Case Studies: Restrictive and Obstructive Respiratory Conditions

Case Study # 1

Jenny Smith, a 14-year-old girl with asthma, had been under relatively good control until last night. She slept over at a friend's house and woke up in the middle of the night with severe shortness of breath ("dyspnea") and a cough (unproductive of sputum). She had expiratory wheezing. Unfortunately, she did not take her bronchodilator medication with her to her friend's house. She was taken to the emergency walk-in clinic. On physical exam, she was wheezing quite loudly and using her accessory muscles of respiration to help her breathe. A chest X-ray revealed hyperlucent and over-inflated lungs. Blood testing revealed an arterial blood pH of 7.25 (normal = 7.35-7.45). Pulmonary function testing revealed the graph shown (Pre-Bronchodilator).

Questions:

Based on the graph, fill in the following data:

1. tidal volume ____________ 350 cc
   inspiratory reserve volume ____________ 1600 cc
   expiratory reserve volume ____________ 400 cc
   forced vital capacity ____________ 2300 cc
   residual volume ____________ 1900 cc
   FEV1 ____________ 950 cc

   Note: 1cc = 1ml; For the above graph use 125 cc per box to record data.

2. What is her FEV1 / FVC ratio? ____________ 950 cc / 2300 cc or 0.41 (0.41 X 100 = 41%)

3. Does this ratio indicate restrictive or obstructive lung disease and why?

Typically, an FEV1 / FVC ratio below 0.70 indicates that a patient is suffering from obstructive lung disease.

4. What is the condition that caused Jenny to come to the emergency clinic? Explain this condition.

The symptoms suggest that Jenny is experiencing an asthmatic attack, a condition in which the bronchiolar smooth muscle undergoes excessive contraction, causing bronchiolar constriction and partial obstruction of her airways. This makes it difficult for Jenny to breathe. The bronchiolar airways oscillate rapidly between a closed and partially open position, creating a wheezing sound, particularly upon exhalation.
5. Explain why Jenny’s chest X-ray revealed hyperlucent (i.e. excessively dark) and over-inflated lungs? Hint: Note her residual volume

During her asthmatic attack, Jenny’s obstructed airways have caused air to become trapped in the alveoli. This is why her residual volume has increased, her lungs have become over-inflated, and her thorax appears hyperlucent (i.e. excessively dark) on the chest X-ray. Unless Jenny receives bronchodilator treatment, the secondary (and more long-lasting) phase of the asthmatic attack may occur in which the airways become inflamed, with excessive mucus production worsening the already obstructed airways.

She is given a bronchodilator called theophylline that makes her breathe more easily, after which pulmonary function tests are repeated (Post-Bronchodilator). Describe the changes in her breathing.

6. Based on the graph, fill in the following data:

<table>
<thead>
<tr>
<th>Volume</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal volume</td>
<td>350 cc</td>
</tr>
<tr>
<td>Inspiratory reserve volume</td>
<td>1750 cc</td>
</tr>
<tr>
<td>Expiratory reserve volume</td>
<td>700 cc</td>
</tr>
<tr>
<td>Forced vital capacity</td>
<td>2800 cc</td>
</tr>
<tr>
<td>Residual volume</td>
<td>900 cc</td>
</tr>
<tr>
<td>FEV1</td>
<td>2200 cc</td>
</tr>
</tbody>
</table>

7. What is her FEV1 / FVC ratio?

2200 cc / 2800 cc or 0.79 (0.79 X 100 = 79%)

8. Describe the reasons for the changes in her residual volume, forced vital capacity, and FEV1/FVC ratio.

Dilation of Jenny’s bronchioles has allowed her to expel some of the air that was trapped in her alveoli, thus reducing her residual volume from 1900 cc to 900 cc and increasing her forced vital capacity from 2300 cc to 2800 cc. Furthermore, the dilated airways make it possible for Jenny to exhale air more quickly. Thus, her FEV1 / FVC ratio has increased from 0.41 to 0.79 (i.e. 2200 cc / 2800 cc).

9. Why was her arterial blood pH lower than normal? What is this condition called?

Jenny’s arterial blood pH is lower than normal because she is having a difficult time excreting carbon dioxide (CO₂) from her bloodstream at an adequate rate. Since CO₂ is continuously produced as a by-product of cellular respiration, its level rises in Jenny’s bloodstream, where it binds to water to produce carbonic acid, which dissociates into hydrogen ion and bicarbonate ion in the following reversible buffering reaction:

\[
\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-.
\]

Thus, as CO₂ accumulates, H⁺ concentration rises, lowering the pH of the bloodstream. Jenny is hypoventilating to the point that her blood pH has fallen below normal, a condition known as respiratory acidosis.
Case Study #2

Joe Smith is a 69-year-old male with a 50-year history of smoking 2 packs of cigarettes a day (i.e. 100-pack-year smoking history). Over the past 5 years, he has become increasingly short of breath. At first, he noticed this only when exercising, but now he is even short of breath at rest. Over the past two years, he has had several bouts of lower respiratory tract infection treated successfully with antibiotics. His shortness of breath hasn't subsided, and his breathing is assisted by use of his accessory muscles of respiration. Pulmonary function testing revealed the following graph:

Based on the graph, fill in the following data:
1. tidal volume ____________ 500 cc
   inspiratory reserve volume ____________ 1800 cc
   expiratory reserve volume ____________ 400 cc
   forced vital capacity ____________ 2700 cc
   residual volume ____________ 2000 cc
   FEV1 ____________ 1000 cc

2. What is the FEV1 / FVC ratio? ____________ 0.37 (1000 cc / 2700 cc)

3. Does this ratio indicate restrictive or obstructive lung disease and why?
   Typically, an FEV1 / FVC ratio below 0.70 indicates that a patient is suffering from obstructive lung disease.

4. What condition would you diagnose the patient with?
   Given Joe's 100-pack-year smoking history and repeated bouts of lower respiratory tract infection, it is likely that he suffers from chronic bronchitis and emphysema or COPD.

5. What is the cause of the elevated residual volume?
   The chronic bronchitis causes larger airway obstruction while the emphysema causes small airway obstruction and air-trapping in the alveoli. The obstructed airways reduce the rate at which air can be exhaled. The trapping of air in the alveoli may explain why Joe's residual volume is larger than normal.
3. Describe the microscopic changes occurring in Joe's lungs. Explanation should include information about macrophage/neutrophils and what they produce as well as the effects of alpha-1 antitrypsin.

Chronic irritation of the respiratory tract by cigarette smoke causes macrophages and neutrophils to proliferate. Activated neutrophils and macrophages, in turn, release protease enzymes such as elastase, which can chemically destroy elastin protein found in lung tissue. **Elastase** and other enzymes are released to destroy foreign microbes and irritants such as cigarette smoke, air pollution, or allergens. Normally, the activity of elastase is modulated by another enzyme called **alpha-1 antitrypsin** that is produced in the liver and travels through the blood to the lungs. However, alpha-1 antitrypsin is destroyed by the chemicals in cigarette smoke and can be overwhelmed by the excess elastase. This tips the balance in favor of elastase and sets the stage for the slow, gradual destruction of elastin in the walls of the alveoli and the connective tissue between adjacent bronchioles. Multiple alveoli coalesce into larger air pockets, destroying much of the surface area previously available for gas exchange. Furthermore, destruction of the elastic connective tissue between adjacent bronchioles causes them to collapse, especially during exhalation, leading to the trapping of air in the alveoli and the ultimate "barrel chest" appearance of Joe's thorax. To overcome the obstructed airways, Joe must use his accessory muscles for respiration (i.e. the sternocleidomastoids, pectoralis minors).

4. What effect do these microscopic changes have on Joe's ability to transfer oxygen and carbon dioxide in the lungs?

The loss of alveolar surface area due to emphysema makes it difficult for Joe to take in sufficient oxygen and excrete carbon dioxide at a sufficient rate.

5. Blood testing showed Joe's hematocrit to be 59% (normal = 42-54%). Why was his hematocrit so high? Explanation should include a description of the physiological mechanism involved in raising his hematocrit. Hint: kidneys.

Joe's obstructive lung disease causes his arterial pO₂ level to be lower than normal. His kidneys sense this decline and start to produce and release increased amounts of the hormone erythropoietin. This hormone, in turn, stimulates the bone marrow to increase its rate of erythropoiesis (i.e. red blood cell production). Joe begins to add new red blood cells to the bloodstream at a faster rate than old red blood cells are being destroyed, thus increasing his hematocrit (or percentage of total blood volume taken up by red blood cells). This increased hematocrit increases the oxygen-carrying capacity of Joe's blood, thus allowing him to extract more oxygen from his alveoli. There are limits to the utility of this compensatory mechanism because, if the hematocrit gets too high, the viscosity of the blood rises to levels that make it difficult for the heart to pump the blood.
Arterial blood tests revealed the following:

- \( pO_2 \) (partial pressure of oxygen in the plasma) = 73 mm Hg (normal = 80-105 mm Hg)
- \( pCO_2 \) (partial pressure of carbon dioxide in the plasma) = 50 mm Hg (normal 35-45 mm Hg)
- pH = 7.32 (normal = 7.35-7.45)
- Hb-O\(_2\) sat (hemoglobin-oxygen saturation) = 84% (normal = 95-98%)

6. Why was Joe\'s \( pCO_2 \) increased above normal?

Joe\'s \( pCO_2 \) level is above normal because his obstructive lung disease makes it difficult for him to excrete CO\(_2\) at a sufficient rate.

7. Why was his arterial blood pH below normal? Is this due decreased pH due to respiratory or metabolic acidosis?

Joe\’s arterial blood pH is lower than normal because he is having a difficult time excreting carbon dioxide (CO\(_2\)) from his bloodstream at an adequate rate. Since CO\(_2\) is continuously produced as a byproduct of cellular respiration, its level rises in Joe\’s bloodstream, where it binds to water to produce carbonic acid, which dissociates into hydrogen ion and bicarbonate ion in the following reversible buffering reaction:

\[
CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-
\]

Thus, as CO\(_2\) accumulates, H\(^+\) concentration rises, lowering the pH of the bloodstream. Joe is hypoventilating to the point that his blood pH has fallen below normal, a condition known as respiratory acidosis.

8. Joe\'s \( pO_2 \) is clearly below the normal range. One\'s first instinct might be to give him air to breathe that is 100% oxygen. Why would this be dangerous for him? Elaborate on what happens to CO\(_2\) and H\(^+\) sensory receptors exposed to chronic high levels of CO\(_2\) and H\(^+\).

Joe has probably lived for many years with chronic bronchitis and emphysema. Thus, his \( pCO_2 \) level has been chronically elevated. Normally, a rising \( pCO_2 \) level is the primary stimulus in the brainstem to increase one\’s rate and depth of breathing. However, Joe\'s \( pCO_2 \) level has been elevated for so long that his CO\(_2\) and H\(^+\) sensory receptors have become somewhat desensitized. Thus, Joe\’s primary stimulus to breathe is his low O\(_2\) level (i.e. \( pO_2 \)), which is monitored by peripheral chemoreceptors in the carotid body. Hence, if one gave Joe 100% O\(_2\) to breathe, his \( pO_2 \) level would immediately rise, removing his last major stimulus for breathing. As a result, Joe could actually go into respiratory failure. This could be exacerbated by the tendency of pure inhaled oxygen to stimulate free-radical-mediated destruction of the respiratory membrane.

9. Why is Joe susceptible to lower respiratory tract infections?

The chronic irritation of the bronchial epithelium by cigarette smoke exposure causes a mild inflammatory response (bronchitis) that can impair the cleansing function of the cilia. Irritation of the lining causes excessive mucus production, which in turn is difficult to clear because of poor cilia function. Mucus begins to pool in the bronchial tree, and Joe develops the familiar "smoker\'s cough," an attempt to clear his airways of this mucus. The pooling mucus provides a nutrient-rich medium for invading bacteria. Joe is thus likely to develop infections of the bronchi, requiring occasional treatment with antibiotics.