What we talk about when we talk with medical students

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Joyner MJ, Charkoudian N, Curry TB, Eisenach JH, Wehrwein EA. What we talk about when we talk with medical students. Adv Physiol Educ 35: 16–21, 2011; doi:10.1152/advan.00058.2010.—In this article, we review how we interact with medical students in our efforts to teach blood pressure regulation and systemic cardiovascular control along with related elements of respiratory and exercise physiology. Rather than provide a detailed lecture with key facts, we attempted to outline our approach to teaching integrative cardiovascular physiology to medical students, which includes five major themes. First, focus on questions versus answers and facts. We believe that this offers both the learner and teacher a number of advantages. Second, avoid teaching dogma in the name of clarity (i.e., heavy focus on teaching “facts” that have not yet been fully investigated). This is especially important because of the way knowledge evolves over time. Third, include laboratory-based experiences in human integrative physiology. Fourth, provide students with intellectual frameworks versus a list of “facts” to serve as a platform for question generation and deeper understanding. We want to educate versus train medical students. To do so, we focus on questions versus rote memorization, and we avoid heavy focus on “answers and facts” because of the way that knowledge evolves over time. Our perspective is also informed by our belief as physiologists and anesthesiologists that laboratory experience in physiology is critical for the future physician. Finally, it is essential to focus on the role of integration and regulatory redundancy in physiology, so this is built into our discussions.

The Problem of “Information Smoothies” and Academic Hurdling

“Basic science” is usually taught to medical students by basic scientists. These individuals are, for the most part, interested in the deep intellectual exploration of a specific set of problems, topics, ideas, and questions. In contrast, the undergraduate education experience leading up to medical school, the admissions process, and success in the didactic portions of medical school can be seen as a collection of reasonably well-defined hurdles that have to be overcome by the student so that the next hurdle or hurdles can be addressed. So, to the basic scientists participating in the education of medical students, it seems as if they are doing no more than creating an “information smoothie.” This can be described as filling the brains of the students with a collection of facts, stirring the facts, and sampling the outcome via some sort of standardized testing procedure. This general approach also leads to terribly frustrating questions, such as:

• “Can you post the slides on the web?”
• “Can you post the answers to the quiz on the web?”
• “Will this be on the test?”
• “Why do we have to know X when my clinical preceptor tells me it’s not relevant to medical practice?”

So, there is a clash of cognitive style that, at some level, requires deeply curious individuals to present oversimplified material (and lots of it) to obviously intelligent people who are too busy to get deeply involved in the material. Frustration abounds, for different reasons, on both sides.

Our Unique Environment Facilitates Our Approach to Teaching

In contrast to the situation described above, our diverse team of authors is lucky because we have varied backgrounds and perspectives that allow us to understand both sides of the frustrations described above. We have backgrounds in basic science, clinical investigation, medicine, and integrative physiology. Additionally, the clinical investigators among us (all anesthesiologists) are willing to make definitive and concrete statements to students about the relevance of integrative physiology and research to
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medical practice. The fact that we are research collaborators also sends a powerful message to the medical students.

We are also lucky because our medical school is small and there is a “mandatory” research quarter during the third year at Mayo Medical School. Additionally, we have students rotating with us in the summer, there are the third-year rotations mentioned above, and our Clinical and Translational Science Activities (CTSA) Program works to recruit, encourage, and fund medical students to spend a year “on” in the laboratory (as opposed to a year off in the laboratory). This means that medical students are familiar with us, and the word on the street is that even when we do unconventional things and really push the students to think, there are methods to our madness. Finally, the institutional leadership at every level is populated with clinical investigators and PhD physiologists with strong translational interests.

“Gold Star Syndrome” Is Your Friend

As noted above, medical schools are populated with academic hurdlers. There is an intense focus on “The Right Answer” and a seemingly endless pursuit for gold stars (that for some seems to have started in preschool) on every test or assignment. As frustrating as this can be to the teacher, it is also a way of life that can be modulated and exploited in the name of education. How is this done? Once the context is shifted to questions, then competing to generate questions or find integrative answers seems to flow from the gold star syndrome. In this setting, we find students to be quite driven and motivated to seek information, ask questions, and discuss the answers. By making our 20-question activity a peer learning format, the gold star syndrome is actually reinforced.

Shifting the Focus to Questions Rather Than Answers

The first requirement is to get out of the information smoothie game and change the paradigm. This means the teacher has to avoid the temptation of simply generating a polished lecture with a clear set of factual information. The second step is to shift the focus from answers to questions, thereby giving responsibility for gathering information and learning to the student. In this context, we generated a series of 20 questions on respiratory and exercise physiology for medical students to think, there are methods to our madness. Finally, the institutional leadership at every level is populated with clinical investigators and PhD physiologists with strong translational interests.

**Why Are Questions More Important?**

It has been estimated that at least 50% of the material taught in medical school is “wrong” in some way, but by presenting information as gospel, this limits the adoption of new ideas. The senior author of the group can clearly remember when β-blockers were considered taboo for patients with heart failure and now they are standard therapy. Similar stories can be told about the management of mechanical ventilation and the use of exercise and physical activity versus bedrest in the treatment of heart disease.

Therefore, the last couple of questions in our 20-question series also represent an effort to send a warning about too much focus and unfiltered reductionism.

- **Question 18** (Fig. 1) considers a substance made by red blood cells, 2,3-diphosphoglycerate (2,3-DPG), which controls the release of oxygen from hemoglobin. Normally, elevated 2,3-DPG causes an increase in the amount of oxygen released from hemoglobin when the red blood cell enters the tissue (i.e., 2,3-DPG causes a rightward shift in the oxygen-hemoglobin dissociation curve). This is, in fact, a primary defense against low oxygen or anemia. This is a standard story of how 2,3-DPG functions at a biochemical level; however, when humans travel to high altitude, the oxygen-hemoglobin curve is shifted to the left. Why does that happen? The 2,3-DPG story at a molecular level versus what actually happens to the oxygen-hemoglobin dissociation curve on a cold high mountain when pH is elevated is presented to students in an effort to encourage a bit of nonlinear and integrative thinking. In addition, this question can be used to point out the value and limitations of both basic and integrative physiology since the basic science provides pieces of the puzzle and the integrative studies allow us to evaluate how the systems work together.

- **Question 20** (Fig. 1) about the bird lung is used to remind medical students about the role comparative physiology has in solving clinical problems. Tissue hypoxia is a common final pathway for many clinical syndromes in humans and is

Questions

#1 What is the Fick equation?
#4 Can Avogadro explain why each gm of Hgb can bind ~1.35 mls of O2?
#17 Is the main cause of increased lactic acid production during exercise hypoxia in the exercising muscles?
#18 2-3DPG causes a right shift in the O2-HGB dissociation curve. Why then is the curve shifted to the left at extreme altitude?
#19 You are 70% saturated while mountain climbing in the Himalayas. Why are you becoming apneic at night?
#20 What feature of the Avian Lung permits birds to fly over Mt. Everest?

Fig. 1. Six of the twenty questions we ask medical students to consider before a discussion/lecture on issues related to oxygen transport, respiratory physiology, and exercise. Hgb, hemoglobin; 2,3-DPG, 2,3-diphosphoglycerate.
also a unique physiological challenge encountered by high altitude-dwelling natives and adventure travelers that can lead to dire consequences; in contrast, many other species, such as bar-headed geese and bats, are remarkably tolerant to hypoxia and altitude (6). Could mechanistic knowledge of how this hypoxic tolerance is achieved lead to novel drugs or other therapies? The avian hypoxia tolerance discussion is useful for many reasons: 1) it brings to light the clinical relevance of integrative and comparative physiology; 2) there are studies on most organ systems of hypoxia-tolerant animals, so this discussion can span several organ systems for teaching or can serve as a stand-alone integrative physiology discussion; and 3) when appropriate, original research articles can be woven into class reading and discussion to promote physiological research and its relevance to clinical studies.

The Internet Is Your Friend

Another advantage of using the question-driven approach is that it turns the internet and other forms of electronic media into your friend. Depending on the age of the teacher, a detailed understanding of how young people use the electronic environment to gain information is more or less clear. Figure 2 is a slide taken from a drug company talk available on the internet that presents a “Readers Digest” version of the kidney and blood pressure control. It can be used to reinforce simple thinking or to ask what is wrong with this schematic. Certainly, unfiltered use of the electronic environment can contribute to the information smoothie problem, but by carefully framing the questions, the educator encourages the learners to take a more targeted and integrated approach to finding the information and putting it in some sort of intellectual context. Again, this approach encourages learners to take charge of their own education and discourages rote performances on both sides of the lectern.

Who Needs a Dog Laboratory When You Have the Students Themselves?

Teaching laboratories have essentially disappeared from the medical school curriculum. While we find this disturbing, there is little we can do about it. Additionally, the videos and simulations that are available seem to us to be inadequate. However, we have used our experiences as human integrative physiologists and clinical anesthesiologists to develop laboratory-based demonstrations for medical students to participate in.

These demonstrations occur in the Clinical Research Unit (formerly GCRC) of our CTSA. They include graded exercise testing with gas exchange measurements, CO₂ rebreathing, measurement of cerebrovascular responses using transcranial Doppler, and demonstrations of the hemodynamic responses to acute physiological challenges. These acute challenges include physical stress (isometric handgrip), mental stress (mental arithmetic or Stroop color-word conflict test), and the cold pressor test performed in conjunction with a number of noninvasive monitors for cardiovascular and respiratory parameters (3, 4, 7, 10, 12, 14). Figure 3 shows an example of the heart rate and blood pressure response to a mental stress test. Mental stress is an easy way to demonstrate a robust increase in blood pressure and can also be used to discuss the physiological relevance of stress on health, the role of the sympathetic nervous system in blood pressure control, and interindividual differences in stress responses. This is a fast and noninvasive protocol that is well suited for demonstration and discussion.

These integrated laboratories, which reinforce points made via our 20-question lectures, are highly popular with the students, lead to numerous inquiries about third-year research rotations, and score well in terms of student evaluations. The obvious caveats are that this work is facilitated by the presence of physiology core facilities in our Clinical Research Unit, requires several independent clinical investigator and PhD physiology research laboratory teams up for teaching, and is dependent on the persistence of the large cadre of investigators who use integrative physiology approaches at our institution. We should also add that we have offered to expand our role in laboratory teaching of human integrative physiology and could envision a number of other demonstrations using simple maneuvers like tilt-table testing, dehydration and/or volume loading, and other techniques.

Give Students Freeways and Let Them Make the Off Ramps

As noted above via the example of β-blockers and heart failure, at least 50% of what students learn today will be seen as outmoded or “wrong” in the coming years. If this material is presented “too well” or overemphatically as “right,” it makes it even harder to “fix” things later. Therefore, it seems reasonable to advocate that the key principles and main regulatory influences be outlined as intellectual “freeways,” with the discussion questions serving to let students build their own mental on and off ramps.

Figure 4 shows what has been affectionately termed the “Gore diagram” by students at the University of Arizona. It is a qualitative effort of Prof. Robert Gore (winner of the 2005 American Physiological Society’s Arthur Guyton Educator of the Year Award) to integrate how local, renal, and autonomic mechanisms influence blood pressure regulation in humans (6). Importantly, in addition to providing useful key principles and
pathways in blood pressure control, the discussion questions that might flow from this include outlining how commonly used antihypertensive medications influence various elements of the diagram and what compensatory mechanisms might occur in response to various drug therapies. Are the redundant regulatory pathways the reason why so many patients fail monotherapy for hypertension, and why there is so much “resistant” hypertension that is nonresponsive to conventional therapy? Blood pressure is clearly important in anesthesiology and critical care, and hypertension is one of three or four conditions that dominate the office practice of internal medicine and family practice. Therefore, a discussion of the system as a whole along with thought-provoking questions about system responses to perturbations will reinforce the key pathways, feedback loops, and redundant mechanisms by way of “thinking” about rather than “listening” to a lecture. This type of active thinking and learning is an important exercise to generate the conceptual freeway that allows students to develop questions rather than memorize facts.

The Gore diagram (Fig. 4), in conjunction with the examples shown in Fig. 3 and the observation that many patients fail monotherapy for hypertension, is also interesting in the context of emerging new device therapies for “resistant” hypertension. These include renal denervation as well as electrical stimulation of the carotid baroreflexes (9, 13). Figures 5 and 6 show data from clinical trials using these physiologically based approaches as a therapy for hypertension (9, 13). The Gore diagram and these observations provide a clear way to question about these therapies and also about the clinical relevance of physiology as a whole. The value of using current research in teaching is that students can keep up with the constantly evolving knowledge and therapies in a particular area and see the immediate clinical relevance of research.

The Retrospectoscope Should Be Required Reading

In the opening parts of this article, we highlighted the role of questions, incomplete information presented as facts, and the need to provide the students with intellectual highways versus fixed ideas. Many of these ideas flow from the work of Prof. Marlys Witte (also from the University of Arizona) on “medical ignorance” (15, 16). They also highlight the nonlinear nature of medical progress and “cures” or novel therapeutic approaches. In this context, in the 1970s, Comroe and Dripps (2) published an intellectual autopsy of the discoveries needed to make open heart surgery at first possible and then routine. They concluded that much, or even most, of the key information was generated by people working or thinking about very different things. Comroe called such exercises looking through a “retrospectoscope.”

The Comroe and Dripps (2) article should be required reading for medical students in an effort to combat fixed thinking and a focus on the right answer. One only has to remember that Viagr and VEGF inhibitors are effective against the “wrong” diseases: originally developed for the treatment of angina, phosphodiesterase type 5 (PDE5) inhibi-

Fig. 3. Individual record of a heart rate response [in beats/min (bpm), ECG; top] and blood pressure response [obtained from an arterial line (Art. Line), bottom] to mental stress. This is an example of a simple record that can be obtained in a medical school demonstration laboratory. For demonstration purposes, a noninvasive blood pressure recording can be used. Values for heart rate and blood pressure are shown as insets. The instructions for the mental stress protocol (Instr.) are given, followed by the stressor, a blood draw, and a recovery period. The test lasts ∼5 min.
tors (i.e., Viagra) work as vasodilators and were first used in an effort to improve symptoms of angina by manipulating nitric oxide-related pathways; however, PDE5 inhibitors are, in fact, now used successfully for the treatment of erectile dysfunction and pulmonary hypertension but not angina. Similarly, VEGF inhibitors are now used successfully for the treatment of macular degeneration versus the originally proposed use of anticancer agents. The other benefit of mandating the retrospectoscope article (2) is that if medical students read it, by diffusion, the ideas in it might infiltrate the clinical faculty and, ultimately, make it to the central administration and (if we are lucky) raise questions about the rush to apply linear “management principles” to activities, including medical education, that work best when they are nonlinear.

**Physiology (and Learning) Is a Process and Not an Event**

There is a narrative quality to medical progress based on physiology. The dramatic decrease in deaths from heart disease is multifactorial but, in large part, reflects very basic ideas about the relationship between oxygen supply and demand in the heart, and almost every successful treatment for heart disease does something in the short or long term to alter this balance in a favorable way. In contrast, one could also argue that progress against cancer has been slowed by a lack of an integrated understanding of what goes wrong and how redundant regulatory systems either reinforce the problem or can be modulated to correct it. The value of research and teaching of integrative physiology is that we are able to focus on the big picture, and this provides a valuable thought tool for students to consider systems. In contrast, the fact-driven lecture is passive to students, and this format tends to treat physiology as an “event” or set of facts, not a “process.” The question-based approach to learning and emphasizing that we need to engage in constant learning as new information becomes available is a valuable tool. By presenting a list of facts in a well-polished lecture, we do a disservice to ourselves and the students by eliminating the active component of the learning process in the “event” of the lecture.

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**Fig. 4.** A “Gore” diagram. This diagram demonstrates the vast majority of the key local, organ, and systemic interactions that regulate blood pressure. In addition to providing useful key principles and pathways in blood pressure control, the discussion questions that might flow from this include outlining how commonly used antihypertensive medications influence various elements of the diagram and what compensatory mechanisms might occur in response to various drug therapies. Educators can use this diagram not only as a factual diagram but, more importantly, as a question generator and discussion builder in conjunction with Figs. 5 and 6. EDV, end-diastolic volume; ESV, end-systolic volume; TPR, total peripheral resistance; CO, cardiac output.

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**Fig. 5.** Effects of renal denervation on systolic and diastolic blood pressure in patients with resistant hypertension. Renal denervation reduces both systolic and diastolic pressure in patients with resistant hypertension. Data such as this, in combination with the Gore diagram (Fig. 4), help students think about therapy for hypertension and why it fails so often. [From Ref. 13.]

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**Fig. 6.** Effects of carotid sinus nerve stimulation on a patient with resistant hypertension. Bilateral carotid sinus stimulation can be used to reduce blood pressure in patients. As is the case with Fig. 5, this graph, in conjunction with the Gore diagram (Fig. 4), can help students think about the pathophysiology of hypertension and why therapy fails so often. [From Ref. 9.]
Summary: This Lecture Has Been Different

We avoided the temptation in this article and also the lecture associated with it to give a detailed and scripted example of a polished “factual” lecture on a topic like blood pressure regulation. From an intellectual perspective, we have strongly challenged the renal-centric view of blood pressure regulation and argued that the role of the sympathetic nervous system has been underappreciated (8). From a philosophical perspective, we believe questions and not answers are where the action is for both research and education.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

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