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REFRESHER COURSE FOR TEACHING CARDIOVASCULAR PHYSIOLOGY

This report presents highlights of a refresher course presented at Experimental Biology '99 on Saturday, April 17, 1999, in Washington, District of Columbia.

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The American Physiological Society (APS) has recently reinstated the presentation of refresher courses on teaching specific topics in physiology. This year's course was organized by the APS Education Committee, which has taken the lead in revitalizing this series of workshops, and was cosponsored by the Teaching and Cardiovascular sections. The first part of the refresher course consisted of a half-day workshop at the Experimental Biology (EB) '99 meeting in April and included talks by Drs. R. J. Solaro, H. V. Sparks, and J. E. Hall and a series of poster presentations. The second part is this special section of *Advances in Physiology Education*. The workshop's poster abstracts and the three talks by the distinguished panel of speakers are included herein. In addition, I have invited several other experienced physiology teachers to write articles on teaching specific topics within the broad field of cardiovascular physiology.

The overall goal of the cardiovascular refresher course comprised two major objectives. First, it was intended to provide critical content updates for those faculty who are responsible for teaching cardiovascular physiology, regardless of whether their own scientific research expertise is in this area. Second, although the objective was not to provide pedagogical theory, it was hoped that the speakers, poster presenters, and chapter authors would model good pedagogy. This would include well-organized and focused presentations, identification of common roadblocks that students encounter on their road to understanding this material, and suggestion of useful tips and strategies for helping students learn these topics.

This refresher course was intended for teachers of introductory human and mammalian physiology courses. Most contributors to the refresher course geared their presenta-

tions toward medical physiology courses. The physiological concepts and pedagogical strategies outlined herein, however, are certainly equally appropriate for students in programs in nursing, allied health sciences, or the biomedical sciences. If a physician needs to have a basic understanding of arterial blood pressure and how it is controlled, for example, does a nurse, pharmacist, physical therapist, sports trainer, or biomedical researcher have any less need for the same level of understanding? Is there an intrinsic difference in the way these different students might best learn this material? In my opinion, no.

Individual authors in this series of articles express their opinions about what material is essential for new students to know and what is best reserved for advanced or specialized courses. These opinions should be helpful to instructors trying to decide what to include in and what to exclude from their own specific lectures. Such instructors, however, should also consult more comprehensive recommendations about curricular content. For example, there is the Medical Physiology Core Curriculum Objectives Project, which is cosponsored by APS and the Association of Chairs of Departments of Physiology (see abstract by R. G. Carroll elsewhere in this report). For undergraduate physiology courses, the Human Anatomy and Physiology Society (HAPS) has promulgated a model curriculum, which has also been endorsed by APS.

In addition to lots of factual and conceptual information, the individual articles in this report contain a wide variety of teaching tips and advice related to each author's topic. I would like to add a few general comments on teaching physiology, based on observations that my colleagues and I have made and discussed over the years. Many of these points echo what you will read in the accompanying articles.

Physiology has always been an integrative science, and modern cardiovascular physiology is no less so. An introductory course will present individual cellular and subcellular mechanisms, using them to explain systemic behavior. It is essential, however, that the student leaves the course with an understanding of that systemic behavior. I have seen students wrestle with the plethora of mechanisms that instructors tend to offer them and which may, on their face, have contradictory effects. As the students attempt to predict the system's behavior from the properties of its various parts, they argue themselves into blind alleys or erroneous conclusions. One of the very great advantages that we instructors have is experience, which has taught us the hierarchical roles of the various constituent mechanisms. Helping the students develop a working mental model of the circulation involves helping them develop a similar "feel" for the relative importance of the different mechanisms that might be involved in a given physiological response. Being selective in what we expose the students to is, therefore, an important responsibility for the instructor. Sometimes, less (detailed information presented) is more (easily assimilated into a sound conceptual framework).

In the context of helping students develop an understanding of the systemic behavior of the cardiovascular system (or any other physiological system for that matter), we often ask them to explain why something happens. Why does arterial pressure rise a little during dynamic exercise? Why is blood viscosity effectively less in the microcirculation than in large vessels? Students usually will give a teleological answer, rather than a mechanistic one. Given that we are trying to get the students to construct a mental model of the circulation, this is not a bad sign. Students should be trying to make sense of it all. However, teleology cannot be the only approach to integration. Therefore, whenever I ask a "why" question, I explicitly separate it into two questions—what is the mechanism responsible for this phenomenon, and what is the physiological consequence of its occurrence? Getting our students to think mechanistically as well as teleologically would be a significant achievement on both our part and theirs.

To analyze the cardiovascular system, students must be able to use and manipulate a number of algebraic

equations; e.g., Poiseuille's equation, the Law of LaPlace, the Fick equation, etc. There are some students who will be resistant to any form of mathematics, but we must help them overcome this. One day, a year after my very first medical school lectures, I asked the first 10 second-year students I encountered in the cafeteria to describe for me the relationship among cardiac output, mean arterial pressure, and total peripheral resistance that they had been taught the previous year. (For those of you who must peek ahead, the answer is found in *Eq. 3* of the article on hemodynamics in this refresher course report.) Eight students could not answer the question. One student could not articulate the equation per se but could recite several accurate relational pairs; e.g., if resistance goes up, pressure goes up; if pressure goes up, cardiac output goes up, etc. The tenth student averred, rather forcefully as I recall, that she was going into psychiatry and had no need to know or remember this relationship. Needless to say, I was appalled and have reported these survey results to every subsequent class I have taught. Students should be able to perform simple calculations with these basic equations and should be given ample opportunity to practice. These basic equations should become part of the student's permanent memory.

Algebraic equations do not, however, indicate which are the independent and which are the dependent variables in a physiological sense. They tell us the mathematical relationships among the variables, but they do not tell us the entire physiological story. Students need the equations, but they cannot rely on them exclusively. You can see students making this error, for example, by asking them to identify the determinants of arterial pulse pressure. Almost invariably, the student will offer systolic pressure and diastolic pressure as the answer. Such a student has not yet constructed a mental model of the circulation but is still at the level of working on his test-taking strategies.

Concrete examples of theoretical concepts are always important. This is true at all levels of education but, I think, especially so in professional and graduate education. At this stage, students have identified a career goal for themselves and are anxious to get there. They are trying to build a framework for their profession. If a particular concept is not relevant in that context,

why should they waste any time on it? On the other hand, if you can show them the context and relevance, now the concept is valuable to them and they will try to remember it and use it. Whether you are committed to problem-based learning or prefer more traditional educational formats, this principle remains true and important. The articles in the section contain numerous examples of how the particular topic being discussed applies to human physiology and medicine. As noted above, this is the most relevant context for courses in the health professions, but human examples are good ones in general because all (certainly most) of our students are themselves human. Examples from comparative physiology can also be very powerful, however. Consider the cardiovascular challenges faced by the giraffe, for example. Why could this creature not survive with an aortic pressure similar to ours and, indeed, to that of most mammals? Whatever the nature of the examples chosen, the important point is to use them to illustrate the meaning and physiological importance of the concept being learned.

Even more valuable than providing the integrative explanation, however, is to pose the example as a puzzle to the students, asking them to explain it. This can be accomplished in any number of formats, such as case presentations, lab exercises, cooperative-learning homework assignments, etc. It is in these tasks that the students get a chance to apply their newly learned vocabulary and mechanistic principles and forces them to put the various factors together. Insist that the students use the proper vocabulary and the proper scientific syntax, and they will better master the basic concepts. Let the students do the integration, and they will begin to appreciate the big picture.

As physiologists, we are comfortable with graphical presentation of data. Transforming horizontal distance on a strip chart into time is second nature to us. Think for a moment about one or two landmark or seminal papers in your own field. What we first call to mind is most often the key figure(s) in such a paper. Yet, not all students bring such eye-to-mind coordination into the classroom. To such students, an aortic pressure trace, for example, loses all its detail and becomes a simple up-and-down arc. They do not see how the dichrotic notch marks the transition from systole to

diastole. They do not see that aortic pressure rises sharply as systole begins, then falls more slowly as diastole progresses. They do not see that the diastolic period is twice as long as the systolic period. When these students are asked to explain why an increased heart rate has a greater impact on diastolic filling time than on systolic ejection time, they just draw more copies of the same simple up-and-down arc they drew initially and do not see the connection. It is important, then, to draw graphs carefully, label the axes, and describe the important details of the curves and traces in quite explicit detail. It might be overkill for some students, but many others will benefit.

I gratefully acknowledge the help of the many people who contributed to this Refresher Course, including the authors of the superb articles in this compendium. I particularly thank the very professional staff of the American Physiological Society, who did so much with regard to the organization and logistics of the EB workshop and with regard to the present publication. Penny Hansen, the editor of *Advances in Physiology Education*, is owed special gratitude for offering us the opportunity to expand and disseminate the refresher courses in this journal. Finally, I thank my colleagues at New York Medical College, specifically Stanley Passo, Carl Thompson, and Edward Messina, who helped review all these manuscripts and who have always been excellent role models for me as teachers of physiology.

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ABSTRACTS OF POSTERS AND DEMONSTRATIONS

Cardiovascular physiology learning objectives: the medical physiology core curriculum objectives project

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An appropriate understanding of physiology is essential to the intelligent practice of medicine. Consequently, physiology instructors, course directors, cur-

riculum committees, and licensing boards each evaluate a medical student's understanding of physiology. Currently, this evaluation suffers from the lack of a national consensus on exactly what constitutes an appropriate breadth and depth of physiological knowledge for medical students. This issue is particularly pressing in light of the diverse, and continually evolving, teaching approaches used in the preclinical years. The Medical Physiology Core Curriculum Objectives Project hopes to achieve a national consensus on this topic. Input is being solicited from the APS sections, the Association of Chairs of Departments of Physiology, physiology course directors, and individual physiologists to help determine the appropriate breadth and depth of physiology understanding for medical students. A working draft of the project can be viewed at <http://www1.ecu.edu/mscarrol/objectives.htm>. The role of faculty is to guide and assess student learning. The Medical Physiology Core Curriculum Objectives Project will provide a national standard against which a student's progress can be assessed.

A physical model of hemodynamic principles

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We use a physical model consisting of readily obtainable materials to demonstrate basic hemodynamic principles in introductory courses on mammalian cardiovascular physiology. The model consists of a squeeze bulb with one-way inlet and outlet valves to represent the heart, Tygon tubing to represent the vasculature, and water to represent the blood. Narrow tubing (plastic pipette tip or Pasteur pipette) is used to simulate resistance vessels. Segments of compliant tubing (e.g., fingers from latex gloves) are used to simulate elastic arteries. A Y connector is used to represent parallel circulatory beds. The model can be used to demonstrate the unidirectional flow of blood, how cardiac output can be raised by increasing either heart rate or stroke volume, the effect of reducing venous return on cardiac output, the effect of resistance on arterial pressure, the ability to increase flow to specific organs by regional vasodilatation, how a pulsatile cardiac output is transformed to a relatively steady microcirculatory flow, and how blood velocity is determined by vessel diameter. The model can be

used as a demonstration or as a hands-on activity. It can be used at any educational level, from elementary school up through medical and graduate school courses. It provides students with a visual and physical appreciation of hemodynamic principles, which effectively complements the mathematical and graphical presentations commonly found in textbooks.

An artificial ventricle for quantitative, hands-on learning of cardiac mechanics

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Concrete experiences are important for many students as they develop an understanding of organ function. Even students who appear to readily assimilate the fundamentals of cardiac mechanics from reading, lectures, and computer-aided learning often have undiscovered gaps in their understanding. The study of cardiac mechanics lends itself to experiential learning with physical models, and such an approach can challenge students to recognize what they do not know and then develop a higher level of understanding. With the single-chambered artificial ventricle presented, students can quantitatively investigate a number of key aspects of cardiac function including 1) the roles of end-diastolic volume, contractility, and heart rate in determining cardiac output, 2) preload and afterload, 3) the compensatory mechanisms that maintain and/or increase stroke volume as rate increases, 4) pressure-flow relationships, 5) atrioventricular and semilunar valve function, and 6) the results of valve failure. Pressure and flow transducers can be attached to the model, so dynamic computer-based measurements and quantitative analyses can be done. The development and application of formal descriptions of cardiac mechanics follow naturally from investigations with this physical heart model. In our experience the artificial ventricle adds an important dynamic dimension to the educational experience. It encourages a type of open-ended exploration and learning that is not possible with either animal experiments or computer-based simulations. (Supported in part by National Science Foundation Grants DUE-9354477 and DUE-9451852 and the City College Division of Science.)

Teaching human cardiovascular and respiratory physiology with the station method

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The station method for student laboratories is ideal for teaching large groups of students when a limited amount of equipment is available for the laboratory exercises. With this approach, a variety of stations are set up for the students, who work in pairs and rotate from station to station. The flow of traffic from station to station is unrestricted, and students may move to any station when it is not occupied by other students. For laboratory exercises that require the greatest amount of time, several stations may be needed for a single exercise to prevent a "bottleneck" with students lined up at a single station. Combining the human laboratories for cardiovascular and respiratory physiology serves several purposes. More equipment and stations may be available, and responses of these systems are frequently related. For stations 1–3, blood pressure, heart rate, and respiratory tidal volume and frequency are measured: 1) postural influences and respiratory modulation (Valsalva maneuver) of cardiovascular and respiratory functions, 2) effects of isotonic and isometric exercise, and 3) cold pressor test (includes measurements of skin blood flow). At other stations, respiratory functions are evaluated with spirometry (FVC, FEV1.0, FEV1.0/FVC, FEF 25–75%, respiratory muscle strength). A station is also available for computer analysis.

Several goals are met during this three-hour student laboratory experience. Students see the variability in human measurements, appreciate the need for control measurements, and are briefly exposed to the scientific method because they must predict an outcome, analyze their data, and interpret the findings of each laboratory exercise.

A "virtual" hemodynamic experiment for understanding arterial blood pressure regulation

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Educators are placing a greater emphasis on the development of laboratory experiences that supplement the traditional lecture format. The new laboratory materials should encourage active learning, problem solving, and inquiry-based approaches. To address these goals, we developed a laboratory experiment designed to introduce students to the hemodynamic variables (heart rate, stroke volume, total peripheral resistance, and compliance) that regulate arterial blood pressure. By collecting, reducing, and interpreting data from chart recordings, students are able to plot results, perform calculations, and answer questions related to cardiovascular regulation. These active learning procedures help students understand and apply basic science concepts in a challenging and interactive format. Furthermore, laboratory experimentation may enhance the student's level of understanding and ability to synthesize and apply information. In conducting this virtual experiment, students are introduced to the joys and excitement of inquiry-based learning through experimentation.

Practical issues for using computer animations in cardiovascular teaching

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Computer-based instruction has become an integral part of physiological education, providing both novel educational tools (e.g., interactive simulations) and allowing improved implementation of traditional methods (e.g., overlays and builds). Animations are especially valuable for teaching cardiovascular physiology because most concepts (e.g., cardiac cycle, vasoconstriction) correspond to dynamic, readily animated processes. Although animations provide new opportunities for improving teaching, they also provide new opportunities for degrading teaching. Thus the goal of this presentation is to provide practical advice on the design, creation, and delivery of computer animation in cardiovascular teaching. The design of animations must take into account the fact that animations unfold continuously, yet learning occurs in "chunks." Thus animations should contain "educational key frames" corresponding to specific chunks of information. Animations can be created with a variety of software: drawing (CorelDraw), two-dimensional animation

(Flash, Director, After Effects), three-dimensional (3D Studio, Truespace), and authoring (Authorware, Asound) programs. Although each has their own advantages and disadvantages, the author currently favors Macromedia Flash for ease of creation and modification and for rapid delivery over the Worldwide Web (WWW). Animations can be delivered to students in lecture (PowerPoint, Authorware), in-class interactive sessions (Toolbook, Visual Basic), and over the WWW (FrontPage). Each approach places limitations on the design and creation of animations.

CIRCSIM-TUTOR: A “smart” tutor about blood pressure regulation

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CIRCSIM-TUTOR is a teaching program about the baroreceptor reflex. Unlike its predecessor (CIRCSIM), it internally generates most of the text needed to carry on a tutorial dialog and it understands answers typed by the student. It also has a complex set of tutoring rules derived from studies of more than 100 transcripts of actual tutoring sessions conducted by two of the authors. CIRCSIM-TUTOR requires the user to predict the qualitative changes that will occur to seven cardiovascular parameters as the result of one of the described disturbances to the system. After the student has made predictions about one of the three phases of the response, the tutor conducts a dialog with the student to correct any errors that were present. CIRCSIM-TUTOR can thus deliver context-specific help that addresses the difficulties encountered by each individual student. CIRCSIM-TUTOR has been used by two groups of first-year medical students. Each student took a pretest and a posttest and completed a survey. Comparison of the pre- and posttest responses suggests that CIRCSIM-TUTOR is effective in correcting student misunderstandings of the events involved in the baroreceptor reflex. Survey results reveal that students find CIRCSIM-TUTOR easy to use and effective as a learning resource, despite its unsophisticated language generation. (This work was supported by the Cognitive Science Program, Office of Naval Research, under Grant N00014-94-1-0338 to the Illinois Institute of Technology. This document does

not reflect the position or policy of the government and no official endorsement should be inferred.)

Teaching integrative cardiovascular physiology: a problem-based learning approach using computer simulations

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In classroom lectures it is often difficult to convey the complexity of the interaction between the various systems of the body involved in cardiovascular control. Problem-based learning (PBL) using preset clinical cases on paper does not overcome this difficulty because it offers a limited number of selected parameters in a rather static environment. We have modified the standard PBL format by using computer simulations. Once familiar with two comprehensive models of the human body (Guyton's model, Quantitative Circulatory Physiology), the students, left on their own in our computer lab, are assigned to run specific simulations of known clinical problems: arteriovenous fistula, renal artery stenosis with or without converting enzyme blockade, right and left heart failure, and mineralocorticoid-induced hypertension. In each case, the student observes the selected disturbance on a “real-time” basis and must decide which variables should be followed, as if it were a private patient. By observing the sequential development of abnormalities and consulting many variables of interest, the student tries to elucidate the mechanisms of disease and understand the complex interaction between the various systems. The results are discussed on a separate day in a small group setting. Such an approach directs the student toward further reading and promotes an integrative understanding of the human body.

An integrated sequence of computer-simulated exercises to teach the concepts of vascular load and heart-vascular interaction

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Preload and afterload, along with ventricular contractility and heart rate, are the basic determinants of cardiac output. Although "load" is the tension borne by the myocardium, cardiac load will depend on vascular properties that determine venous return, central venous pressure, and mean arterial pressure. Learning to understand how changes in vascular properties will lead to changes in cardiac load is facilitated by first learning the core concepts of vascular compliance and resistance. Compliance can be learned using a computer-simulated capacitive chamber to study the association between volume and pressure. Resistance can be learned using a simulation that connects two capacitive chambers through a resistive pathway, to study the association between the rate of flow and the pressure difference between

the two chambers. Students have control over the compliance and resistance so that they can experimentally determine how these properties will alter the associations between volume, pressure, and flow. A third simulation based on a time-varying elastance model of the ventricle allows independent control of ventricular filling and output pressures, enabling students to construct the characteristic associations between these loading pressures and stroke volume. Control over ventricular contractility allows further exploration of how this property interacts with these characteristic associations. A final integrated simulation connects the ventricle with both venous and arterial models to study how distinct vascular properties will collectively determine cardiac output, relative to the prevailing level of ventricular contractility.