TEACHING MODEL FOR VENTILATION AND PERFUSION MISMATCHING

Team Members: Alex Houle, Charlie Zhu, Darshigaa Gurumoorthy, Kendra Besser, and Milica Lukic
Client: Dr. Chris Green
Advisor: Professor Chris Brace

Abstract

The concept of ventilation (V) and perfusion (Q) mismatch in the lungs is of great clinical significance. V/Q mismatching leads to a variety of problems, the most serious of which is hypoxemia which can cause respiratory failure. There is currently no effective teaching model for learning this concept, which is why the client, Dr. Christopher Green has commissioned BME design students to create an intuitive and visually helpful teaching model. The model uses a 3D printed board designed in the image of an alveolus and capillary in the lungs, LED lights to demonstrate air and blood flow at different V/Q ratios, knobs to view a wide range of V/Q ratios, and a digital display to show the V/Q ratio and partial pressure of oxygen.

Problem Definition

MOTIVATION

It is very important for medical students to understand V/Q mismatching as it is the cause of many issues in the lungs, such as hypoxemia or dead space ventilation. Currently, students rely on models in textbooks to visualize the effects of V/Q mismatching on the lungs. This teaching model is necessary as it provides students with an interactive, visual tool to understand what occurs in the alveolus and capillary during mismatching.

BACKGROUND

- The lungs contain alveoli, which are the main sites of gaseous exchange. [1]
- V/Q ratio refers to the ratio of air entering and leaving the alveoli to flow of blood to and from the capillaries. [2]
- Both V and Q are measured in liters/minute,
- A healthy individual would have an average V/Q ratio of 1. [1]

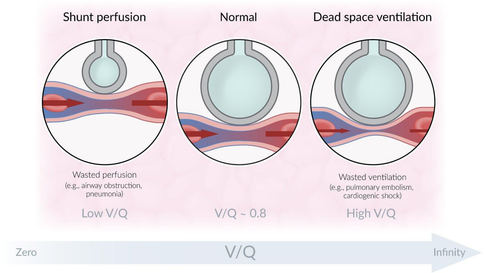

Figure 1. Obstruction of capillary at different V/Q ratios. [5]

- Alveolar dead space refers to lack of ventilation, resulting in some alveoli not being ventilated, lowering V/Q, causing hypoxemia. [2]
- Hypoxemia occurs when there is a low level of oxygen in the blood, and it can lead to respiratory failure. [3]
- Partial pressure of oxygen (P_aO_2) is the measure of the pressure of oxygen dissolved in the blood [4]

Design Criteria

- Intuitive use for students and teachers
- Knobs that control V and Q to allow the user to view a wide range of V/Q ratios
- Digital display that shows the V/Q ratio and partial pressure of oxygen (P_aO_2)
- Visibility under a document camera in a lecture hall
- No larger than 22.86 cm x 22.86 cm
- No heavier than 6.8 kg
- Easily storable with a service life of at least 5 years
- Not necessarily anatomically realistic, but good visual representation of the alveolus and capillary at different V/Q ratios

Materials

- PLA for 3D printing
- Arduino
- Adafruit potentiometers
- Adafruit knobs
- Adafruit Neopixel LED strips
- LED bulbs
- Adafruit RGB LCD 20x4
- Total Cost = $175.41

Final Design: Progress

In order to address the client's desires, make a variety of improvements, and create an intuitive model, the team went through the following steps and more:

- Redesign the board for knobs rather than buttons
- Alter the shape of the capillary on the board in order to better represent the capillary network present in the lungs
- Change the color of the PLA board in order to improve visibility under the document camera and increase the contrast of the lights against the board
- Change the shape of the LEDs in the alveolus to better show the movement of air down and dispersing throughout the alveolus
- Calibrate and program the potentiometer knobs
- Program the LEDs in the alveolus and the capillary to respond accurately to different V/Q ratios
- Program the display to show the V/Q ratio as well as P_aO_2

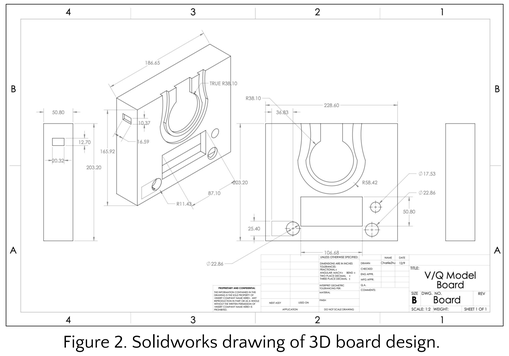

Figure 2. Solidworks drawing of 3D board design.

Initial Testing: Qualitative

In order to create the most effective fabrication plans, we tested the previous model in a classroom setting under a document camera. The findings were as follows:

- Model has to be connected to personal laptop through USB to obtain power
- Black PLA would increase the visibility of the LEDs
- Electronic display needs to be larger than the previous model
- No red or dark colored text; green and white text are visible
- Green LEDs do not display well under the document camera
- Scratches on the PLA are very apparent under the document camera
- Previous model alveolus is too complex and difficult to understand
- Parts of the model need to be labeled

Final Design: Results

The team was able to create a final model with the following features:

- One knob to control V values and another to control Q values
- Larger display for clearer and more visible text
- P_aO_2 calculated based on V/Q ratios and included on display
- Power button
- Yellow 3D printed board - Makerspace out of black PLA
- More accurate capillary and alveolus design
- More accurate alveolus light movement

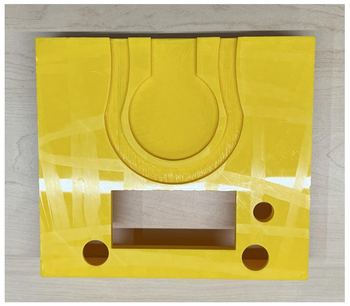

Figure 3. 3D printed board

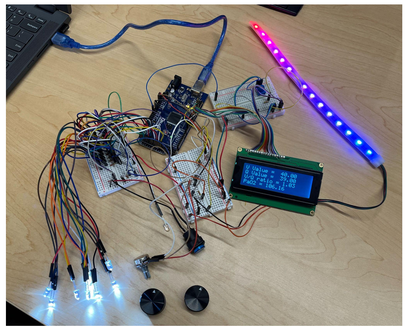

Figure 4. Circuit with LEDs, potentiometers, and display

Figure 5. Device at V/Q = 0.16

Figure 6. Device at V/Q = 0.67

Figure 7. Device at V/Q = 2.54

Final Testing: Quantitative

Table 1. Comparing the displayed values from the code to the calculated values

V Value (L/min)	Q Value (L/min)	V/Q Ratio Displayed	P_aO_2 Displayed (mmHg)	V/Q Ratio Calculated	P_aO_2 Calculated (mmHg)
90.00	100.00	0.90	101.84	0.9000	101.8412
6.00	37.00	0.16	50.42	0.1622	50.4199
29.00	56.00	0.52	82.14	0.5179	82.1384
59.00	100.00	0.59	86.86	0.5900	86.8567
6.00	74.00	0.08	43.33	0.0811	43.3342

Future Work

- Reprint the board with black PLA
- Testing the model in a lecture hall to examine the LEDs and screen under a document camera
- Testing the model with the client and a small group of his medical students to receive feedback on criteria such as intuitive use and helpful visual representation
- Later testing with a larger population of medical students to determine the impact of this teaching model on a larger scale
- Continuing with programming and circuitry to ensure the code runs smoothly
  - Specifically, working on the speed and accuracy with which the LEDs respond to the potentiometer knobs
- Addition of another alveolus to better mimic the lung

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