2nd Edition

Practical Applications of Mechanical Ventilation

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Foreword
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JAYPEE

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Applied Respiratory Physiology

Defining Respiration: Figure 3.1

Respiration is the biological process of oxygen and carbon dioxide exchange across permeable membranes. The single celled animal directly acquires oxygen from the environment and directly expels the carbon dioxide metabolite. The entire process requires nothing more than simple diffusion across the cell membrane. In humans, O_2 and CO_2 diffusion (respiration) involves a number of elements separating the environment from the cell.

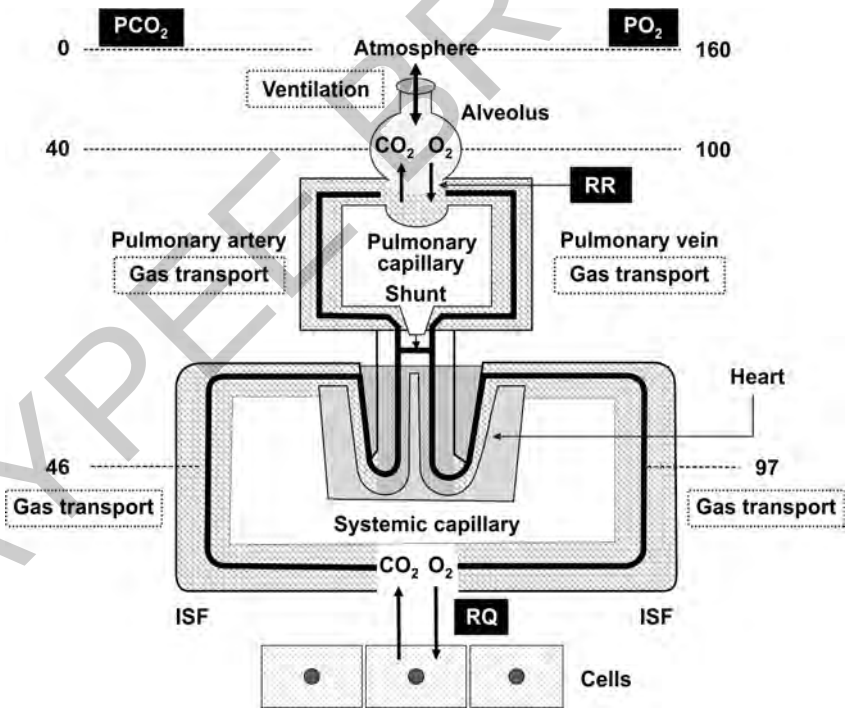

Figure 3.1: Normal pressures of oxygen and carbon dioxide throughout the body
ISF (Interstitial fluid). The units of PCO_2 and PO_2 are mmHg

This '***obstacle course'*** requires complex cardiovascular and pulmonary systems capable of maintaining internal stability through physiological system of coordinated feedback responses, a process referred to as 'respiratory 'homoeostasis'.

Four Stages of Respiration in Humans: Figure 3.2

1. *Ventilation*
   Ventilation means moving of the ambient (atmospheric) air into and out of the pulmonary alveoli.
2. *Pulmonary gas exchange: Respiratory exchange ratio: (RR) (External respiration)*
   Pulmonary gas exchange is exchange of gases between the alveoli and the pulmonary capillaries. The relationship of the volumes of carbon dioxide and oxygen exchanged per minute by the lungs is referred to as the '***Respiratory exchange ratio'***.
3. *Gas transport*
   Gas transport is movement of gases within the *pulmonary* capillaries through the circulation to the *peripheral* capillaries in the organs, and then a movement of gases back to the lungs along the same circulatory route.
4. *Peripheral gas exchange: Respiratory quotient: (RQ) (Internal respiration)*
   Peripheral gas exchange is exchange of gases between the tissue capillaries and the tissues or organs, including cells and the mitochondria within the cells. The relationship of the volumes of carbon dioxide and oxygen exchanged per minute at the tissue level is referred to as the '***Respiratory quotient'***.

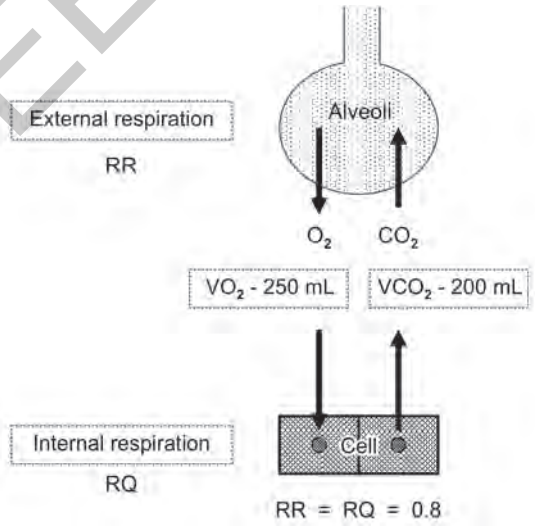

Figure 3.2: External and internal respiration

Respiratory Homoeostasis

Respiratory homoeostasis requires that the RR and the RQ be equal. A change of any respiratory homoeostasis factor results in one of the following three alternatives:

1. The arterial blood gas values change.
2. Gas values may remain relatively unchanged because cardiovascular and pulmonary system increases work to maintain the homeostatic balance.
3. Various combinations of the previous two may occur.

The balance between the severity of disease and the degree of compensation by the cardiovascular and pulmonary system determines the degree of any abnormality in arterial gas values. Normal arterial blood gases does not mean that there is an absence of disease because the homoeostatic system can compensate: Figure 3.3

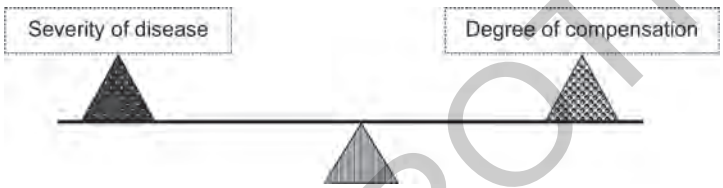

Figure 3.3: Normal arterial blood gases due to compensated disease

Abnormal arterial blood gas values reflect uncompensated diseases that may be life threatening: Figure 3.4

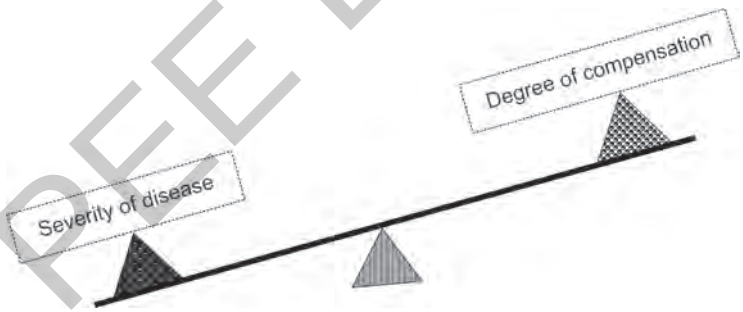

Figure 3.4: Abnormal arterial blood gases due to uncompensated disease

External Respiration or Respiratory Exchange Ratio

This can be expressed in many ways:

- The respiratory exchange ratio represents the overall exchange capability of the lungs but not the individual variation within the different parts of the lungs.
- An alternative method of expressing the effectiveness of pulmonary gas exchange is to consider the matching of ventilation and perfusion or more precisely, the relationship between the volumes of gas moving into

an alveolus and the blood flow through the adjacent capillary. The advantage of this approach is that it takes into account the efficiency of molecular gas exchange in all areas of the lung and the disadvantage is the complexity of the concept. A basic understanding of the ventilation/perfusion ($\dot{V}_A/\dot{Q}$) concept is essential for the clinical application of blood gas measurements.

Influence of Gravity on Fluid

In any fluid compartment, gravity pushes against the top of the fluid. As a result, the pressure at the bottom of the fluid compartment will be greater than it is at the top of the fluid compartment. In other words, the pressure increases as you go toward the bottom of the fluid compartment due to the effects of gravity.

In a vertical (upright) lung, gravity causes the pleural pressure (P_{pl}) to be less negative at the base of the lung than at the apex of the lung. When the glottis is open and there is no airflow, the alveolar pressure (P_{alv}) at both the apex and the base is 0 mmHg (equal to atmospheric pressure).

The P_{pl} at the base of the lung is around – 2 mmHg while the P_{pl} at the apex of the lung is approximately –10 mmHg . Since the P_{alv} is 0 mmHg in both situations, the transpulmonary pressure (P_{tp}) at the base of the lung is + 2 mmHg while the P_{tp} at the apex of the lung is + 10 mmHg. This means that the lung units at the top of the lungs are more expanded than those at the bottom of the lung.

Regional Differences in Ventilation/perfusion Concept

Regional Differences in Ventilation: Figure 3.5

Regional differences in ventilation refer to volume changes in relation to resting volume.

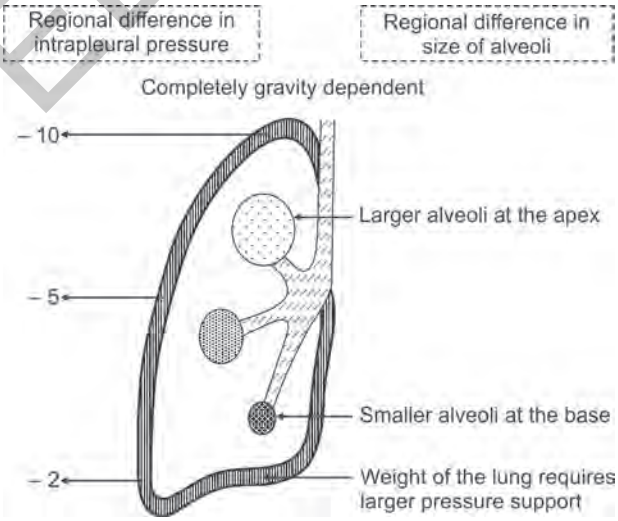

Figure 3.5: Regional difference in ventilation

a. *Regional difference in intrapleural pressure*
In a healthy person standing erect, intrapleural pressure is more subatmospheric at the apex than at the base. The most probable reason for this is that the lung is **'***suspended***'** from the hilum due to the effect of gravity and the weight of the lungs require larger pressure support below the hilum than above. Thus, pressure near the base is greater and thereby the intrapleural negativity is less. This phenomenon is completely a *'gravity dependent'* phenomenon.

b. *Regional differences in the size of alveoli in the upright position*
In the upright position, the lungs tend to sag towards the most dependent part under the influence of gravity so that the alveoli are smaller at the base than they are at the apex. This *'gravity dependence'* is true for any position.

c. *Regional difference in the transpulmonary pressure gradient at the* ***end of expiration****: Figure 3.6*
Airway pressure and alveolar pressure is zero (atmospheric) at the end of expiration. Intrapleural pressures are negative to a greater degree at the apex than at the base.

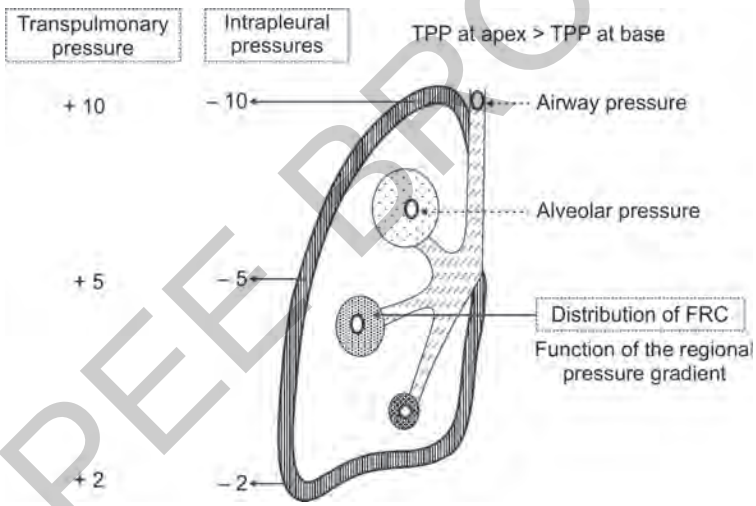

Figure 3.6: Regional difference in transpulmonary pressure gradient during end of expiration

Approximately 40% of the total lung capacity (i.e. FRC) remains in the lung at the end of exhalation. The distribution of this lung volume will primarily be a function of the regional pressure [transpulmonary pressure (TPP)] gradients across the lung. Transpulmonary pressure (airway pressure minus intrapleural pressure) is greater at the apex than at the base. This is the primary reason why alveoli are larger at the apex and smaller at the base of the lungs.

d. *Regional difference in the transpulmonary pressure (TPP) gradient* ***during inspiration****: Figure 3.7*
When inspiration creates more subatmospheric pressure in the pleural space, the change in TPP at the base will be far greater than the change in

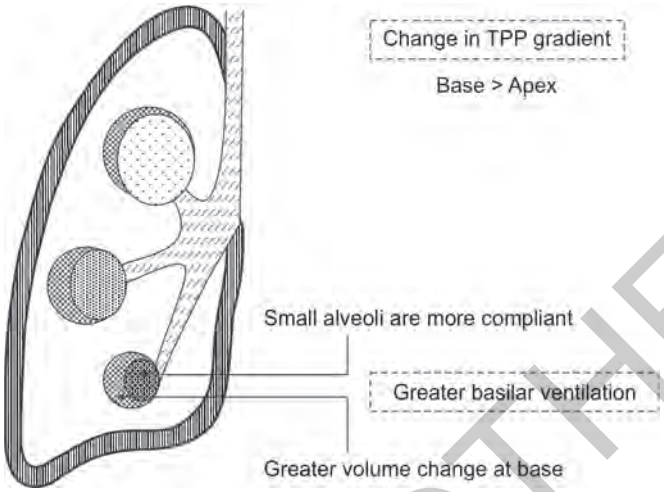

Figure 3.7: Regional difference in TPP gradient during inspiration

TPP at the apex. Small alveoli are more compliant than larger ones so that during inspiration a greater volume change occurs in the former. Thus, relatively more of the inspired tidal volume will tend to distribute to the basilar alveoli.

e. *Regional differences in ventilation for dependent lungs in any body position*
Compared to the apex, the base of the lungs has a smaller resting volume and undergoes a larger volume change per unit of lung; therefore, basilar ventilation is greater. This is true for dependent lung in any body position.

Ventilation is preferentially distributed to the dependent parts of the lung provided the basal areas are not so compressed that airway closure has occurred. Also, the differences in regional ventilation become less during exercise and are reversed in the inverted position.

Diseased Lungs

In diseased lungs, the two main factors controlling the distribution of ventilation are:

1. *Patency of airways*
Any factor which reduces the airway caliber and raises the resistance to airflow, will result in a fall in ventilation to the affected region.
2. *Local changes in compliance within the lungs*
Similarly, any area in which the local compliance has decreased will be less ventilated than the surrounding more expandable normal lung tissue.

Regional Differences in Perfusion

The normal distribution of blood flow throughout the pulmonary vasculature is dependent primarily on gravity and cardiac output.

a. *Gravitational effects on blood flow: Figure 3.8*
In a healthy person standing erect, there is a distance of approximately 30 cm from the apex to the base of the lungs. Assuming the pulmonary artery enters the lungs halfway between the top and bottom, the pulmonary artery pressure would have to be high enough to overcome a gravitational force of 15 cm H_2O to supply flow to the apex.

A column of blood (essentially water) of 15 cm height exerts a pressure of approximately 11 mmHg. This gravitational effects on blood flow results in a pulmonary artery pressure at the lung base of greater magnitude than the pulmonary artery pressure at the apex. Thus blood will preferentially flow through the gravity dependent areas of the lungs. This is true for any body position.

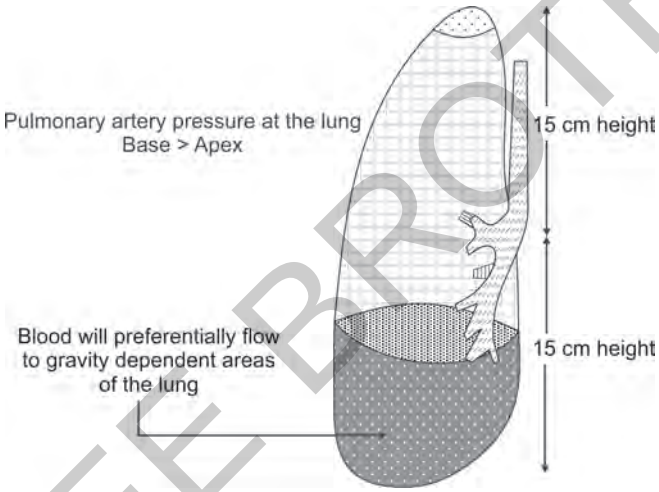

Figure 3.8: Gravitational effects on blood flow

b. *Effects of gravity on pulmonary perfusion: Figure 3.9*
It has become well accepted to refer to the effects of gravity on pulmonary perfusion in terms of the three zone model. Under normal circumstances alveolar pressures are equal throughout the lungs while the vascular pressures vary throughout the lungs.

- *Zone 1: Least gravity dependent area*
  Zone 1 is the least gravity dependent area of the lungs and has alveolar pressures higher than the pulmonary arterial pressures, resulting in the virtual absence of blood flow. It should be noted that the total absence of pulmonary blood flow to these areas does not exist to any significant extent in the normally perfused lung.

  However, if pulmonary artery pressure is significantly decreased (hypoperfusion) or if alveolar pressure significantly increases (positive pressure therapy), then the absence of perfusion to the least gravity dependent areas of the lung can become significant.

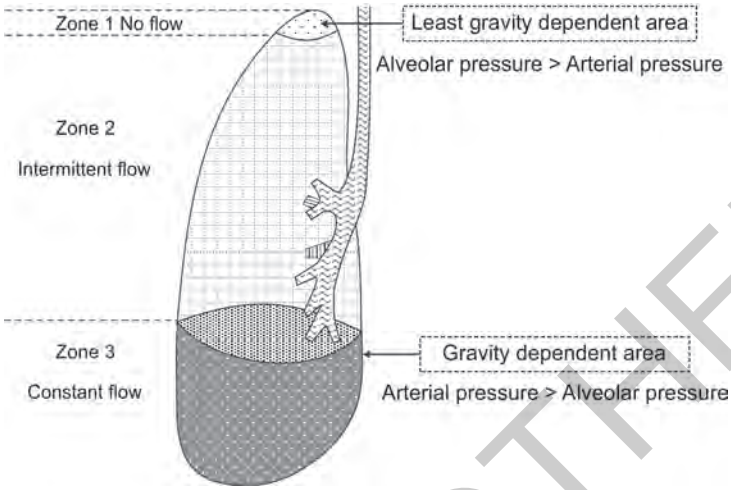

Figure 3.9: The three zone model illustrating the effects of gravity on pulmonary perfusion

- *Zone 2: Cardiac cycle is more important than the ventilatory cycle*
  Zone 2 is an area of complex and varying intermittent blood flow. The extent of blood flow in zone 2 depends primarily on the relationship of pulmonary artery pressure to alveolar pressure. Under normal circumstances this is determined more by the cardiac cycle than by the ventilatory cycle.
- *Zone 3: Gravity dependent area*
  Zone 3 is the gravity dependent area of constant blood flow (arterial pressure is always greater than alveolar pressure).

Cardiac output is the amount of blood ejected by the ventricle per minute and the amount of blood ejected from the right ventricle per minute is a major determinant of blood flow through pulmonary vasculature. In general, the greater the cardiac output, the greater the pulmonary artery pressure. Thus, in normal lung, as the cardiac output increases, zones 2 and 3 extend upwards. Conversely, as the cardiac output decreases, zones 2 and 3 descend.

Compared to the systemic vasculature, the autoregulatory capability of the pulmonary vasculature is inferior. Thus, the effects of gravity on the distribution of blood flow secondary to cardiac output changes is more significant in the pulmonary vasculature than in systemic vasculature.

Internal Respiration

The O_2 and CO_2 exchange between systemic capillary blood and cells is referred to as internal respiration. The primary purpose of respiration is to provide O_2 to the cells. The secondary purpose is to remove CO_2 from the cells.

The RQ is the relationship of CO_2 production in 1 minute ($\dot{V}CO_2$) to oxygen consumption in 1 minute ($\dot{V}O_2$). The volume of CO_2 normally produced in

1 minute is approximately 200 mL and the volume of O_2 normally consumed in 1 minute is approximately 250 mL, therefore the normal RQ is 0.8.

This process of internal respiration primarily depends on regional perfusion, metabolism and arterial blood gases. Although the pulmonary system is essential to external respiration, the cardiovascular system is essential to both external and internal respiration. Perfusion that is inadequate to serve the O_2 demands threatens internal respiration despite adequate pulmonary function. This is complicated by several factors:

1. The rate of metabolism normally varies greatly among different organ systems (brain vs skin vs gastrointestinal tract).
2. Changes in metabolic rates of different organ systems vary in the presence of disease and stress.
3. Changes in the perfusion of different organ systems can vary tremendously in the presence of disease and stress.

These complex factors must always be considered in the clinical settings.

Practical Applications of Mechanical Ventilation

Remarks

I still remember how challenging my first ICU rotation posting was. It was also intimidating, especially when it came to the ventilator. I had a basic understanding of mechanical ventilation, but I wanted to learn more. There are a lot of excellent books on Critical Care Medicine. What I was looking for was a book that would concisely indicate how to set the ventilator up and help me troubleshoot a challenging clinical scenario. My search ended with the first edition of *Practical Applications in Mechanical Ventilation*.

The second edition of the book, I find it even more advanced, with the content being enriched with more practical aspects and clinical applications. The topic is explained in simple language and supported with a large number of illustrations, all drawn by the author herself. This makes the book interesting and easy to understand. The emphasis throughout the book is on presenting material in a reader-friendly, practical way. The book will be a vital reference for all involved in the management of patients requiring mechanical ventilation in the ICU. I would unhesitantly recommend the book to all postgraduate students preparing for their examinations as it covers most of the syllabus for mechanical ventilation.

—*Teena Dessai* (Senior Resident, Department of Anaesthesiology, GMC)

Mechanical ventilation for intensive care unit (ICU) patients can be rather mysterious, with its many technical aspects and confusing terminology. This book provides a comprehensive review of mechanical ventilation by an experienced clinician and dedicated teacher. It serves as a theoretical as well as a practical guide, for both, amateurs and practicing clinicians. The liberal use of illustrations, drafted by the author herself, with a clear, concise and easy-to-understand text, enhances the exchange of knowledge to the reader and is clearly the book's strength.

—*Nimisha Parker* (Junior Resident, Department of Anaesthesiology, GMC)

Shaila Shodhan Kamat MBBS DA MD (Anaesthesiology) is Professor and Head, Department of Anaesthesiology, Goa Medical College (GMC), Bambolim, Goa, India. She is known for her innovative ways. She started the highly effective Parent-Head of the Department meetings for the postgraduate students. She is the author of the much acclaimed book, *Practical Applications of Mechanical Ventilation* ,which was published internationally by a reputed publisher. She has also authored *Practical Applications of Intravenous Fluids in Surgical Patients* for M/s Jaypee Brothers Medical Publishers (P) Ltd, New Delhi, India.

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