Case 38

Respiratory Acidosis: Chronic Obstructive Pulmonary Disease

Bernice Betweiler was a 73-year-old retired seamstress who had chronic obstructive pulmonary disease secondary to a long history of smoking (see Case 24). Six months before her death, she was examined by her physician. Her blood values at that time are shown in Table 4-16.

**TABLE 4-16 Bernice’s Laboratory Values 6 Months Before Her Terminal Admission**

<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>$P_{O_2}$</td>
<td>48 mm Hg (normal, 100 mm Hg)</td>
</tr>
<tr>
<td>$P_{CO_2}$</td>
<td>69 mm Hg (normal, 40 mm Hg)</td>
</tr>
<tr>
<td>$HCO_3^-$</td>
<td>34 mEq/L (normal, 24 mEq/L)</td>
</tr>
<tr>
<td>pH</td>
<td>7.32 (normal, 7.4)</td>
</tr>
</tbody>
</table>

Against her physician’s warnings, Bernice adamantly refused to stop smoking. Six months later, Bernice was desperately ill and was taken to the emergency department by her sister. Her blood values at that time are shown in Table 4-17.

**TABLE 4-17 Bernice’s Laboratory Values at Her Terminal Admission**

<p>| | |</p>
<table>
<thead>
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</thead>
<tbody>
<tr>
<td>$P_{O_2}$</td>
<td>35 mm Hg (normal, 100 mm Hg)</td>
</tr>
<tr>
<td>$P_{CO_2}$</td>
<td>69 mm Hg (normal, 40 mm Hg)</td>
</tr>
<tr>
<td>$HCO_3^-$</td>
<td>20 mEq/L (normal, 24 mEq/L)</td>
</tr>
<tr>
<td>pH</td>
<td>7.09 (normal, 7.4)</td>
</tr>
</tbody>
</table>

She remained in the hospital and died 2 weeks later.

**QUESTIONS**

1. When Bernice visited her physician 6 months before her death, what acid-base disorder did she have? What was the cause of this disorder?

2. Why was her $HCO_3^-$ concentration increased at that visit?

3. At that visit, was the degree of renal compensation appropriate for her $P_{CO_2}$?

4. At the terminal admission to the hospital, why was Bernice’s pH so much lower than it had been 6 months earlier? Propose a mechanism to explain how her $HCO_3^-$ concentration had become lower than normal at the terminal admission (when it had previously been higher than normal)?

5. Given your conclusions about Bernice’s condition at the terminal admission, would you expect her anion gap to have been increased, decreased, or normal?
1. At the initial visit to her physician, Bernice had respiratory acidosis. Decreased alveolar ventilation, secondary to her obstructive lung disease, led to an increase in $P_{CO_2}$ because perfused regions of her lungs were not ventilated (ventilation-perfusion defect). In those poorly ventilated regions of the lungs, $CO_2$ could not be expired. The increase in $P_{CO_2}$ caused a decrease in her arterial pH.

2. The $HCO_3^-$ concentration is always increased to some extent in simple respiratory acidosis. The extent of this increase depends on whether the disorder is acute or chronic. In acute respiratory acidosis, the $HCO_3^-$ concentration is modestly increased secondary to mass action effects that are explained by the following reactions. As $CO_2$ is retained and $P_{CO_2}$ increases, the reactions are driven to the right, causing an increase in $HCO_3^-$ concentration.

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$$

In chronic respiratory acidosis, the increase in $HCO_3^-$ concentration is much greater because, in addition to mass action effects, the kidney increases the synthesis and reabsorption of “new” $HCO_3^-$ (renal compensation). This compensation for respiratory acidosis occurs in the intercalated cells of the late distal tubule and collecting ducts, where $H^+$ is secreted and new (i.e., newly synthesized) $HCO_3^-$ is reabsorbed. When arterial $P_{CO_2}$ is chronically elevated, renal intracellular $P_{CO_2}$ is elevated as well. This increased intracellular $P_{CO_2}$ supplies more $H^+$ for urinary secretion and more $HCO_3^-$ for reabsorption (see Figure 4-15).

Why is this renal response, which causes an increase in the blood $HCO_3^-$ concentration, called a compensation? Compensation for what? The increase in $HCO_3^-$ concentration is “compensating for,” or correcting, the pH toward normal, as shown in the Henderson-Hasselbalch equation:

$$pH = 6.1 + \log \frac{HCO_3^-}{P_{CO_2}}$$

In respiratory acidosis, $CO_2$ (the denominator of the ratio) is increased secondary to hypoventilation. This increase in $P_{CO_2}$ causes a decrease in arterial pH. In the chronic phase of respiratory acidosis, the kidneys increase the $HCO_3^-$ concentration (the numerator). This increase tends to normalize the ratio of $HCO_3^-$ to $CO_2$ and the pH. Although Bernice had retained significant amounts of $CO_2$ (her $P_{CO_2}$ was 69 mm Hg), her pH was only modestly acidic (7.32) 6 months prior to her death. Bernice “lived” at an elevated $P_{CO_2}$ of 69 mm Hg because her kidneys compensated, or corrected, her pH almost to normal. (Incidentally, healthy persons “live” at a $P_{CO_2}$ of 40 mm Hg.)

3. The question asks whether the degree of renal compensation (for her elevated $P_{CO_2}$) was appropriate. In other words, did Bernice’s kidneys increase her $HCO_3^-$ concentration to the extent expected? The Appendix shows the rules for calculating the expected compensatory responses for simple acid-base disorders. For simple chronic respiratory acidosis, $HCO_3^-$ is expected to increase by 0.4 mEq/L for every 1 mm Hg increase in $P_{CO_2}$. To calculate the expected, or predicted, increase in $HCO_3^-$, we determine how much the $P_{CO_2}$ was increased above the normal value of 40 mm Hg, then multiply this increase by 0.4. The predicted change in $HCO_3^-$ is added to the normal value of $HCO_3^-$ to determine the predicted $HCO_3^-$ concentration.

$$\text{Increase in } P_{CO_2} = 69 \text{ mm Hg} - 40 \text{ mm Hg}$$
$$= 29 \text{ mm Hg}$$

$$\text{Predicted increase in } HCO_3^- = 29 \text{ mm Hg} \times 0.4 \text{ mEq/L per mm Hg}$$
$$= 11.6 \text{ mEq/L}$$

$$\text{Predicted } HCO_3^- \text{ concentration} = 24 \text{ mEq/L} + 11.6 \text{ mEq/L}$$
$$= 35.6 \text{ mEq/L}$$
In other words, if Bernice had simple chronic respiratory acidosis, her $\text{HCO}_3^-$ concentration should have been 35.6 mEq/L, based on the expected renal compensation. At the initial visit, her actual $\text{HCO}_3^-$ concentration was 34 mEq/L, which is very close to the predicted value. Therefore, we can conclude that Bernice had only one acid-base disorder at the earlier visit: simple chronic respiratory acidosis.

4. At the terminal admission, three changes in Bernice's blood values were noted. (1) Her $\text{P}_\text{O}_2$ was lower than it had been previously, (2) her $\text{HCO}_3^-$ concentration had switched from being higher than normal to being lower than normal, and (3) her pH had become much more acidic. Her $\text{P}_\text{CO}_2$ was unchanged (still elevated, at 69 mm Hg).

Bernice's pH was more acidic at the time of her terminal admission because her $\text{HCO}_3^-$ concentration had decreased. Recall from our earlier discussion that Bernice had "lived" with an elevated $\text{P}_\text{CO}_2$ because renal compensation elevated her $\text{HCO}_3^-$ concentration, which brought her pH almost to normal. At the terminal admission, her $\text{HCO}_3^-$ was no longer elevated; in fact, it was decreased to less than normal. Referring back to the Henderson-Hasselbalch equation, you can appreciate that either a decrease in the numerator ($\text{HCO}_3^-$) or an increase in the denominator ($\text{P}_\text{CO}_2$) causes a decrease in pH; if both changes occur simultaneously, the pH can become devastatingly low!

An important issue we must address is why Bernice's $\text{HCO}_3^-$ was decreased at the terminal admission when it had been increased (by renal compensation) earlier. What process decreased her $\text{HCO}_3^-$ concentration? The answer is that Bernice had developed a metabolic acidosis that was superimposed on her chronic respiratory acidosis. (In metabolic acidosis, excess fixed acid is buffered by extracellular $\text{HCO}_3^-$, which lowers the $\text{HCO}_3^-$ concentration.) Although it is difficult to know with certainty the cause of this metabolic acidosis, one possibility is that lactic acidosis developed secondary to hypoxia. At the terminal admission, Bernice's $\text{P}_\text{O}_2$ was even lower (35 mm Hg) than it was at the earlier visit. As a result, O$_2$ delivery to the tissues was more severely compromised. As the tissues switched to anaerobic metabolism, lactic acid (a fixed acid) was produced, causing metabolic acidosis.

5. If the superimposed metabolic acidosis resulted from accumulation of lactic acid, Bernice's anion gap would have been increased. Lactic acid causes a type of metabolic acidosis that is accompanied by an increased concentration of unmeasured anions (lactate), which increases the anion gap.