A VISUAL AID FOR TEACHING VENTILATION-PERFUSION RELATIONSHIPS

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To help students understand the concept of the ventilation-perfusion ratio (VA/Q) and the effects that VA/Q mismatching has on pulmonary gas exchange, a "sliding rectangles" visual aid was developed to teach VA/Q relationships. Adjacent rectangles representing "ventilation" and "perfusion" are slid past one another so that portions of the ventilation and perfusion rectangles are not touching, illustrating the concepts of dead-space ventilation (VD) and shunt flow (QS). The portion of the ventilation bar representing Vo is further subdivided into anatomical and alveolar Vo and used to show the effects of alveolar dead space on the PO2 (PAO2) and PCO2 of alveolar air (PACO2; movement away from the "ideal" point). Similarly, the portion of the perfusion bar representing Qs is used to define anatomical and physiological shunts and the effect of shunts on the PO2 (PAO2) and PCO2 of arterial blood (PACO2). The genesis of the A-a PO2 difference as well as the effects of VA/Q mismatching and diffusion abnormalities can all be discussed with this visual aid. This approach has greatly assisted some students in mastering this traditionally difficult area of respiratory physiology.

Key words: teaching of physiology; learning styles; ventilation-perfusion ratio

INTRODUCTION AND BACKGROUND

For some students, the concept of the ventilation-perfusion ratio (VA/Q) and the effect that VA/Q mismatching has on pulmonary gas exchange has remained an unfathomable mystery even after my best attempts to explain it using the conventional formulas and illustrations. This concept, however, has been identified as one of the top 10 biomedical concepts of critical importance to the practice of medicine by medical school basic science and clinical faculty alike (1). An approach that finally proved useful for me in explaining this important concept to a number of frustrated students who visited my office for extra help was a "sliding-bar" visual aid that frequently generated the "Aha!" response from these students.

DESCRIPTION OF THE SLIDING-BAR VISUAL AID AND ITS USE

The visual aid begins rather simply, as shown in Fig. 1. Two bars are used: one on top representing ventilation and the other below it representing perfusion. Initially, the two boxes are exactly aligned, indicating the ideal situation of perfect matching of ventilation and perfusion. The boxes are then depicted as sliding past one another, so that a portion of the ventilation bar is not touching the perfusion bar and vice versa.
Ventilation and perfusion are “mismatched,” and this imperfect relationship between ventilation and perfusion is clearly distinguishable from the ideal. The general concepts of “dead-space” ventilation ($V_d$) and “shunt” flow ($Q_s$) are introduced at this point and are further developed and expanded as described below.

**USE OF THE VISUAL AID TO DEMONSTRATE THE CONCEPTS OF ANATOMICAL AND PHYSIOLOGICAL DEAD SPACE**

When the two bars are slid past one another (or mismatched), a portion of the ventilation bar does not touch the perfusion bar. This “overhang” represents the dead space, as shown in the lower portion of Fig. 1. At this point, the term “anatomical dead space” is introduced and defined, the anatomical and functional properties of the conducting system are discussed, and a line is drawn to divide the ventilation bar into “anatomical $V_d$” ($V_{d,anat}$) and “alveolar ventilation.” Sliding the ventilation bar out a little more, as shown in Fig. 2, illustrates the idea that even some of the alveolar gas-exchange areas of the lung may not be perfused, thereby introducing the concept of “alveolar $V_d$” ($V_{d,alv}$). The entire region of overhang, which now includes both the $V_{d,anat}$ and $V_{d,alv}$, is then described as the “physiological $V_d$.” A combination of the visual aid and the appropriate mathematical expressions found in standard texts on respiratory physiology and pathophysiology (2–5) can then be used to show the effect of alveolar dead space on alveolar $PO_2$ and $PCO_2$ (and their movement away from the ideal point) as well as the effects of $V_d$ as a whole on expired gas concentrations.

**USE OF THE SLIDING-BAR VISUAL AID TO DESCRIBE THE CONCEPT OF ANATOMICAL AND PHYSIOLOGICAL $Q_s$ FLOW**

The concepts of anatomical and physiological $Q_s$ and the effect of $Q_s$ on arterial blood gas values are described using the visual aid in a fashion analogous to that described above for the concept of dead space. When the bars are slid apart, the portion of the perfusion bar that juts out beyond the ventilation bar is initially and somewhat nonspecifically shown in the lower portion of Fig. 1 as $Q_s$, the addition to pulmonary venous blood of deoxygenated blood that has not exchanged oxygen and carbon dioxide with ventilated regions of the lung. At this point, the idea that some shunting (and therefore venous admixture) normally occurs because of the anatomy of the pulmonary vasculature (e.g., bronchial veins) and peculiarities of the coronary circulation (e.g., Thebesian veins) is used to introduce the concept of “anatomical $Q_s$,” and a line is drawn on the perfusion bar dividing it into anatomical $Q_s$ and pulmonary capillary flow. Sliding the bars further apart (increasing the mismatch between ventilation and perfusion), as shown in Fig. 2, demonstrates that some portions of the pulmonary circulation that normally participate in gas exchange may not be able to do so, because they perfuse alveoli.

**FIG. 1.**

Top: perfect matching of ventilation and perfusion. Middle: mismatching of ventilation and perfusion, with some regions ventilated but not perfused and others perfused but not ventilated. Bottom: dead-space ventilation ($V_d$), alveolar ventilation ($V_A$), pulmonary capillary flow ($Q_c$), and shunt flow ($Q_s$). In this and subsequent figures, the dimensions of the bars and bar segments are not meant to indicate quantitative relationships, only conceptual ones.
that are not ventilated (intrapulmonary shunts). This would increase the amount of venous admixture and would increase the total amount of QS beyond that of the anatomical QS alone. The term “physiological QS” (QSphys) is then introduced to describe the entire portion of the perfusion bar that juts out beyond the

\[ \text{FIG. 2.} \]

\[ V_D \text{ may include anatomical dead space (} V_{D_{anat}} \text{) and alveolar dead space (} V_{D_{alv}} \text{), with the combination of these 2 comprising physiological dead-space ventilation (} V_{D_{phys}} \text{). Similarly, QS may include intrapulmonary shunts (} Q_{S_{ip}} \text{) as well as anatomical shunts (} Q_{S_{anat}} \text{), with the combination of these 2 comprising physiological QS (} Q_{S_{phys}} \text{).} \]


\[ \text{FIG. 3.} \]

\[ \text{Ideally, the } P_O_2 \text{ of alveolar gas and pulmonary end-capillary blood are identical. In reality, the } P_O_2 \text{ of alveolar air (} P_{A_{alv}} \text{) is shown to be the result of mixing of air from the alveolar dead space with air from perfused alveoli and therefore is a higher } P_O_2 \text{ than would be found in alveoli that participate in gas exchange. Similarly, the } P_O_2 \text{ of arterial blood (} P_{A_{arterial}} \text{) is shown to be the result of mixing of blood that has passed through pulmonary capillaries with } Q_{S_{phys}} \text{ and therefore is a lower } P_O_2 \text{ than would be found in pulmonary end-capillary blood that has participated in gas exchange. The presence of alveolar dead space and physiological shunting therefore move } P_{A_{alv}} \text{ and } P_{A_{arterial}} \text{ in opposite directions and create the A-a } P_O_2 \text{ difference.} \]
ventilation bar (anatomical shunts and intrapulmonary shunts), and the visual aid at this point can be supplemented with the appropriate mathematical expressions used to quantify $Q_s$ and demonstrate the effect of increasing $Q_s$ on arterial $P_O_2$ (5).

USE OF THE SLIDING-BAR VISUAL AID TO ILLUSTRATE THE GENESIS OF THE A-a $P_O_2$ DIFFERENCE

This visual aid can be used to reinforce the reasons for the normal A-a $P_O_2$ difference and the effects of $VA/Q$ mismatching on alveolar and arterial $P_O_2$ and $P_{CO_2}$, as shown in Fig. 3. The movement of alveolar $P_O_2$ away from the ideal is demonstrated by bracketing the portions of the ventilation bar corresponding to all alveoli that are ventilated and thus contributing to the $P_O_2$ of alveolar air (including both perfused alveoli and alveolar dead space) and comparing it to the portion of the ventilation bar representing ventilation of perfused alveoli only. The addition of alveolar dead space is seen to “pull” the measured alveolar $P_O_2$ away from the ideal value obtained when ventilation and perfusion are perfectly matched.

Similarly, comparison of the portion of the perfusion bar that corresponds to pulmonary capillary flow with the portion that corresponds to the entire cardiac output of the left ventricle (pulmonary capillary flow and $Q_{S\text{phys}}$ together) demonstrates how $Q_{S\text{phys}}$ pulls the measured arterial $P_O_2$ away from the ideal “end-capillary” value (Fig. 3) obtained when ventilation and perfusion are perfectly matched.

USE OF THE SLIDING-BAR VISUAL AID TO ILLUSTRATE THE CONCEPT OF PULMONARY DIFFUSION CAPACITY

The concept of pulmonary diffusion capacity can also be addressed by the sliding-bar diagram and is related visually to the extent of overlap between the ventilation and perfusion bars (corresponding roughly to the surface area available for diffusion) and the thickness of the line separating the two bars (corresponding to diffusion distance). Figure 4, top, illustrates an increase in diffusion distance as a thickening of the line separating alveolar air and pulmonary capillary blood. Again, the visual aid is supplemented at this point with a mathematical, quantitative discussion of the determinants of pulmonary diffusing capacity (2, 5, 6).

Finally, the visual aid can be used to demonstrate heterogeneity among lung units that are both ventilated and perfused by varying the thicknesses of the alveolar ventilation and “pulmonary capillary flow” bars, as shown in Fig. 4, bottom. This produces a unique $VA/Q$ ratio at each point along the region of overlap between these two bars, ranging from very high $VA/Q$ ratios at the dead-space end of the overlap (“dead-space-like” regions), and very low $VA/Q$ ratios at the shunt end of the overlap (“shuntlike” regions).

IMPRESSION OF THE USEFULNESS OF THE SLIDING-BAR VISUAL AID FOR VENTILATION-PERFUSION RELATIONSHIPS

After selected students have been acquainted with the $VA/Q$ visual aid to supplement the usual graphs and diagrams regarding ventilation, perfusion, and gas ex-
change, they seem to understand better the pathophysiological causes of low arterial $\text{PO}_2$ (hypoventilation, shunts, $\text{VA/Q}$ mismatching, diffusion abnormalities, and ambient hypoxia), the genesis of the $\text{A-a PO}_2$ difference, and the effects of supplemental oxygen administration on arterial $\text{PO}_2$ and the $\text{A-a PO}_2$ difference in patients with arterial hypoxemia.

I have found that such a visual aid is definitely not for everyone and is viewed by some students as an unnecessary or complicating addition. Those students who can readily and intuitively grasp the concept of ventilation-perfusion relationships through reading the textbook or who understand it more quantitatively from a mathematical approach find the visual aid to be superfluous. But for others, the sliding-bar concept of $\text{VA/Q}$ matching has made all the difference and has enabled them to understand this traditionally difficult but very important area of physiology.

SUMMARY AND CONCLUSION

In physiology courses offered to students in the College of Osteopathic Medicine and graduate students in the physicians’ assistant and nurse anesthesia programs at the University of New England, a sliding-bar visual aid was developed to supplement the teaching of $\text{VA/Q}$ relationships. The sliding-bar visual aid appears to have value as a visual means of describing the concepts of $\text{VA/Q}$ ratios and $\text{VA/Q}$ mismatching and could be used either in a large-group lecture format with all students or with a subset of students who visit the office for additional help in mastering physiological concepts.

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