic)
- tails: facing the alveolar lumen

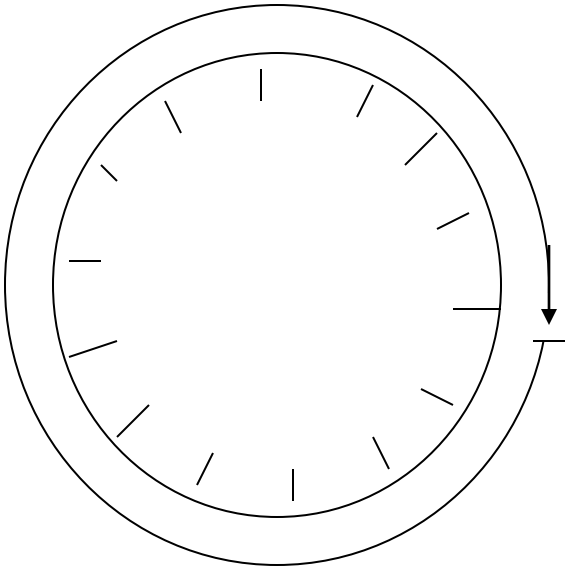
Surface Tension

- is the force due to molecular attraction that pulls the water molecules towards the interior thereby tending to reduce the surface area.
- The surface tension at the air-fluid interface; interface between air in the alveoli and the fluid that lines the lung alveoli
- If ST of this film of fluid is high, the wall of the alveoli collapses
- Surfactant lowers the surface tension of the fluid that lines the lung alveoli.

$$T \propto \frac{1}{[S]}$$

S = 14

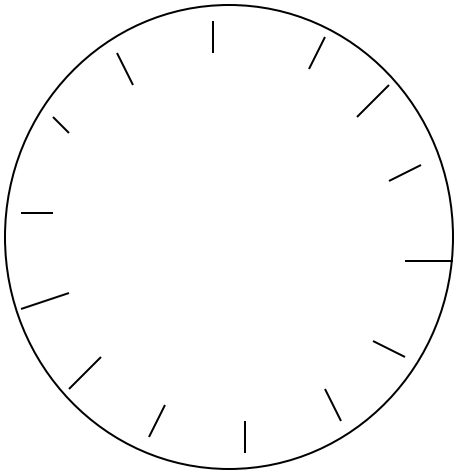
Area = 10 cm^2



[S] = 14/10 = 1.4 /cm^2

$$T \propto \frac{1}{[S]}$$

S = 14



Inspiration

Alveoli: enlarged

Area = increased

20 cm^2

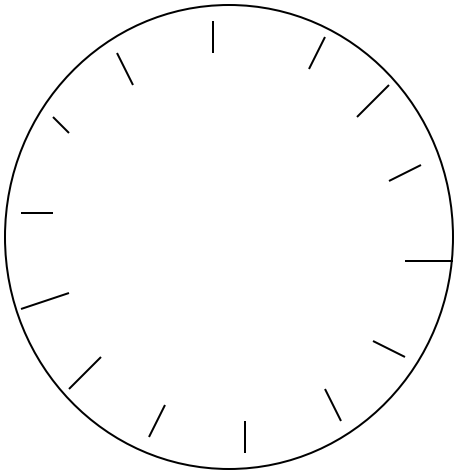
Molecular dispersion

$[S] = 14/20 = 0.7\ /cm^2$

T = increased

$$T \propto \frac{1}{[S]}$$

S = 14



Expiration

Alveoli: smaller

Area = decreased

5 cm^2

Molecular reaccumulation

[S] = 14/5 = 2.7 /cm^2

T = decreased

Inspiration

Surface tension: increased

Expiration

Surface tension: decreased

1. prevents collapse of the lungs during expiration

Expiration

Law of Laplace

r is reduced

If T is not reduced

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

$$P < T$$

alveoli collapse

Expiration: T decreased (because [S] increased)

2. reduces the effort of breathing thereby reducing the pressure require to inflate the lungs

- Elastic resistance = the resistance offered by the elastic tissues of the cheat wall and lungs
  (i.e. tendency of recoil of the lungs and the cheat wall to the resting positing

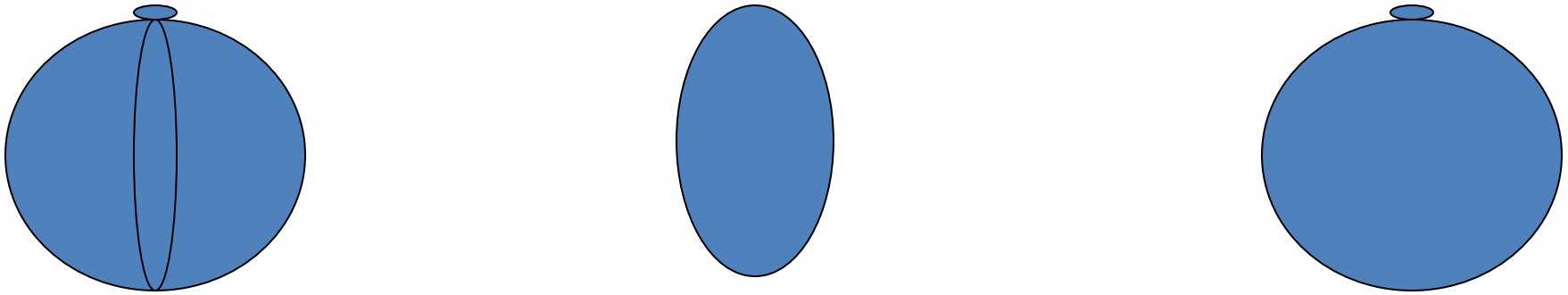
- ST = the force due to molecular attraction that pulls the water molecules towards the interior thereby tending to reduce the surface area.

- ST = 2/3 of the elastic resistance

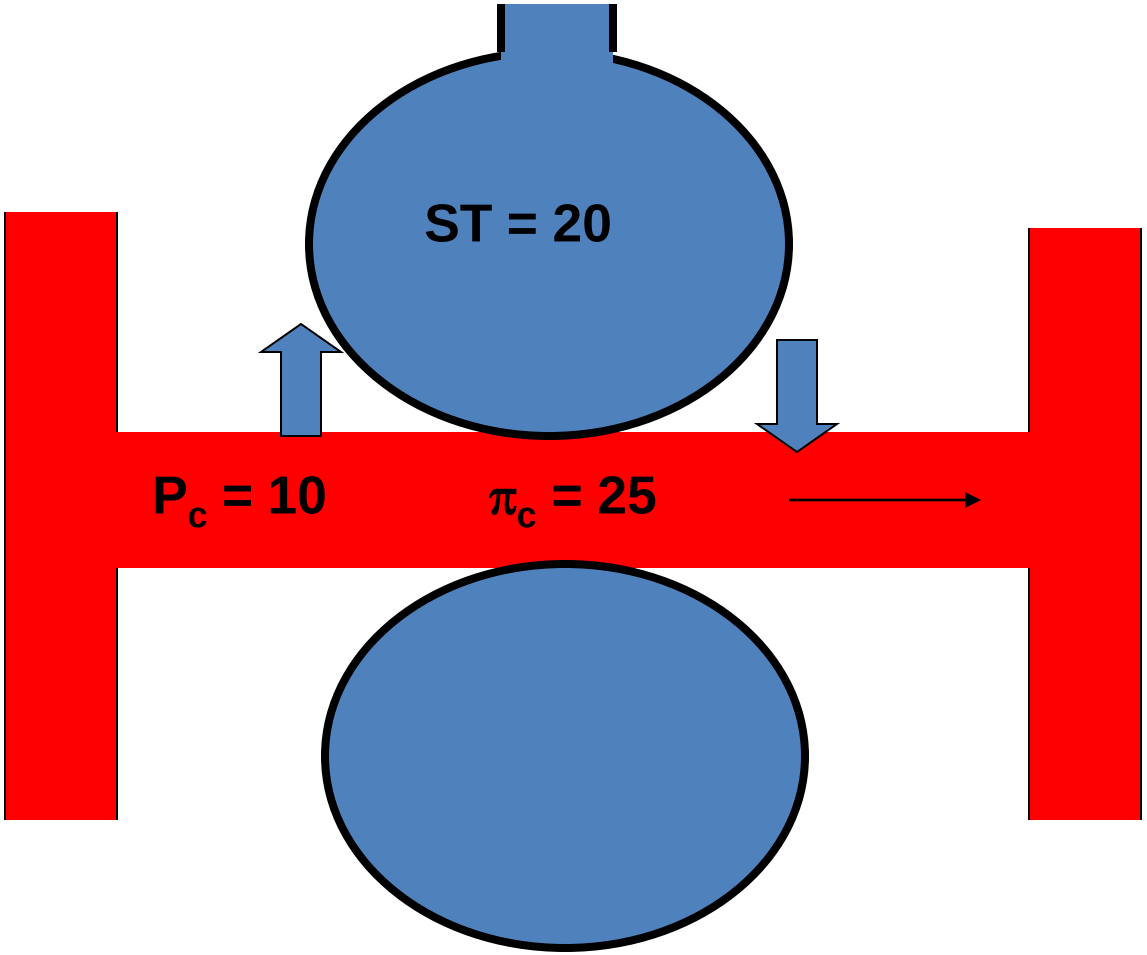
- first breath at birth

At birth: first breath

At birth



3. prevent pulmonary edema



Outward force = Pc + ~~ST~~

= 10 + ~~20~~ = ~~30~~

Inward force = π_c = 25

Synthesis:

- completed after 28th week of gestation
- thyroid hormones

Maturation:

- glucocorticoids

Surfactant deficiency

- Babies
  - Premature babies
  - Hypothyroid babies
  - Babies borne to diabetic mother

Infant Respiratory distress syndrome (IRDS)

- Adults
  - Chronic smokers
- Those who underwent cardiac operation (patchy atelectasis)
- Occlusion of a main bronchus
- Long term inhalation of inhale 100% O_2

Surfactant deficiency

Features

- lung collapse
- respiratory distress
- pulmonary edema

- decreased alveolar P_{O_2} and increased P_{CO_2}
- decreased arterial P_{O_2} and increased P_{CO_2}

- hypoxia and hypercapnia
- Respiratory failure

Mechanics of Respiration (Breathing)

- Pulmonary ventilation: movement of the gases in and out of the lungs
- is brought about by variation in the size of the thoracic cavity which is followed by the movement of the lungs

Inspiration

I neurones discharge (in medulla oblongata)

Respiratory motor neurones (in spinal cord)

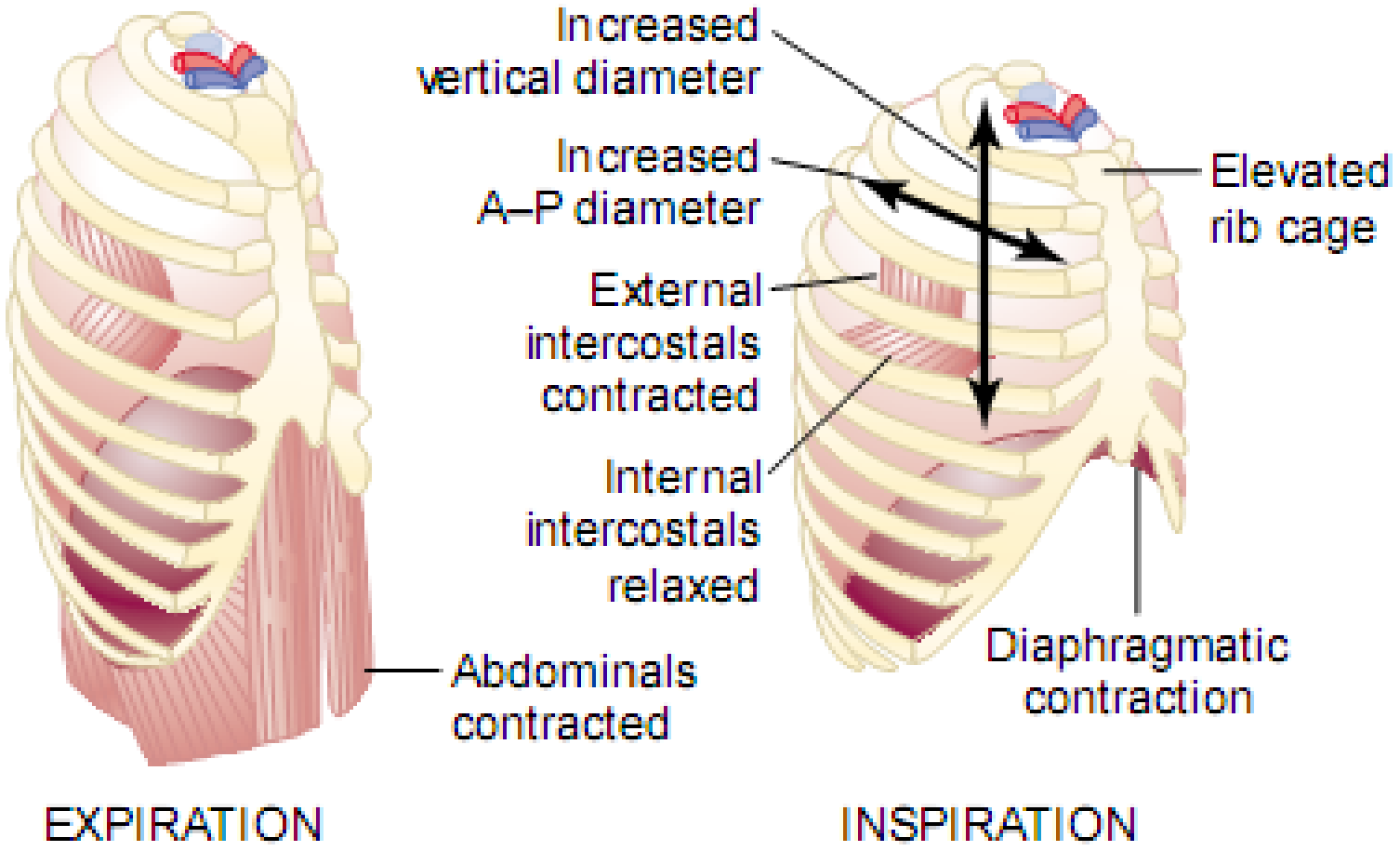
RMN to diaphragm (C3,C4, C5)

Contraction of diaphragm (move downward)

RMN to external intercostal muscles (T1 to T12)

Contraction of ext. IC ms (move outward)

an increase in intrathoracic volume


Increased vertical diameter
Increased A–P diameter
External intercostals contracted
Internal intercostals relaxed
Abdominals contracted
Elevated rib cage
Diaphragmatic contraction
EXPIRATION
INSPIRATION

an increase in intrathoracic volume

ACTIVE

↓

Decrease in IPLP (from -2.5 to -6 mmHg)

↓

LUNGS: pulled into more expanded position

↓

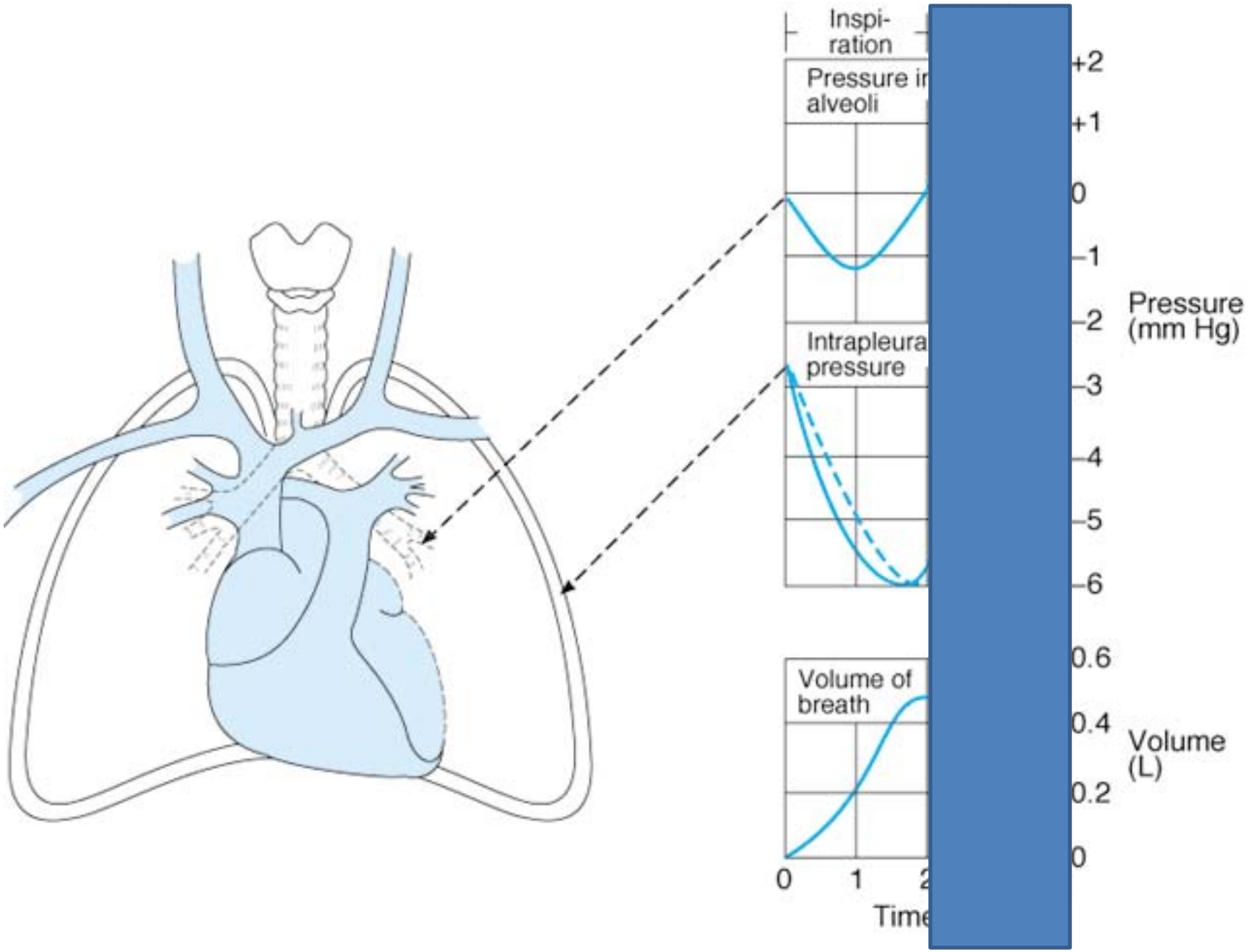
Decrease in IPulP (from 0 to -1 mmHg)

↓

Air enters the lungs (pressure gradient)

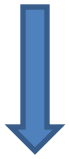
↓

Air flow stop (when IPulV increases and IPulP increases to 0 mmHg)


Inspi-
ration
Pressure in
alveoli
Intrapleural
pressure
Volume of
breath
+2
+1
0
–1
–2
–3
–4
–5
–6
Pressure
(mm Hg)
0.6
0.4
0.2
0
Volume
(L)
0
1
Time

Expiration

I neurone discharge stops (in medulla oblongata)



Respiratory motor neurones activity stop (in spinal cord)

Contraction of diaphragm and ext. IC ms stops

Lund recoils: the chest back to the expiratory position)

a decrease in intrathoracic volume

a decrease in intrathoracic volume

↓

An increase in IPLP (from -6 to -2.5 mmHg)

↓

Lungs recoil

PASSIVE

↓

An increase in IPulP (from 0 to +1 mmHg)

↓

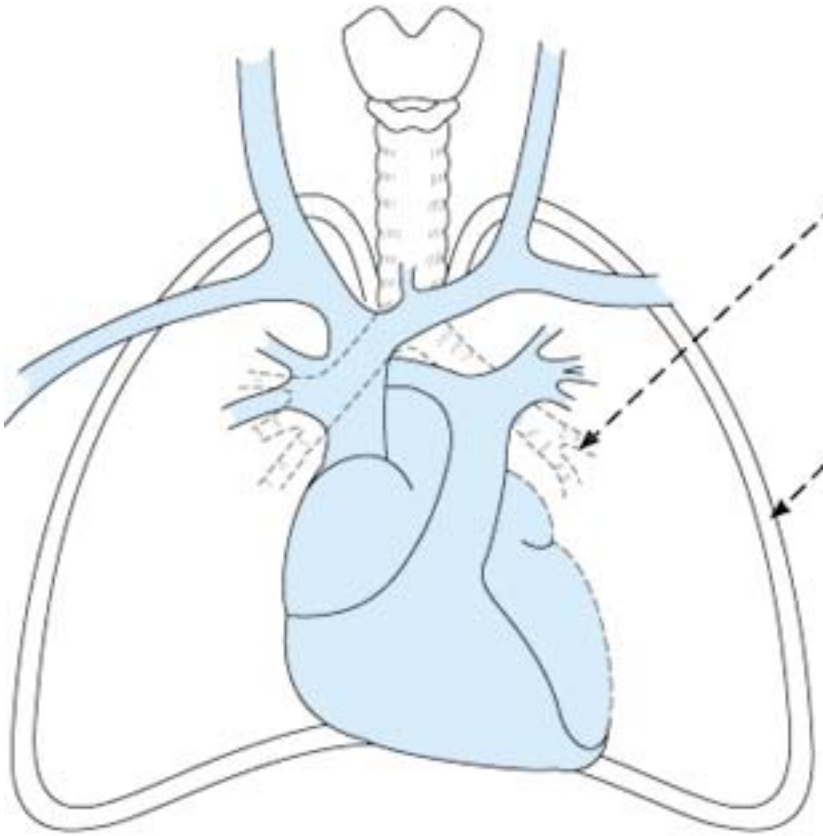
Air moves out of the lungs (pressure gradient)

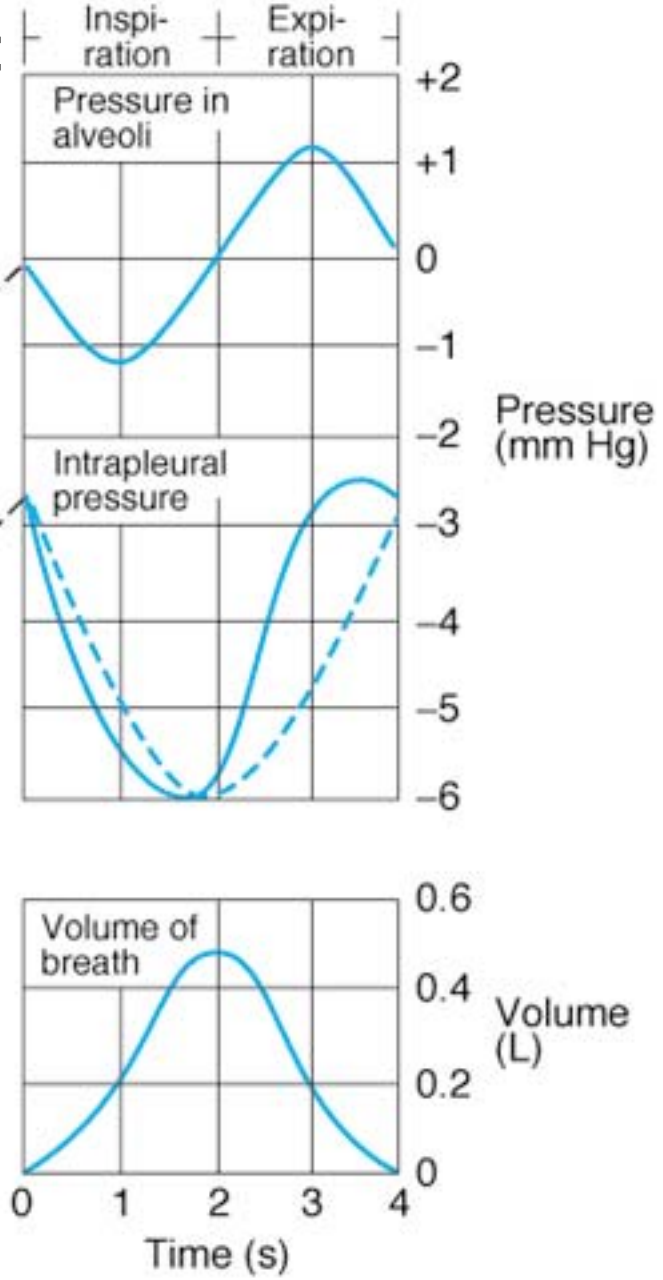
↓

Air flow stop (when IPulV decreases and IPulP falls back to 0 mmHg)

Some contraction of inspiratory muscle:

Braking action





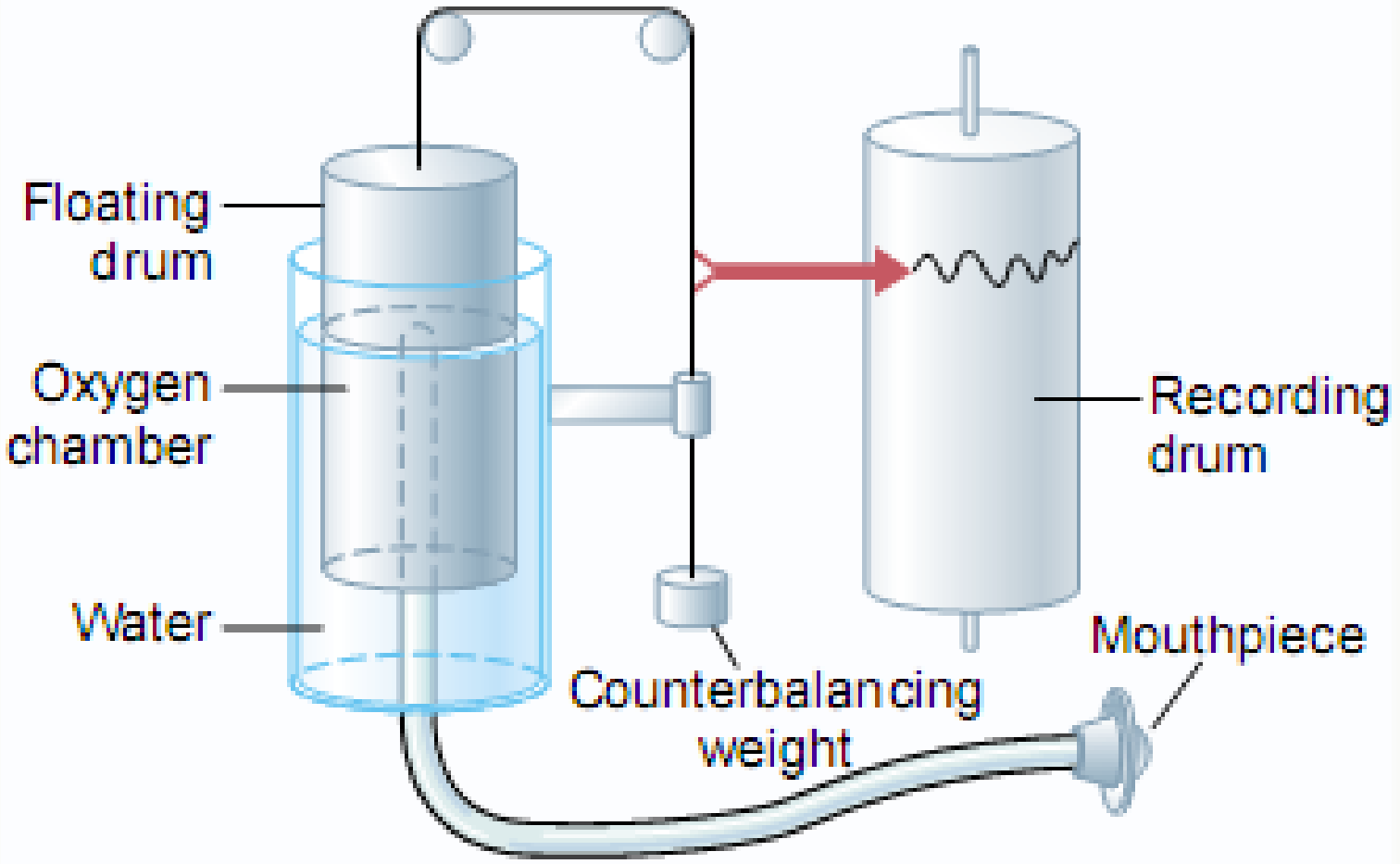
Forced inspiration

- Accessory muscles of inspiration: sternomastroid, sclenes, pectoralis, serratus anterior, rhomboid, trapezius, latissimus dorsi
- IPLP: **-30 mmHg**

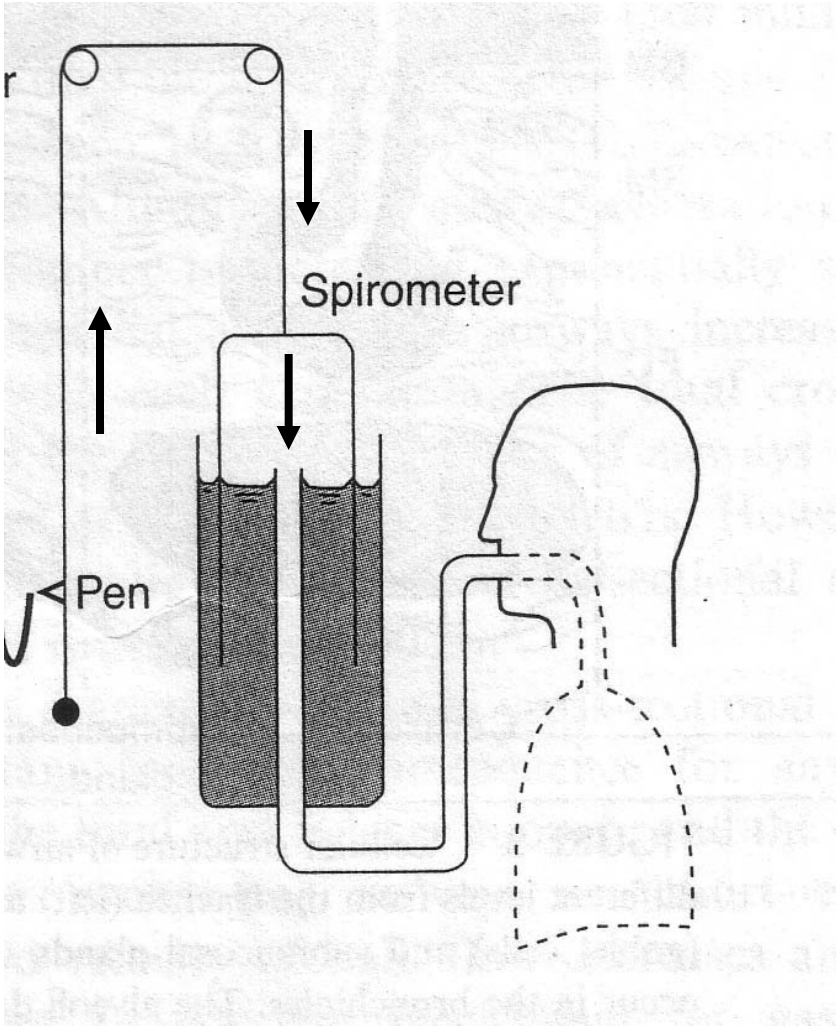
Forced expiration

- Expiratory muscles : internal IC, ant. abdominal ms
- IPLP: **+30 mmHg to +300 mmHg**

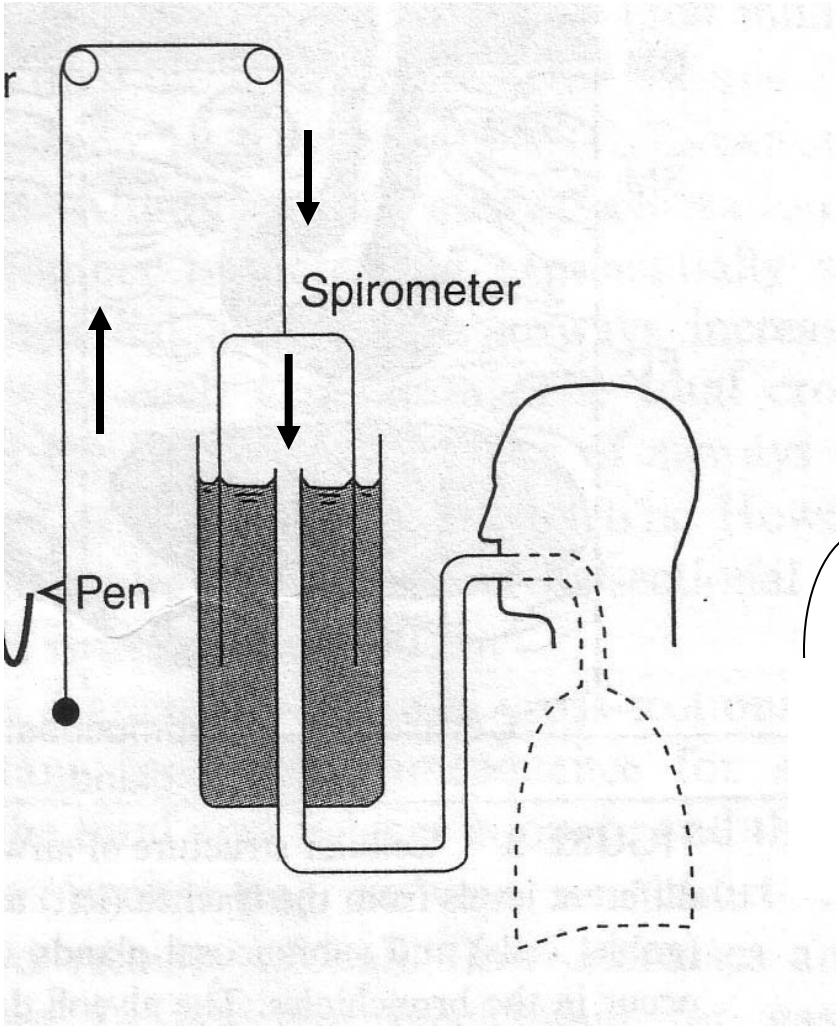
SPIROMETER


Floating drum
Oxygen chamber
Water
Counterbalancing weight
Recording drum
Mouthpiece

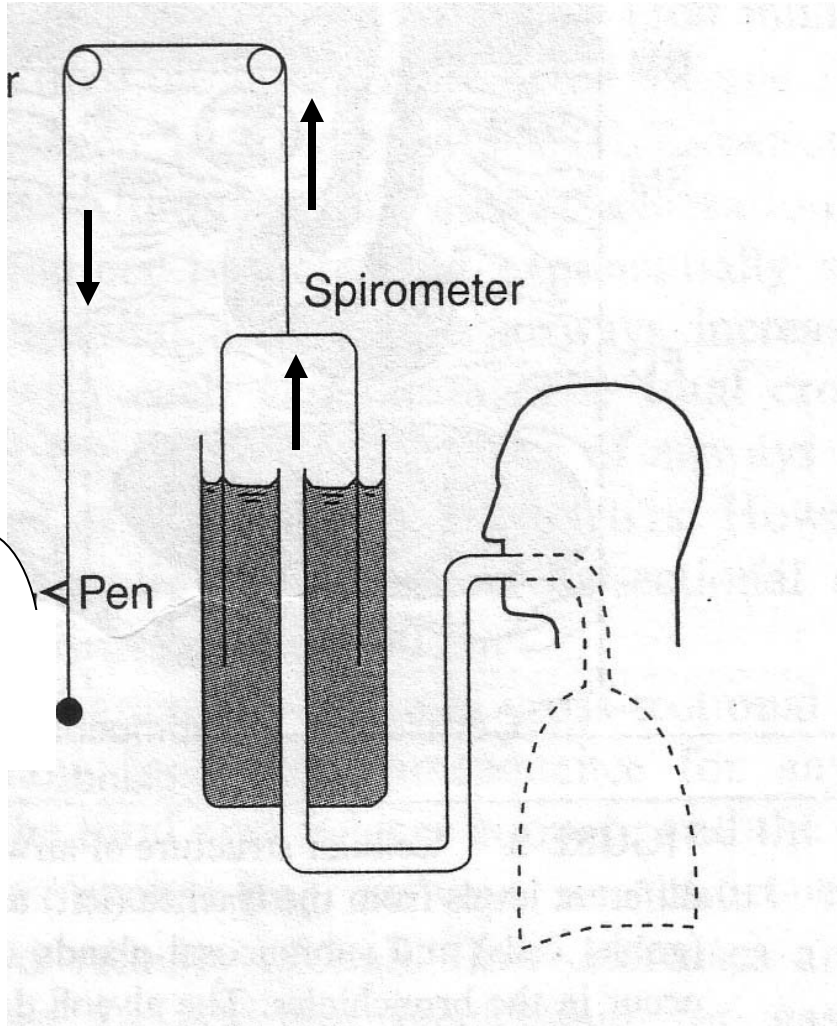
INSPIRATION

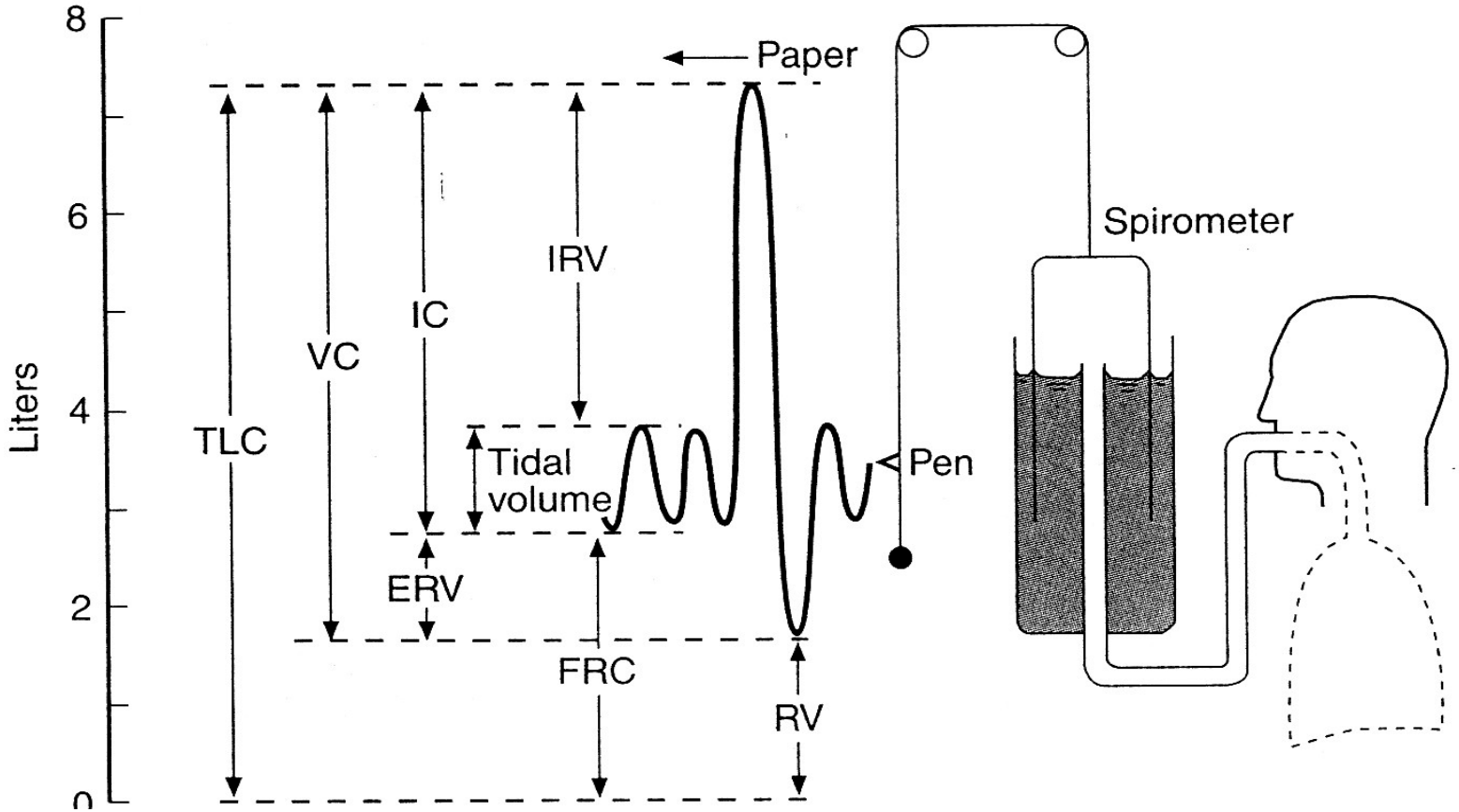


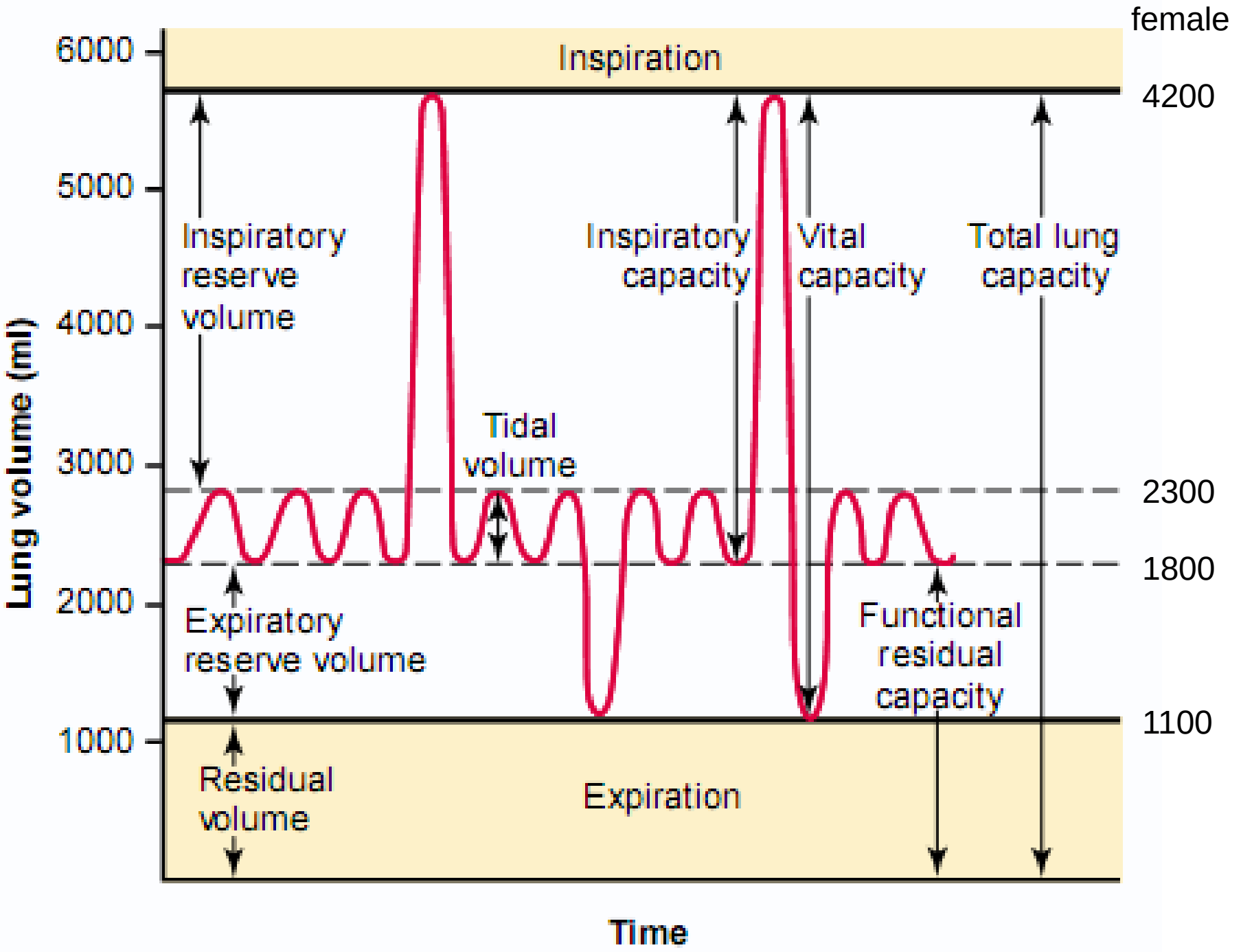
INSPIRATION

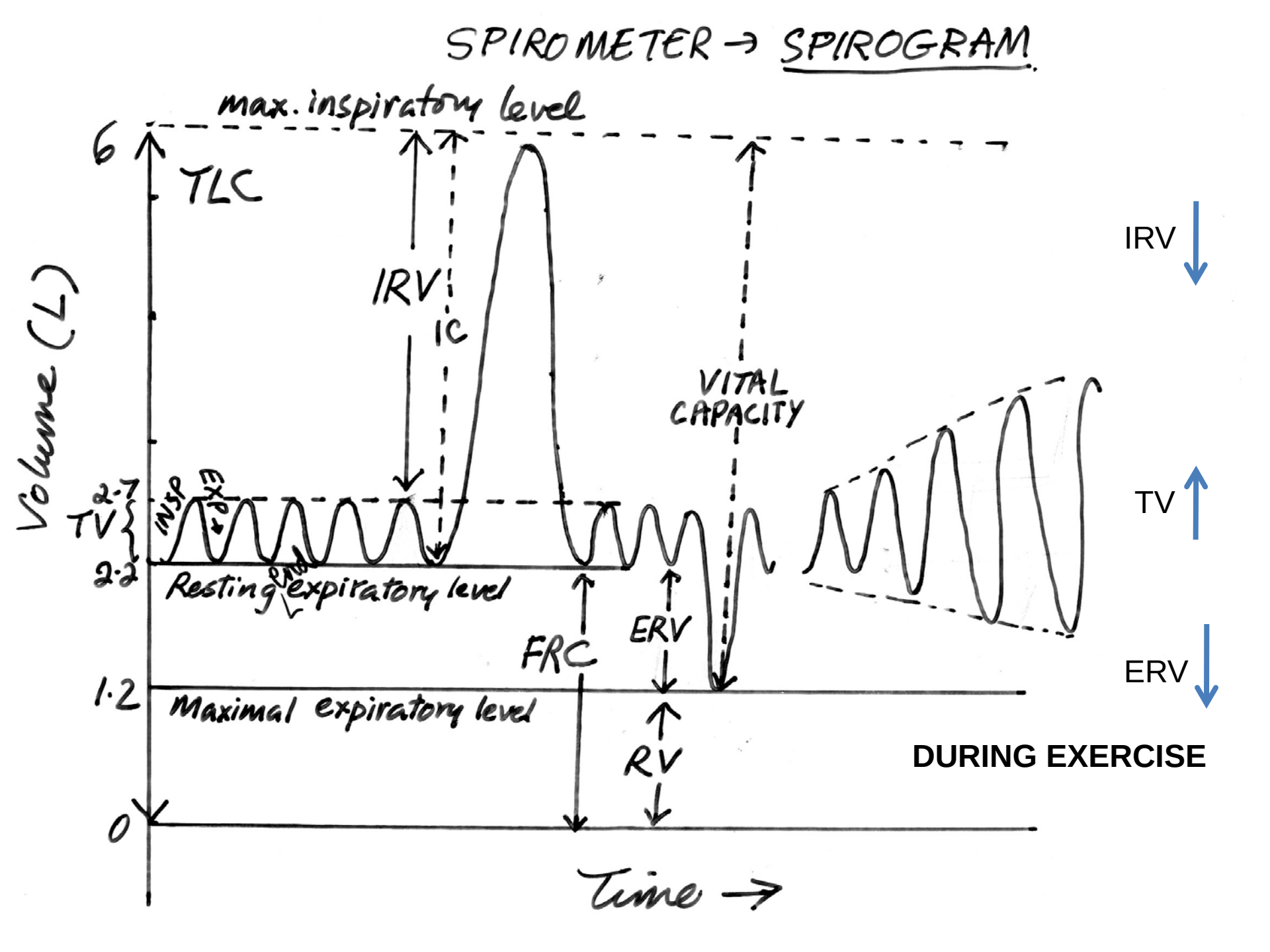


EXPIRATION




8
6
4
2
0
Liters
Paper
TLC
VC
IC
IRV
Tidal volume
ERV
FRC
RV
Pen
Spirometer


female
6000
5000
4000
3000
2000
1000
Lung volume (ml)
Inspiration
4200
Inspiratory reserve volume
Tidal volume
Inspiratory capacity
Vital capacity
Total lung capacity
2300
1800
Expiratory reserve volume
Functional residual capacity
1100
Residual volume
Expiration
Time


SPIROMETER → SPIROGRAM
max. inspiratory level
6
TLC
IRV
IC
VITAL CAPACITY
Volume (L)
TV 2·7
2·2
INSP
EXP
Resting expiratory level
FRC
ERV
1·2
Maximal expiratory level
RV
0
Time →
IRV
TV
ERV
DURING EXERCISE