Problem-Solving Studio 3D - Cardiac Review, Respiratory Physiology: Ventilation and Gas Exchange

BMED 3100

November 4, 2024

Group Number: _____

Names: _____

Objectives:

1. Understand how clinicians perform disease diagnosis via ECG.
2. Evaluate accuracy of Machine learning models to diagnosis cardiac events via ECG
3. Understand pros and cons of large data and visual approaches to cardiac disease diagnosis
4. Integrate cardiovascular, microcirculation, and respiratory system functions.
5. Explain the process and influencing factors of external respiration.
6. Analyze the effects of different factors on oxygen-hemoglobin saturation.
7. Evaluate the effects of oxygen saturation on dissolved O2 content, O2 bound to hemoglobin, and total O2 content in volume of oxygen per dL of blood.

A 63-year-old woman was admitted to the hospital with a diagnosis of pneumonia in the right lower lobe, complicated by coronary artery disease, pulmonary edema, and atrial fibrillation. She had a history of severe coronary artery disease, multiple myocardial infarctions, poor left ventricular function, and chronic obstructive pulmonary disease (COPD). The patient was in her customary state of health until approximately 10 days before her admission to the first hospital when she began experiencing a productive cough, fever, chills, and mild dyspnea. Eight days prior to her first admission, her physician prescribed ciprofloxacin, but she did not improve after taking three doses. The chest pain recurred and was relieved by nitroglycerin. The following day, the patient's fever increased, and her husband noticed that she was coughing up small amounts of blood and was in increasing respiratory distress.

The patient was admitted to a second hospital. On the first day of admission, her physical examination revealed a temperature of 38.6°C, a pulse of 112 beats per minute, and a respiratory rate of 36 breaths per minute. Her oxygen saturation was 80% while breathing ambient air and improved to 90% following oxygen administration. The arterial PaO_2 was recorded at 80 mmHg after oxygen therapy, while the $PaCO_2$ was 38 mmHg. Blood pressure was noted to be 90/60 mmHg (normal range: 120/80 mmHg). The patient appeared chronically ill, with signs of toxicity, and exhibited moderate respiratory distress; cyanosis was observed prior to the administration of oxygen.

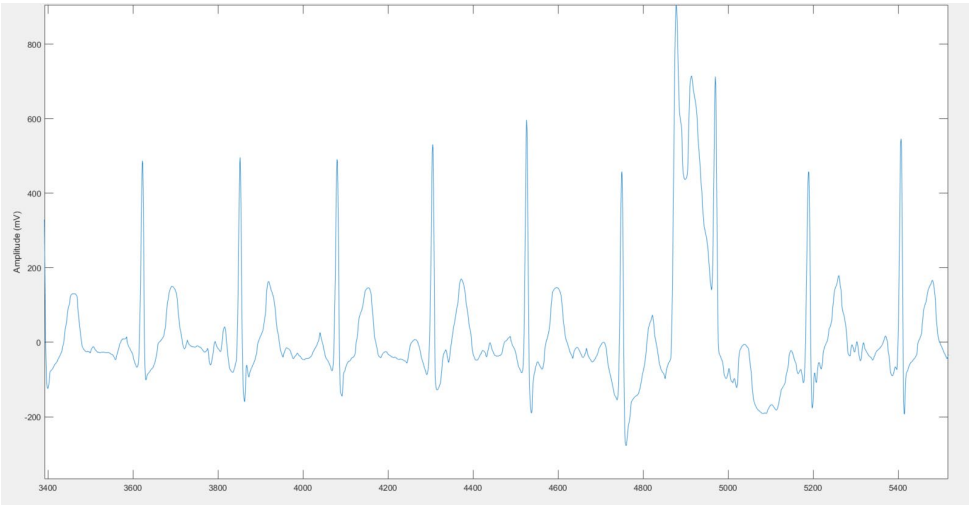
Problems:
Zip.file.of.Matlab.materials¿https://gtvault-my.sharepoint.com/:u:/g/personal/tfernandez32_gatech_edu/ESBms-5HEHJFnyMYGr6bz8EBp_MeMKGyB87l-_QTnfR3cA?e=Hp4tUo

Google.spreadsheet.to.share.class.results¿ https://docs.google.com/spreadsheets/d/17FEcMVFmLvDsaqsBdV4diKtRI4wriYNojLKinSLRl1o/edit?gid=2125507337#gid=2125507337

1. One of the first tests administered to the patient was an electrocardiogram (ECG). Pretend you are an ER resident. A cardiologist reports that the patient is NOT in atrial fibrillation (A-Fib), but you disagree.

   a. Download the zip file from the link to the Matlab files above. Find it on your computer, unzip the folder, and then from within that folder open the file: BMED3100_ECG_PSS_compressed.mlx

   b. Examine the following ECG and determine and annotate, i.e. mark the features that you think could indicate the patient is in A-Fib.



   c. Run SECTION 1 of the Matlab code (read the instructions in Matlab carefully). When it is done running it will print two ECGs that are the same for everyone in the class (#4 and #1) and one random ECG that is different for each team. Look at the signals and decide whether you think each is an A-Fib signal and why. Enter those decisions in the google spreadsheet you were sent the link to. [Completion grade only]

   When you are done, as a team discuss the questions below. As everyone finishes, you will discuss them as a class:

d. Were your diagnoses correct? (The correct classification for ECGs 4 and 1 will be discussed as a class.) [Completion grade only]

i. What did you see in the plots that led you to make the choice you did?

ii. Why does A-Fib result in the changes you indicated in part 1A to the ECG signals?

iii. What was challenging about making the diagnoses? [Completion grade only]

Run section 2 of the matlab code. There are two options. If you have Matlab 2024 – run **section 2A**. If you have Matlab 2023, run **Section 2B**. Your version of Matlab can be found in the the very top left of your Matlab window, by the Matlab icon. Once your code is running, read the below.

With the increasing prevalence of AI prediction tools, hospitals would be interested in a tool that can accurately, with low false positives and low false negatives, predict A-Fib. We pretrained a deep learning model on about 8000 ECG signals[1]. Pretraining means the model learned what to look for in ECGs to best predict AFib/not AFib. After the model is trained, we can use it for *inference* – meaning to look at a new signal and classify it as AFib/not AFib. The code in Section 2 does the inference step on 998 new ECG signals that the model has never seen before. That allows us to test the accuracy of our model.

While the code is running, (between 2 and 5 minutes), start working on the problems below (e, g-j).

e. Why might a raw ECG signal be challenging to fit to a mathematical model? [Completion grade only]

f. Enter the data from section 2 of the code into the spreadsheet. You should enter the time it took to run (inference_time), the overall accuracy (Test_Accuracy) and the true positives, false positives, true negatives, and false negatives from the confusion chart. **What do you think about the accuracy of this model for diagnosing AFib in clinical settings?** [Completion grade only]

g. As a clinician, would you rely on the AI tool you just used to <u>diagnose</u> A-Fib/decide a treatment procedure based on the output? [completion grade only]

h. As a clinician, would you rely on the AI tool you just used to eliminate A-Fib diagnosis/decide a treatment procedure based on the output? [completion grade only]

i. As an ER resident, you make the decision to treat the patient in the case study as if she is in A-Fib. Would metoprolol, a beta-1-blocker, affect A-Fib? Would shocking the patient with an external defibrillator fix A-Fib? An external defibrillator is a synchronized shock that can be applied to a patient. Explain why.

Template Answers
Beta 1 blockers work by reducing the heart rate and decreasing the force of contraction, which helps control the ventricular rate in A-Fib. By blocking beta-1 adrenergic receptors in the heart, metoprolol slows down the transmission of electrical impulses through the AV node, which is crucial for rate control in patients with A-Fib. However, metoprolol does not directly convert A-Fib into normal sinus rhythm; it primarily helps to manage symptoms by preventing rapid heart rates.

Shocking a patient with an **external defibrillator** can potentially "fix" A-Fib. It works by resetting the heart's electrical activity, allowing the sinus node to resume its normal pacemaking function.

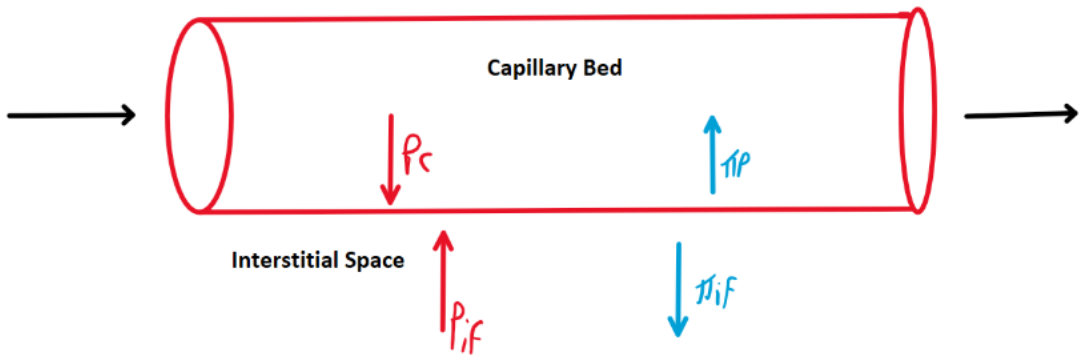
j. If you had decided that the patient was not in A-Fib but she actually was (a false negative), what would be the consequences of untreated A-Fib in terms of blood pressure?

Template ans: Failing to diagnose A-Fib leads to unmanaged irregular heart rhythms, putting the patient at risk for both short-term blood pressure variability and long-term chronic hypertension. These complications can further progress to heart failure and increase the risk of systemic events such as stroke.

2. Considering the patient's pulmonary edema in the case study, explain the following:

i. Could atrial fibrillation have contributed to the patient's pulmonary edema? Support your answer by drawing a diagram on the whiteboard illustrating capillary dynamics, specifically the filtration and reabsorption processes in capillary microcirculation. Be sure to clearly label each of the Starling forces and indicate which force is responsible for the edema.

Yes, atrial fibrillation (Afib) can contribute to the patient's pulmonary edema. Afib leads to ineffective atrial contraction, which can cause blood to pool in the atria and subsequently back up into the pulmonary circulation. This increased pressure in the pulmonary capillaries elevates the hydrostatic pressure. This increase favors filtration over reabsorption since the increased pressure pushes more fluid out of the capillaries and into the surrounding lung tissue. As a result, the balance shifts toward net filtration, leading to an accumulation of fluid in the interstitial space and alveoli.



3. On the second hospital admission, while breathing 100% O2, the patient presented with PaO2= 80 mmHg (normal values= 100 mmHg); PaCO2=135 mmHg (normal values 35-45 mmHg).

Based on your understanding of external respiration, explain why the patient's arterial blood PaO2 remains abnormal even when breathing 100% O2. Of these three main reasons, i.e. increased fluid accumulation, extended diffusion distance, low respiration rate, related to the patient's pulmonary edema. In addition, explain how cooperative binding of hemoglobin might factor into this situation.

1. **Increased fluid accumulation** between the alveoli and blood vessels due to edema creates a barrier to gas exchange. Since oxygen has low solubility in water, it has difficulty diffusing through this additional fluid layer, leading to reduced oxygen uptake.
2. **Extended diffusion distance**: The presence of excess fluid increases the distance between alveoli and capillaries, which slows the rate of gas diffusion. Because oxygen and carbon dioxide exchange are distance-dependent, this extended gap further limits oxygen transfer into the bloodstream.
3. **Low respiration rate**: Pulmonary edema can lead to decreased respiratory efficiency, where shallow or labored breathing may occur, lowering the effective respiratory rate. This decreases overall oxygen intake and exacerbates the patient's low arterial PaO2. In addition, **cooperative binding of**

hemoglobin is affected under these conditions. When less oxygen is available for initial binding, it further decreases hemoglobin's ability to get full saturation, this compounds the effects of the limited oxygen transfer caused by the edema.

4. Clinically relevant values and calculations:

Note: Concepts Clarified

1. Dissolved O_2 Content: Dissolved O_2 refers to the amount of oxygen that is physically dissolved in the plasma of the blood, as opposed to oxygen that is bound to hemoglobin. It is influenced by the partial pressure of oxygen (PaO_2) and its solubility in blood.
2. O_2 Saturation (SaO_2): The percentage of hemoglobin binding sites occupied by oxygen. It reflects how much oxygen is carried by hemoglobin in the blood.
3. Total O_2 Content (CaO_2): The total amount of oxygen carried in the blood, which includes both dissolved O_2 (in plasma) and O_2 bound to hemoglobin.

Assumptions:
Oxygen carrying capacity by hemoglobin is 1.34 mL O_2/g Hb
Hb concentration = 12.9 g Hb/dL blood
O2 solubility = 0.003 mL O2 per dL*mmHg

Problems:
i. Calculate the dissolved O_2 content:
Dissolved O2 context (SaO2) = solubility of O2 x Pa O2

While breathing ambient air:

Dissolved O2 content= (0.003 mL/(dL·mmHg)) × (55 mmHg) = **0.165 mL O2/dL blood**

While on 100% oxygen:

Dissolved O2 content= (0.003 mL/(dL·mmHg) × (80 mmHg) = **0.240 mL O2/dL blood**

ii. Calculate O_2 bound to hemoglobin:

O2 bound to Hb= (Hb concentration × carrying capacity of Hb) ×O2 saturation

On ambient air:

(12.9 g Hb/dL blood) × (1.34 mL O2/g Hb) × (0.80) =**13.83 mL O2/dL blood g Hb/dL blood**

After O_2 administration:

(12.9 g Hb/dL blood) × (1.34 mL O2/g Hb) × (0.90) =**15.42 mL O2/dL blood g Hb/dL blood**

iii. Calculate the total O_2 content (CaO_2) in volume of oxygen per dL of blood:

Total O2 content=Dissolved O2 content+O2 bound to Hb

While breathing ambient air:

0.165 mL O2/dL blood+13.83 mL O2/dL blood=**14.00 mL O2/dL blood**

After O_2 administration:

0.240 mL O2/dL blood+15.42 mL O2/dL blood=**15.66 mL O2/dL blood**

5. Analyze Calculated Values:

a. Did the patient's dissolved O_2 content reach 100% after receiving 100% oxygen? If not, identify one of the following factors, pulmonary edema, chronic obstructive pulmonary disease (COPD), atrial fibrillation, related to the patient's diagnosis that may have prevented this. Support your answer.

graders any one of the following are fine:

The patient's dissolved O_2 content did not reach 100% after receiving 100% oxygen due to several factors, including the presence of pulmonary edema, chronic obstructive pulmonary disease (COPD), and atrial fibrillation (AFib).

1. **Pulmonary Edema:** The accumulation of fluid in the alveoli creates a barrier that hinders the diffusion of oxygen from the alveoli into the bloodstream. This fluid impedes gas exchange, limiting the amount of oxygen that can enter the blood, even when oxygen is administered at high concentrations.
2. **Chronic Obstructive Pulmonary Disease (COPD):** COPD leads to structural changes in the lungs that further reduce gas exchange efficiency. The damaged airways and alveoli cannot adequately transfer oxygen into the blood, exacerbating the difficulty in achieving higher dissolved O_2 content.
3. **Atrial Fibrillation (AFib):** AFib can cause irregular and ineffective heartbeats, reducing cardiac output and impairing the ability of the blood to transport oxygen efficiently throughout the body. This can result in lower oxygen delivery to tissues, compounding the effects of edema and COPD.

b. Analyze the change in your patient's O_2 saturation after receiving 100% oxygen. Was this increase substantial (defined here as more than a 50% increase)? If not, which factor likely had the greatest effect on O_2 saturation: the patient's body temperature, respiratory rate, or high arterial $PaCO_2$ (refer to values in Q3, i.e the values on the second hospital visit) ? Provide reasoning to support your answer.

Template Answer: Graders look for an explanation for WHY high CO2 levels decreases pH, WHY low pH would lead to Hemoglobin's lower affinity for O2 (bolded text below)- if one or both of these are missing then the grade is an automatic M.

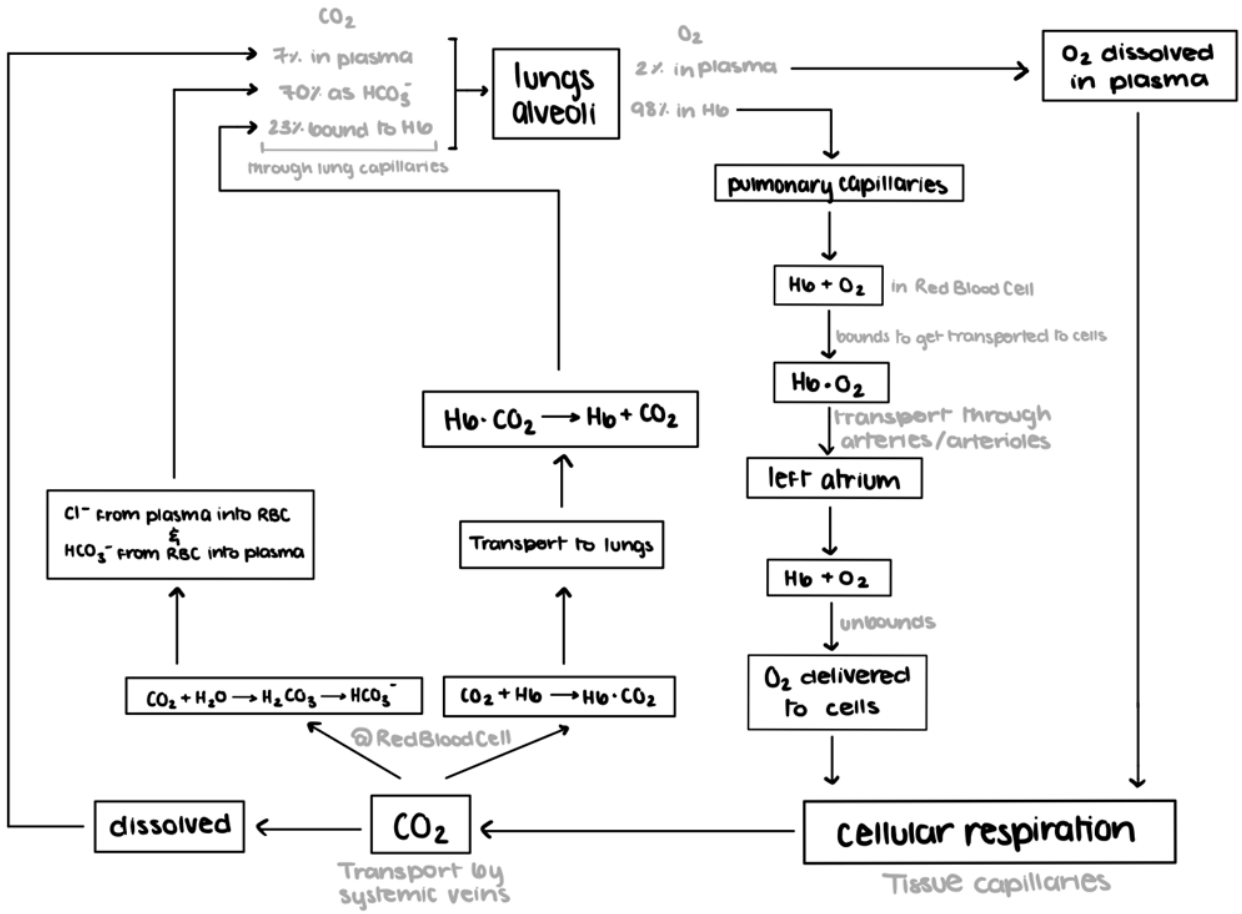
The increase in the patient's O_2 saturation following 100% oxygen administration was not substantial, as it did not exceed a 50% change. Among the factors given—temperature, respiratory rate, and arterial $PaCO_2$—the patient's elevated $PaCO_2$ levels likely had the greatest influence on the limited increase in O_2 saturation. **High $PaCO_2$ (136 mmHg in this case) will lead to lower blood pH since CO2 + H2O and carbonic anhydrase leads to the formation of H+ and HCO3-. This condition reduces hemoglobin's affinity for oxygen (the Bohr effect) b/c H+ binds to oxygenated Hg changing its conformation such that its affinity for oxygen is lowered.** This means hemoglobin is less likely to bind to oxygen even when PaO_2 is increased through supplemental oxygen. As a result, despite higher oxygen delivery to the lungs, the saturation remains lower than expected due to the decreased ability of hemoglobin to carry O_2 effectively under these acidic conditions.

c. Explain how elevated $PaCO_2$ affects the hemoglobin-oxygen saturation curve.

This increase in O2 unloading shits the hemoglobin saturation curve to the right. This rightward shift means

hemoglobin will release oxygen more readily at a given partial pressure, facilitating greater oxygen unloading to the tissues.

6. In gas transport, O2 and CO2 are continuously transported between lungs and tissues via blood. Using a CONCEPT MAP describe the process of O2 and CO2 transport between lungs and systemic tissues. Emphasize different ways these gases are getting transported by blood (dissolved, bound to Hb etc.), and factor(s) that influence their loading and unloading.



7. Now go back and take a look at the class data from the AFib AI/ML model on the Google Spreadsheet. Use it to discuss/answer the questions below. Look at two sheets: The *Manual Diagnostics Summary* sheet shows how well you and your classmates did at evaluating ECGs for AFib. The *Neural Network Accuracy Summary* sheet shows how the AI tool did at classifying ECG signals. [All completion grade only]

A. Based on the accuracy of the class (Manual) diagnosis and the accuracy of the AI tool (Neural Network), how would a positive diagnosis of A-Fib from either your classmate or from the AI tool affect the treatment you would give the patient?

B. How does the accuracy of the AI tool compare to different levels of doctor (Manual). How does that affect your evaluation of the accuracy of the AI tool?

C. How is B. affected by the inference time it takes the AI tool to interpret one ECG?

D. Based on what you have seen today, what role do you think AI/ML has in diagnosing cardiac measures (ECGs, blood pressure, patient symptoms, medical records, etc.) now and in the future?

E. What is one thing about this entire PSS that your group is struggling with or confused by?