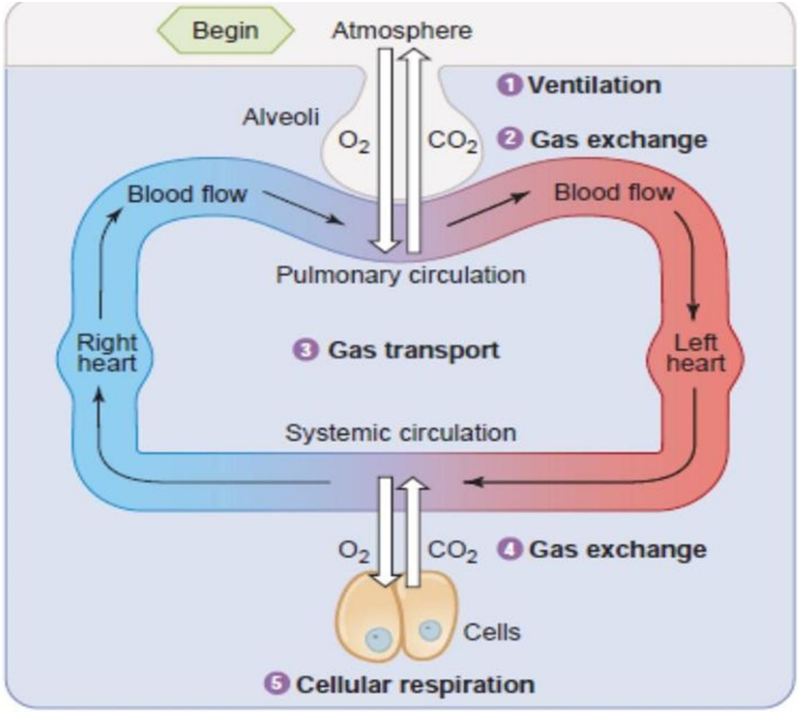
Pulmonary Circulation

MEDEMIA ACADEMY

Functions of the pulmonary circulation

1. Conduction of blood from the right side of the heart to its left side.
2. Blood oxygenation and wash of CO2 (arterialization of venous blood).
3. Filtration of various emboli from the venous blood (The lungs contain a fibrinolytic system that lyses blood clots in the pulmonary vessels).
4. Blood reservoir: Because of their distensibility, the pulmonary veins are an important blood reservoir. When a normal individual lies down, the pulmonary blood volume increases by up to 400 ml, and when the person stands up this blood is discharged into the general circulation. This shift is the cause of the decrease in vital capacity in the supine position and is responsible for the occurrence of orthopnea in heart failure.



Characteristics of Pulmonary Vasculature

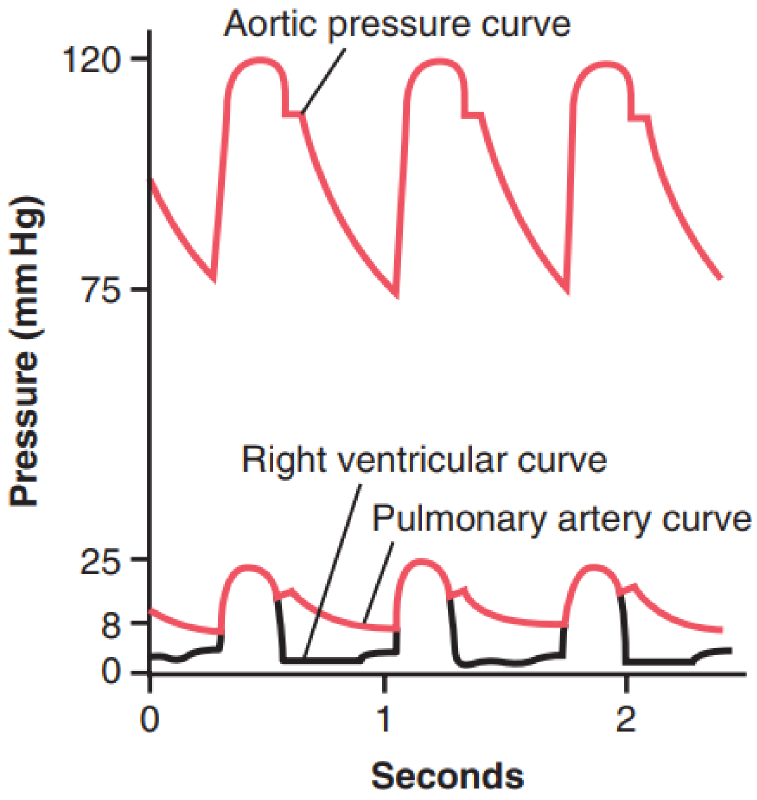
1. The lungs receive arterial blood from the pulmonary and bronchial arteries (branches of systemic circulation) and their venous blood is drained mainly by the 4 pulmonary veins.
2. The walls of the pulmonary artery and its large branches are thin (30 % as thick as aortic wall) while the small pulmonary arteries & pulmonary arterioles are short, wide & have little smooth muscle. These properties render the pulmonary arterial tree highly compliant (i.e. easily distensible).
3. The pulmonary veins are short and compliant as systemic veins.
4. Considerable anastomoses exist between the branches of the pulmonary and bronchial arteries and most of bronchial blood is drained by pulmonary veins. So, the left ventricular output is normally slightly greater than that of the right ventricle.
5. The pulmonary capillaries are large, have a high permeability and an extensive exchange surface area as well as multiple anastomoses, so each alveolus sits in a basket (i.e. a network) of capillaries.
6. The lungs are also richly supplied by lymphatic vessels. (which help against pulmonary edema)

Normal Pressures in pulmonary circulation

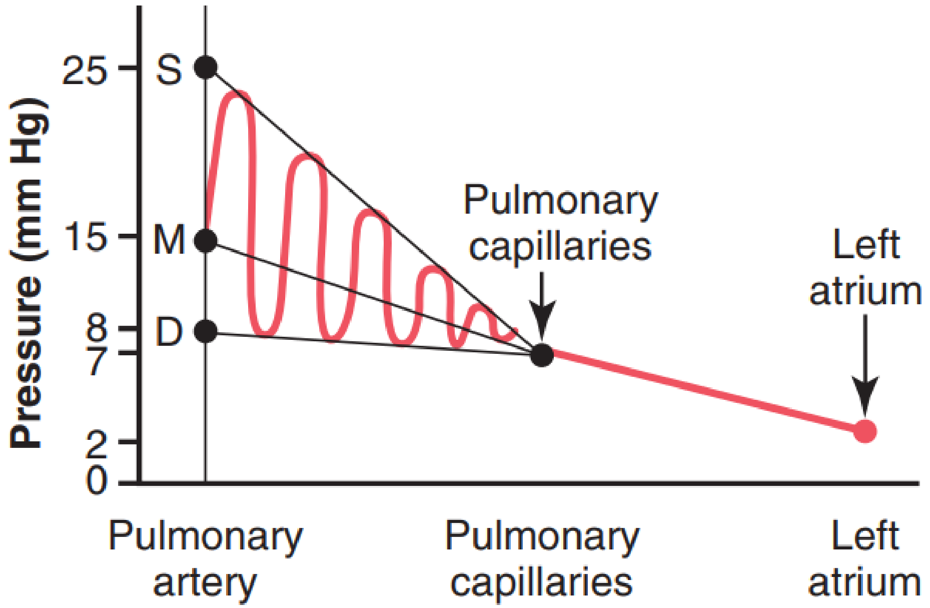
- **Right ventricular pressure values** are only 1/5 those for the left ventricle
  - **Systolic** = ~25 mmHg
  - **Diastolic =** almost 0 mmHg
- **Pulmonary artery**
  - **Systolic** = RV systolic = ~25 mm Hg (about 1/5 that in the aorta because the pulmonary vessels offer a much smaller peripheral resistance)
  - **Diastolic** = ~8 mmHg
  - **Mean pulmonary artery** = ~15 mmHg
- **Pulmonary capillary pressure**
  - Averages 7 mmHg (lowest capillary pressure in the body; the highest capillary pressure found in kidney)
- **Pulmonary veins and left atrium**
  - The pressure range is 1-5 mmHg (average: 2 mmHg)

Pressure curves

Pressure Pulse Curve in the Right Ventricle and pulmonary artery



Pressures in the different vessels of the lungs. **S**: systolic; **D**: diastolic; **M**: mean.



Pulmonary Vascular Resistance (PVR)

- The PVR is normally low (about 1/6 that in the systemic circulation) because of the large distensibility of the pulmonary vasculature
- **It is determined by the pulmonary arteriolar diameter**
  - Factors that ↓ the arteriolar diameter (i.e. produce V.C.) ⟶ ↑PVR
  - Factors that ↑ the arteriolar diameter (i.e. produce V.D.) ⟶ ↓ PVR

Factors that cause pulmonary V.C.	Factors that cause pulmonary V.D.
○ Hypoxia. ○ Low pH (i.e. acidosis). ○ Sympathetic stimulation. ○ Catecholamines (noradrenaline). ○ Angiotensin II. ○ Thromboxane A2 and PGF2	○ Vagal (parasympathetic) stimulation. ○ Acetylcholine. ○ ANP. ○ PGI2.

- N.B. The PVR increases significantly in certain lung diseases e.g. emphysema, pulmonary fibrosis and pulmonary embolism as a result of obliteration of pulmonary vessels and local hypoxia in the lungs.

Relation between lung volume & PVR

PVR changes with lung volume

- ❖At mid thoracic position, the total PVR is typically lowest at functional residual capacity (i.e. FRC = ERV = RV).
- ❖At high volumes (at max deep forced inspiration) …. (total lung capacity), the alveolar vessels are compressed by stretched alveolar walls and contribute more to PVR.
- ❖At low volumes (at deep forced expiration) …. (residual volume), extra-alveolar vessels are compressed due to increased positive intrathoracic (intrapleural) pressure, contributing to an increased PVR.

Regulation of Pulmonary Blood Flow (PBF)

- **The PBF normally equals the cardiac output** (about 5.5 liters/minute)
  - i.e. the pulmonary circulation accommodates a blood flow that is equal to that of all the other organs in the body.
- **The PBF is regulated as follows**
  - **Overall regulation of the PBF**
    - This is mostly a passive process e.g. during exercise, the cardiac output increases markedly and the pulmonary vessels dilate passively (due to their high distensibility). So, the PVR drops and PBF increases.
  - **Regional regulation of the PBF; controlled by 2 factors**:
    1. O2 tension
    2. Gravity

- **Note**: Cardiac output = (SV*HR)

Regional regulation of the PBF – O_2 tension

- Local hypoxia (due to obstruction of a bronchus or a bronchiole) causes local V.C. by stimulating the vascular smooth muscle (This isopposite to the effect observed in systemic vessels, which dilate rather than constrict in response to low oxygen).
- Such effect shifts the blood away from the hypoxic area to other normally ventilated alveoli without affecting the total PBF (thus providing an automatic control system for distributing blood flow to the pulmonary areas in proportion to their alveolar oxygen pressures).
- Local CO2 accumulation produces the same effect. Accumulation of CO2 leads to a drop in pH in the area, and a decline in pH also produces vasoconstriction in the lungs, as opposed to the vasodilation it produces in other tissues. Conversely, reduction of the blood flow to a portion of the lung lowers the alveolar PCO2 in that area, and this leads to constriction of the bronchi supplying it, shifting ventilation away from the poorly perfused area.
- This is autoregulatory mechanism in the lungs that shifts blood from the low-ventilated areas to other well-ventilated areas.

Regional regulation of the PBF – Gravity

- Gravity has a relatively marked effect on the pulmonary circulation. In the upright position, the apices of the lungs are well above the heart level while their bases are below it.
- By the effect of gravity, this normally creates a gradient in the pulmonary arterial pressure of about 23 mmHg (at the lung apices, the pulmonary arterial pressure becomes about 15 mmHg less than that at the heart level, while at the lung bases, it becomes about 8 mmHg greater than that at the heart level). Such pressure differences have profound effects on blood flow through the different areas of the lungs. It causes intermittent PBF at the lung apices (only during systole) and a continuous PBF at the lung bases (during both systole and diastole), which leads to an increase of the PBF from above downwards, becoming maximal at the lung bases (= waterfall effect).

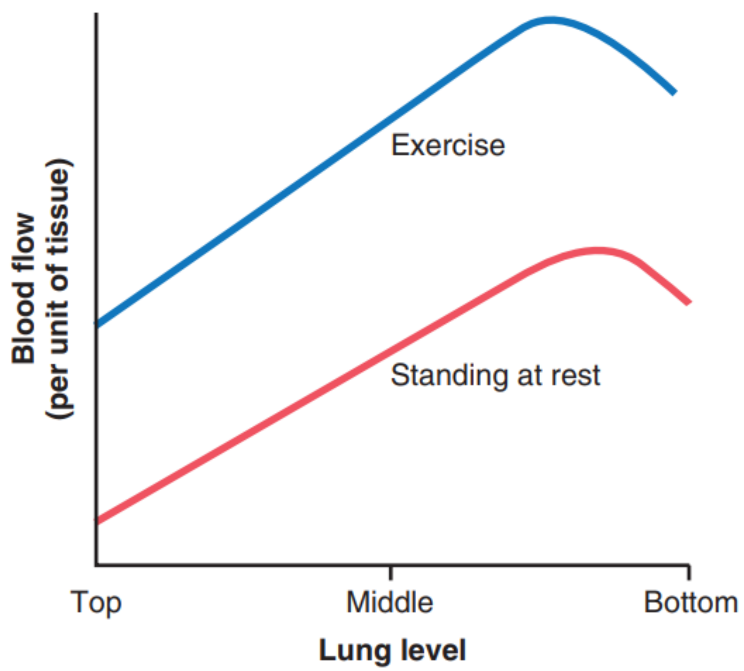
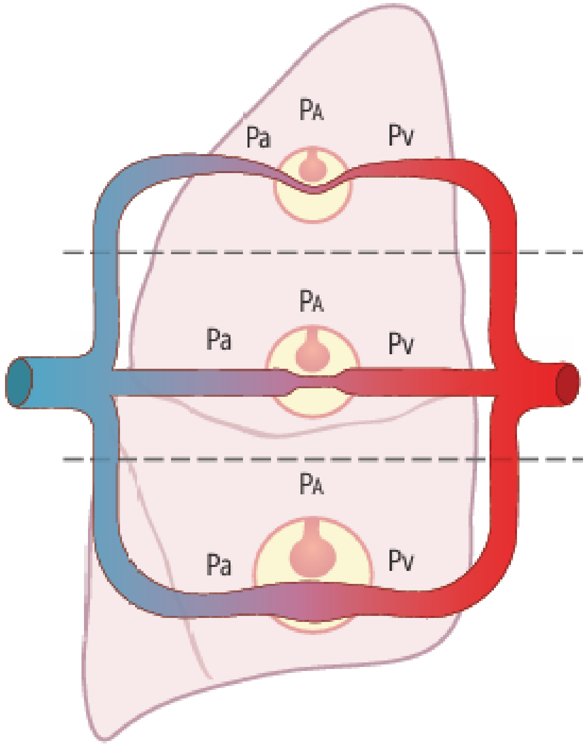


Figure. Blood flow at different levels in the lung of an upright person at rest and during exercise. Note that when the person is at rest, the blood flow is very low at the top of the lungs; most of the flow is through the bottom of the lung

The 3 zones of the lung

- The capillaries in the alveolar walls are distended by the blood pressure inside them, but simultaneously, they are compressed by the alveolar air pressure on their outsides.
- Therefore, any time the lung alveolar air pressure becomes greater than the capillary blood pressure, the capillaries close and there is no blood flow.
- Under different lung conditions, one may find any one of three possible zones of pulmonary blood flow, as follows:
  - **Zone 1**: No blood flow during all portions of the cardiac cycle because the local alveolar capillary pressure in that area of the lung never rises higher than the alveolar air pressure during any part of the cardiac cycle
  - **Zone 2**: Intermittent blood flow only during the pulmonary arterial pressure peaks because the systolic pressure is then greater than the alveolar air pressure, but the diastolic pressure is less than the alveolar air pressure.
  - **Zone 3**: Continuous blood flow because the alveolar capillary pressure remains greater than alveolar air pressure during the entire cardiac cycle.



The 3 zones of the lung cont.

- Normally, the lungs have only zones 2 and 3 blood flow—zone 2 (intermittent flow) in the apices, and zone 3 (continuous flow) in all the lower areas.
- For example, when a person is in the upright position, the pulmonary arterial pressure at the lung apex is about 15 mm Hg less than the pressure at the level of the heart. Therefore, the apical systolic pressure is only 10 mm Hg (25 mm Hg at heart level minus 15 mm Hg hydrostatic pressure difference). This 10 mm Hg apical blood pressure is greater than the zero alveolar air pressure, so that blood flows through the pulmonary apical capillaries during cardiac systole. Conversely, during diastole, the 8 mm Hg diastolic pressure at the level of the heart is not sufficient to push the blood up the 15 mm Hg hydrostatic pressure gradient required to cause diastolic capillary flow.
- Therefore, blood flow through the apical part of the lung is intermittent, with flow during systole but cessation of flow during diastole; this is called zone 2 blood flow
- In the lower regions of the lungs, the pulmonary arterial pressure during both systole and diastole remains greater than the zero alveolar air pressure. Therefore, there is continuous flow through the alveolar capillaries, or zone 3 blood flow.
- Also, when a person is lying down, no part of the lung is more than a few centimeters above the level of the heart. In this case, blood flow in a normal person is entirely zone 3 blood flow, including the lung apices

Factors affecting pulmonary arterial B.P.

1. **Pulmonary vascular resistance (PVR)**
   - All factors that ↑ PVR also ↑ the pulmonary arterial B.P. and vice versa
   - **The commonest of these factors include the following**

Nervous factors	• Sympathetic stimulation causes VC of pulmonary arterioles which increases the PVR and pulmonary arterial B.P. • Vagal stimulation produces opposite effects.
Chemical factors	• Pulmonary VC substances (e.g. catecholamines) increase the PVR and pulmonary arterial B.P. while V.D. substances (e.g. acetylcholine (para…vagus)) produce opposite effects. • Systemic hypoxia: this leads to V.C. of pulmonary arterioles which increases the PVR and pulmonary arterial B.P.
Respiratory movements	During inspiration, the pulmonary arterioles dilate resulting in reduction of both PVR and pulmonary arterial B.P. During expiration, opposite effects occur.
Lung diseases	The diseases that cause narrowing of the pulmonary arterioles (e.g. emphysema, pulmonary fibrosis and pulmonary embolism) increase the PVR and pulmonary arterial B.P.

Factors affecting pulmonary arterial B.P.

2. **Left atrial pressure**
   - An increase in left atrial pressure above 7-8 mmHg leads to back pressure in the pulmonary vascular system, resulting in a nearly equivalent rise in pulmonary arterial blood pressure.
   - Commonly occurs secondary to
     - Left ventricular failure
     - Severe mitral stenosis
   - When the left atrial pressure has risen above 30 mmHg pulmonary edema is likely to develop

Factors affecting pulmonary arterial B.P.

3. Cardiac output

- During heavy exercise, the cardiac output increases 4-7 folds. However, this leads to only a small rise of the pulmonary arterial B.P., because the PVR is rather decreased as a result of increasing the pulmonary capacity
- The latter occurs by
  - Distension of all pulmonary capillaries
  - Increase of the number of open pulmonary capillaries and the rate of blood flow through them (an RBC takes about 0.75 second to traverse a pulmonary capillary during rest, and 0.3 second or less during exercise).
  - This ability also prevents a significant rise in pulmonary capillary pressure, thus also preventing the development of pulmonary edema.

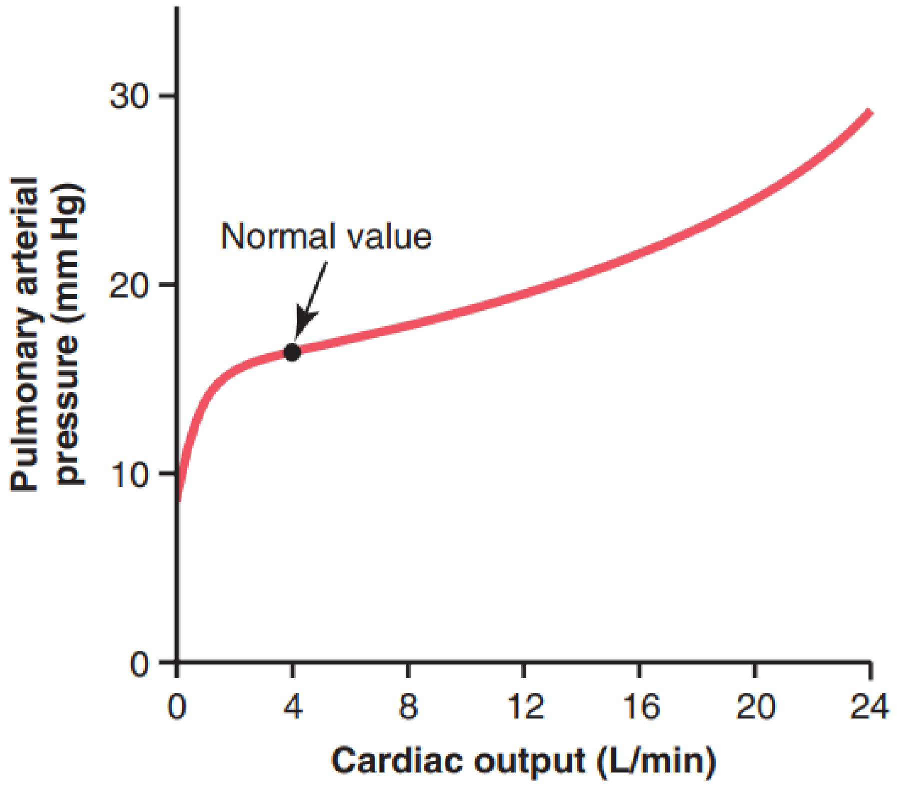


Figure. Effect on mean pulmonary arterial pressure caused by increasing the cardiac output during exercise

Functional Characteristics of Pulmonary Circulation

1. The pulmonary vascular system is a distensible low pressure system.
2. It is a high flow circulation (PBF = CO); it accommodates a blood flow that is almost equal to that of all the other organs in the body.
3. Its venous return at the left atrium is 1-2 % greater than the right ventricular output.
4. It has a high compliance, acting as blood reservoir of varying capacity.
5. The blood flow in the pulmonary capillaries is rapid (about 0.75 second during rest and 0.3 during exercise).
6. Both the pulmonary capillary surface area and permeability are great.
7. The regional pulmonary blood flow is affected by gravity (it is much greater in the lung bases than in the apices).
8. The alveoli are normally kept almost completely dry.
9. It has special reactions to gas changes e.g. hypoxia, hypercapnia and excess H+ produce V.C. and not V.D. as in other tissues.
10. The mean velocity of the blood in the root of the pulmonary artery is the same as that in the aorta (about 40 cm/s).

The Physiological Shunts

- These are normal shunts that allow drainage of some systemic venous blood into the pulmonary venous blood (which is arterial blood after equilibration with the alveolar air).
- **This systemic venous blood is derived from**
  - The bronchial veins, which drain some of their blood into the pulmonary capillaries and veins.
  - The coronary veins, which drain some of their blood directly into the left side of the heart.
- As a result of these physiological shunts, the Po2 and % saturation of Hb with O2 in the systemic arterial blood (about 95 mmHg and 97% respectively) are normally slightly less than their corresponding values in the blood that has equilibrated with alveolar air at the venous ends of the pulmonary capillaries (about 97 mmHg and 97.5% respectively).

Diseases Affecting the Pulmonary Circulation

❖Pulmonary Hypertension

Definition	• Sustained primary pulmonary hypertension is a condition that can occur at any age and is characterized by elevated pressure in the pulmonary arteries. • Mean pressure >20 mmHg at rest
Causes include	• Hypoxia • Inhalation of cocaine • Use of appetite-suppressing drugs (which increase extracellular serotonin) • Familial cases (linked to mutations affecting pulmonary vessel sensitivity to growth factors or causing deformations in the pulmonary vascular system)
Mechanism	These factors contribute to increased pulmonary vascular resistance, which raises the afterload on the right ventricle. Without timely treatment, this can lead to right heart failure and potentially death.
Treatment	Vasodilators such as prostacyclin and prostacyclin analogs are effective in managing the condition.

Achieve MCQs

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Achieve MCQs

Q1 Which of the following is NOT describing the pulmonary circulation?

a. Increase the arterial or venous pressure one at a time would increase the pulmonary vascular resistance because of capillary recruitment and distension
b. Pulmonary vascular resistance is affected by upstream and downstream pressure
c. If you reduce the capillaries pressure below the alveolar pressure; the capillaries would be compressed
d. Increase or decrease the lung volume would increase the pulmonary vascular resistance so we tend to breath at minimum pulmonary vascular resistance
e. The pressure of the extra alveolar vessels affected by the tension of the lung parenchyma

- **Answer**: a

Achieve MCQs

Q2 Which of the following matched pairs regarding PVR is wrong?

a. Increased venous or arterial pulmonary pressure Decreased PVR
b. Distension of Capillary vessels Decreased PVR
c. Decreased lung volume below normal breathing Decreased PVR

- **Answer**: C

Achieve MCQs

Q3 By comparing between pulmonary and systemic circulation, which of the following is NOT TRUE?

a. Pulmonary vascular resistance is 1/10 of Systemic vascular resistance
b. Pulmonary capillary blood flows in thin sheets, as opposed to the distinctly tubular flow in systemic capillaries
c. The thin walls of pulmonary vessels and vast area of the capillary bed make the pulmonary vasculature highly distensible compared with the systemic vasculature
d. The right ventricle receives mixed venous blood and pumps it through the pulmonic valve, which marks the beginning of the pulmonary circulation
e. The diffusion distance between air and blood in pulmonary circulation is ten times the diffusion distance that exists between systemic capillaries and tissue cells

- **Answer**: e