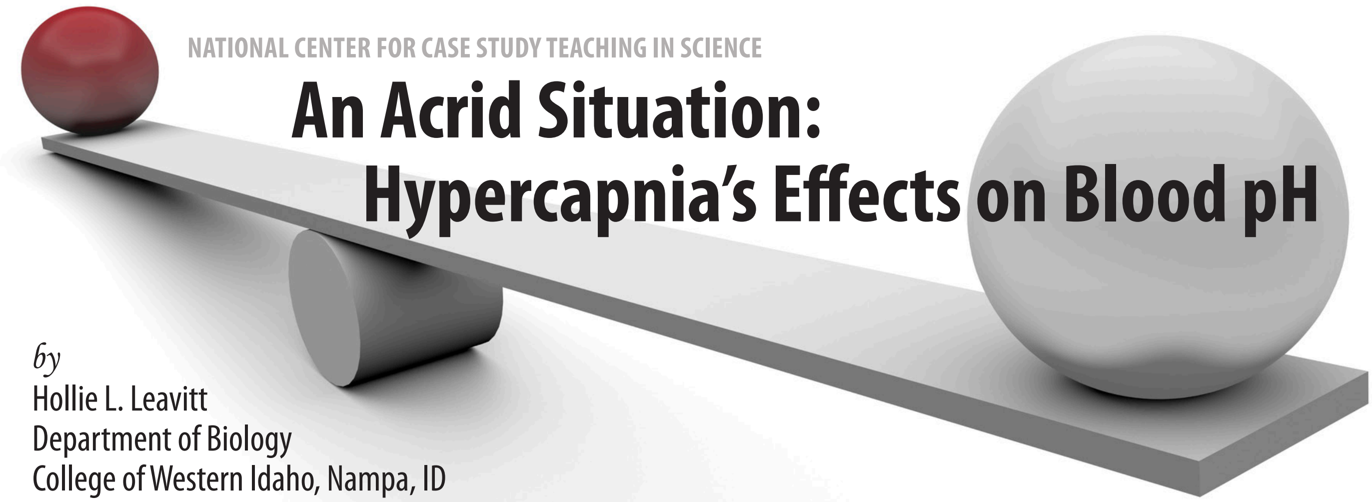
NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE



An Acrid Situation: Hypercapnia's Effects on Blood pH

by
Hollie L. Leavitt
Department of Biology
College of Western Idaho, Nampa, ID

Part I – Idiopathic Pulmonary Fibrosis

"Hi Jill," said Grandma as she opened up the door. "Come on in, Grandpa is waiting for us at the kitchen table." Jillian, a 20-year-old nursing student had come over to play cards with her grandparents, a weekly Sunday night tradition.

"Hi Pop!" she said cheerfully as she sat down next to her grandpa at the dinner table. "How has your week been?"

"Well," Grandpa began, "I was diagnosed with idiopathic pulmonary fibrosis on Friday." He paused for a moment, then added good-naturedly, "You're in nursing school, so tell me if you know what that means."

Jillian was the oldest granddaughter, and her grandfather had always enjoyed taking opportunities to help her learn. He bought her a subscription to *National Geographic* when she was only five, before she could even read, so she could look through the pictures of far off interesting places. Jillian recognized her grandfather's question as one more opportunity he had taken to encourage her in learning.

"Uh . . . it means that the tissues in your lungs that are used for gas exchange are being replaced with scar tissue, and the doctors aren't sure why. Grandpa," she asked, her voice beginning to quiver, "what is the prognosis?"

"The doctor gave me 18 to 24 months to live and I plan to enjoy every second of it," was his reply. "Jillian, you know I spent my career as a structural engineer designing buildings and bridges. I always designed with the function in mind: form fits function, so to speak. Tell me how the structure of my lungs is changing, and how this will affect the ability of my lungs to function."

Questions

1. The alveoli in the lungs where gas exchange occurs are composed of a simple squamous epithelium. What is the structure of this tissue type, and how does its structure make gas exchange possible?

2. How does idiopathic pulmonary fibrosis change the structure of the lungs, and how will this affect gas exchange?

3. Idiopathic pulmonary fibrosis is a progressive disease. Predict what will happen to Grandpa's blood pO_2 and pCO_2 as the condition worsens.

Part II – Equilibrium Reactions

"So Jill, I've been reading a lot about lungs since my diagnosis. Does the change in my lung structure mean that I will have problems with getting oxygen into my blood?" Grandpa asked.

"Yes," Jillian began, "but there is more to it than that. It's tempting to think that low blood pO_2 is the major issue for someone with a lung disease. However, high blood pCO_2 (hypercapnia) is also present and a problem. Actually, it's high blood pCO_2 that drives breathing (not low pO_2), and it's high pCO_2 that can make you feel short of breath, or 'air hungry.' One other issue with hypercapnia is it changes the blood's pH!"

Never missing an opportunity to learn, Grandpa responded in his inquisitive manner, "Jillian show me how this works."

"Okay," she replied. "I'll do my best. I'm going to have to draw this out though. This chemical equation illustrates how CO_2 has the potential to change blood pH," Jillian said as she wrote the formula on a piece of scratch paper:

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

"This chemical reaction where CO_2 reacts with water to form H^+ and HCO_3^- is an 'equilibrium reaction.' What this means is, the equation can run from left to right (using CO_2 and H_2O to produce the products H^+ and HCO_3^-) or it can run from right to left (using H^+ and HCO_3^- to produce CO_2 and H_2O). The H_2CO_3 is just an unstable intermediate; it's never around long."

"So, Jill," Grandpa interrupted, "what determines the direction this equation will run?"

"It's simple; the reaction tries to keep equal amounts of both the reactants and the products, so the ratio of CO_2 and H_2O to H^+ and HCO_3^- is the same. I'm more visual, Grandpa, so I like to think of it as a teeter totter. Let me draw you a picture."

Jillian then sketched out a simple drawing on the scratch paper:

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

"Now imagine all the reactant CO_2 and H_2O in your blood decided to ride the teeter totter with all the product H^+ and HCO_3^-- in your blood," she said. "In this picture, there are exactly equal amounts of the reactants and products on the teeter totter. They are balanced, or in equilibrium, right?"

Her grandfather nodded in agreement.

"Okay then, Grandpa, I've got some questions for you," Jillian said.

Questions

1. Suppose that for whatever reason, H^+ levels become lower than normal. Draw what the teeter totter would look like with less H^+ in the blood.

2. In which direction would this equilibrium reaction have to run (which would need to be produced, CO_2 and H_2O or H^+ and HCO_3^-) in order to rebalance the ratios when H^+ is lower than normal?

3. Now suppose that for whatever reason CO_2 levels in the blood become lower than normal. Draw what the teeter totter would look like with less CO_2 in the blood.

4. In which direction would the reaction have to run in order to rebalance the ratios of CO_2 and H_2O to H^+ and HCO_3^- when CO_2 levels are lower than normal?

5. What will happen to Grandpa's blood pCO_2 levels as his disease progresses, and what would the teeter totter look like in this situation?

6. In which direction would the reaction have to run in an attempt to rebalance the ratio of product to reactant in Grandpa's blood?

7. Complete this sentence based on what you've learned above: If CO_2 levels increase, the reaction will run _______________ (toward/away from) CO_2 to produce more ___________ ($CO_2 + H_2O$ / $H^+ + HCO_3^-$). If CO_2 levels decrease, the reaction will run _______________ (toward/away from) CO_2 to produce more _____________ ($CO_2 + H_2O$ / $H^+ + HCO_3^-$).

Part III – The Effects of CO_2 on Blood pH

The more H^+ there is in the blood, the more acidic the blood becomes (and the more its pH decreases). The basic rule is:

Higher levels of H^+ = lower pH (acidic)
Lower levels of H^+ = Higher pH (basic or alkaline)

Normal blood pH is slightly alkaline at 7.35 – 7.45, and the body cannot tolerate a blood pH outside of that range. Acidosis is a condition where blood pH is lower than 7.35, while alkalosis occurs when blood pH is higher than 7.45. Either can be fatal.

Questions

1. Based on what you've read in Part III, select the correct terms to fill in the blanks:
   When there is more H^+ in the blood, pH is ____________ (higher/lower). When there is less H^+ in the blood, pH is _____________ (higher/lower). If a solution such as the blood is acidic, this means it has a ____________ (high/low) pH, and there is ________ (a lot of/very little) H^+ present. If a solution such as the blood is alkaline or basic, this means it has a _____________ (high/low) pH, and there is ____________ (a lot of/very little) H^+ present.

2. Write a few sentences that describe the relationship between H^+ and pH.

3. Write a few sentences that describe the relationship between CO_2 and H+ in the blood.

4. Write a few sentences that describe the relationship between CO_2 and pH of the blood.

5. Predict what will happen to Grandpa's blood pH as his condition worsens. Be sure to explain your answer.

References

The Canadian Lung Association. *n.d.* Idiopathic pulmonary fibrosis. [Webpage]. <https://www.lung.ca/lung-health/lung-disease/idiopathic-pulmonary-fibrosis>.

National Heart, Lung, and Blood Institute). *n.d.* Idiopathic pulmonary fibrosis. [Webpage]. <https://www.nhlbi.nih.gov/health-topics/idiopathic-pulmonary-fibrosis>.

American Lung Association. *n.d.* Types, causes and risk factors of pulmonary fibrosis. [Webpage]. <http://www.lung.org/lung-health-and-diseases/lung-disease-lookup/pulmonary-fibrosis/introduction/types-causes-and-risk-factors.html>.