 SMALL GROUP TEACHING:  
CLINICAL CORRELATION WITH A  
HUMAN PATIENT SIMULATOR

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The popularity of the problem-based learning paradigm has stimulated new interest in small group, interactive teaching techniques. Medical educators of physiology have long recognized the value of such methods, using animal-based laboratories to demonstrate difficult physiological principles. Due to ethical and other concerns, a replacement of this teaching tool has been sought. Here, the author describes the use of a full-scale human patient simulator for such a workshop. The simulator is a life-size mannequin with physical findings (palpable pulses, breath/heart sounds, blinking eyes, etc.) and sophisticated mechanical and software models of the cardiovascular and pulmonary systems. It can be connected to standard physiological monitors to reproduce a realistic clinical environment. In groups of 10, first-year medical students explore Starling’s law of the heart, the physiology of the Valsalva maneuver, and the function of the baroreceptor in a clinically realistic context using the simulator. With the use of a novel pre-/postworkshop assessment instrument that included student confidence in their answers, student confidence improved for all questions and survey items following the simulator session (P < 0.0001). The students give these laboratory exercises uniformly superior evaluations with >85% of the students rating the workshop “very good” or “excellent.”

Key words: cardiovascular physiology

Small-group teaching and problem-based learning have been the highlights of a revolution in medical education over the last 40 years. Reported advantages include increased retention of knowledge, enhanced transfer of concepts to new problems, increased student interest, and improved self-directed learning skills (6). Increased student-faculty and peer-peer interaction improves communication skills and provides the opportunity to clarify points of confusion before they become the basis for erroneous mental models. Furthermore, small group size offers opportunities for interactive demonstrations and student participation that is impractical in formal lectures.

The teaching of dynamic sciences such as physiology is greatly enhanced with such demonstrations.

Historically, animal-based laboratory exercises were used to supplement and reinforce material from physiology lectures. Over the last several decades, however, laboratory time has been drastically reduced (3, 4) and the use of live animals for these exercises is rapidly declining (1). Several reasons were cited in a 1994 Association of American Medical Colleges survey including expense, curricular changes, compression of course time, students’ concern over the use of animals, lack of faculty and technicians with the required skills, lack of
laboratory space due to its conversion for research purposes, and availability of alternative computer-based teaching packages and videos (1). These alternatives, however, cannot replicate the real-time excitement and realistic interaction in an actual lab.

Several medical educators at the author’s institution believed the elimination of animal laboratories in the mid-1980s hindered comprehension of some key physiological concepts. No prospective statistical data were collected to confirm this impression, however. In the early 1990s, a prototype of the Human Patient Simulator (HPS; Medical Education Technologies, Sarasota, FL) was under development at the University of Florida Department of Anesthesiology. The faculty offered to conduct a simulator-based clinical correlation laboratory for the physiology department. A simulator workshop was added to the respiratory physiology section and was well received by the students. The following year the director of the cardiovascular physiology section asked for a similar workshop, which has received exceptional student evaluations each of the 3 yr since its inception.

**Simulator**

The HPS consists of a patient mannequin, a mechanical lung, and a computer interface. The mannequin has many physical features including a realistic airway that may be instrumented, chest excursion with ventilation (either spontaneous or mechanical), palpable radial and carotid pulses, breath and heart sounds that may be auscultated with a standard stethoscope, eyes that blink and respond to light, external genitalia that may be catheterized with realistic urine production, and others. Intravenous access is present with fluids attached through standard tubing to the mannequin. Fluid boluses are simulated through swiping a 250-ml bag of intravenous fluid across a bar code reader next to the intravenous stopcock. More than 50 medications may be administered through the stopcock. The drug’s identity, concentration, and dose administered are automatically detected by the system with accurate pharmacokinetic and pharmacodynamic effects.

The mechanical lungs are housed inconspicuously external to the mannequin. In addition to having realistically alterable resistance and compliance for each lung, they consume oxygen and produce carbon dioxide at physiological rates. Sophisticated computer models represent the cardiovascular system, uptake and distribution of respiratory gases, pharmacokinetics and pharmacodynamics of inhaled and intravenous drugs, and physiological control mechanisms (e.g., baroreceptor reflex, hypercarbic/hypoxic drive). These models transmit data to the patient mannequin and to electronic physiological monitoring instruments.

Scenarios can be developed to replicate animal-based laboratories and/or actual clinical scenarios. These are usually preprogrammed by the instructor using >50 available physiological parameters and are designed to progress either automatically based on designated transitions (time, drug administration, etc.) or under instructor (or assistant) control. During the session, students can experiment with different therapies to see the response, then “reset” and try again. In addition, individual physiological variables can be altered through the computer interface at any time (e.g., contractility, systemic vascular resistance, or baroreceptor sensitivity) to investigate their impact on the system.

The simulator classroom at the investigator’s institution comfortably accommodates 20 students, but to maximize the opportunity for interaction, groups of 10 or less are preferred.

**METHODS**

The University of Florida retains a traditional medical school curriculum with a self-contained physiology course taught during the first (preclinical) year. The cardiovascular physiology section consists of 21 h of lecture, supplemented with 4 h of clinical correlation lectures, and two 1-h small-group (10 students) workshops: a heart-sounds simulator (Harvey) and the HPS. The workshops are interspersed during the 2-wk course, with students attending on a rotating schedule. Their purpose is to reemphasize the lecture material and provide clinical correlation.

**Teaching Topics**

The author met with the course director to identify topics that the students have consistently found difficult to understand in past years. The following areas were selected:
• concept of venous return and its effect on cardiac output

• physiology of the Valsalva maneuver

• function of the baroreceptor

• Starling curves and their derivation

Scenarios

Valsalva maneuver. An intubated and mechanically ventilated patient is invasively monitored with central venous pressure (CVP) and arterial pressure waveforms displayed on a standard Hewlett Packard component monitoring system monitor (Hewlett Packard, Andover, MA). After describing the monitors and ventilator, the instructor invites thoughts on the variability in the CVP trace (due to mechanical ventilation). Next, a student is asked to apply a Valsalva maneuver to the patient. This is achieved by applying constant pressure to the anesthesia machine’s reservoir bag, maintaining elevated airway and intrathoracic pressure. The chest is seen to expand while the CVP increases followed by a decrease in the arterial pressure and an increase in heart rate. Release of the bag allows resolution of the hemodynamic insult. The students are invited to explain the physiological effects in a stepwise fashion (Fig. 1). The presence of increased CVP with decreased venous return requires explanation.

Normal Starling curve. A 65-yr-old, 70-kg man is admitted to the intensive care unit (ICU) after undergoing a major abdominal operation. The patient’s medical history is significant for a myocardial infarction 10 years ago, but no problems since. He plays golf three times per week without chest pain. He quit smoking 15 years ago and reports no breathing problems. His history is otherwise unremarkable. He was not taking any medications before admission.

During the operation, the patient lost a lot of blood (~2 liter), which was replaced with 5 liters of crystalloid (balanced salt solutions) and 2 units of packed red blood cells. The anesthesiologist decided to leave the patient intubated until he could be further evaluated in the ICU.

The students are provided with a blank table similar to Table 1 (only the column headers are present) and asked to complete it at each step during the simulation. Additionally, the instructor has the same table on a large white board that is visible to all participants. Each column is explained, along with a description of the determination of cardiac output by thermodilution.

From the patient’s initial vital signs, the students readily recognize he is hypotensive and tachycardic (Table 1: Baseline). Potential etiologies are discussed, but usually someone quickly suggests hypovolemia and recommends administration of intravenous fluid (which they are invited to accomplish) resulting in

Physiology of the Valsalva maneuver

\[ \begin{align*}
\uparrow & \text{ Intrathoracic Pressure} \\
\downarrow & \text{ Venous Return} \\
\downarrow & \text{ Stroke Volume} \\
\downarrow & \text{ Cardiac Output} \\
\downarrow & \text{ Blood Pressure} \\
\downarrow & \text{ Baroreceptor Firing} \\
\downarrow & \text{ Inhibition of Vasconstrictor Center of Medulla} \\
& \text{ Excitation of Vagal Center} \\
\downarrow & \text{ Vagal Outflow} \\
\uparrow & \text{ Sympathetic Outflow} \\
\downarrow & \text{ Heart Rate} \\
\uparrow & \text{ Contractility} \\
\uparrow & \text{ Vasoconstriction}
\end{align*} \]
some improvement (Table 1: +1 liter). Again a stepwise analysis of the effect of the intervention is encouraged (Fig. 2). Usually, the students spontaneously recognize the need for additional volume with further improvement (Table 1: +2 liters). Students record the data and are instructed to plot a Starling curve with a discussion of the clinically relevant axes (length vs. force becomes right atrial pressure vs. cardiac output or CVP vs. stroke volume; Fig. 3). A typical question regards the selection of an end point to therapy, which encourages discussion of the interdependence of physiological parameters. Concepts of myocardial oxygen supply and demand are reviewed and help to explain that multiple parameters must be optimized in view of the entire clinical picture.

The students are congratulated on a job well done, then told they left for the weekend, and returned on Monday to find the patient still in the ICU. They again find him to be hypotensive and tachycardic (Table 2: Baseline), although some recognize the higher CVP. Again the students elect to administer fluids, but this time the patient becomes “worse” (Table 2: +1 liter). A diuretic is administered (with visible urine production in the Foley catheter) after discussing methods to remove fluids, and the patient returns to baseline. Because removal of fluid was therapeutic, the students are encouraged to remove additional fluid, but this results in worsening hemodynamics (Table 2: −1 liter).

Therefore, this patient will not improve by moving along his Starling curve (Fig. 4: −Inotrope). The students are asked what other interventions may be appropriate, and an inotrope-induced upward shift of the Starling curve is eventually considered. This intervention is therapeutic (Table 2: +Inotrope), and a second Starling curve is derived to demonstrate a new curve above the initial one (Fig. 4: +Inotrope). The scenario is explained as mobilization of third-space fluids resulting in congestive heart failure.

**Table 1**

<table>
<thead>
<tr>
<th>Intervention (vs. baseline)</th>
<th>BP, mmHg</th>
<th>HR, beats/min</th>
<th>CVP, mmHg</th>
<th>CO, l/min</th>
<th>SV, ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>80/50</td>
<td>97</td>
<td>0</td>
<td>4.0</td>
<td>41</td>
</tr>
<tr>
<td>+1 liter</td>
<td>97/54</td>
<td>80</td>
<td>4</td>
<td>5.4</td>
<td>67</td>
</tr>
<tr>
<td>+2 liter</td>
<td>106/56</td>
<td>74</td>
<td>10</td>
<td>6.1</td>
<td>82</td>
</tr>
</tbody>
</table>

BP, blood pressure; HR, heart rate; CVP, central venous pressure; CO, cardiac output; SV, stroke volume.

**Baroreflex**. Although discussed with each of the above scenarios, the function of the baroreceptor is reemphasized by administering phenylephrine. After the medication was introduced and its alpha-I agonist and peripheral vasoconstrictive effect were explained, the students are asked what response they would anticipate in a new, healthy patient. A volunteer administers the drug to the simulated patient. Blood pressure predictably rises with a decline in heart rate and cardiac output. The scenario is then

Events following administration of intravenous fluid

\[ \uparrow \text{Intravascular Volume} \]
\[ \downarrow \]
\[ \uparrow \text{Central Venous Pressure} \]
\[ \downarrow \]
\[ \uparrow \text{Stroke Volume} \]
\[ \downarrow \]
\[ \uparrow \text{Cardiac Output} \]
\[ \downarrow \]
\[ \uparrow \text{Blood Pressure} \]
\[ \downarrow \]
\[ \uparrow \text{Baroreceptor Firing} \]

\[ \uparrow \text{Inhibition of Vasoconstrictor Center of Medulla} \]
\[ \downarrow \]
\[ \uparrow \text{Excitation of Vagal Center} \]
\[ \downarrow \]
\[ \uparrow \text{Vagal Outflow} \]
\[ \downarrow \]
\[ \downarrow \text{Sympathetic Outflow} \]
\[ \downarrow \]
\[ \downarrow \text{Heart Rate} \]
\[ \downarrow \text{Contractility} \]
\[ \downarrow \text{Vasoconstriction} \]

**FIG. 2.**

Events following administration of intravenous fluid.
repeated in a patient without a baroreflex, emphasizing that the heart rate change is not a drug effect but purely baroreceptor mediated.

**Evaluation Methods**

An anonymous examination and survey were administered immediately before and after the workshop (APPENDIX). Each examination question was followed by an assessment of their confidence. The subsequent survey used a similar five-point Likert-type scale with the question “how well do you feel you understand the following concepts?” and anchors of “not at all” (1) and “very well” (5). Data were analyzed with Wilcoxon rank-sum tests. In addition, the students were required to complete an anonymous course evaluation at the end of the cardiovascular physiology section.

**RESULTS**

Each year, >85% of the students rate this workshop very good or excellent, with a mean score of 4.5 out of 5. These scores are consistently among the highest of all course evaluations throughout our medical school.

Seventy-five exams/surveys were returned (an 86% response rate), but eight were incomplete (students arrived late, missing the presession quiz). On the examination, performance improved on each question except 1-a and 2-a, the location of “the point at which the heart normally functions” on both Starling curves. However, confidence in the answer improved for all questions and survey items following the simulator session ($P < 0.0001$).

**DISCUSSION**

The survey included two “control” questions unrelated to the simulator workshop. Student confidence in their understanding of these concepts (excitation-contraction coupling and the cardiac cycle) improved at a level that reached statistical significance, although the test statistic ($W$) was less than one-quarter that of the other questions. Although this suggests a failure of the evaluation tool, it may be evidence of the increased interest and confidence apparent during the sessions. At the beginning, the students were apprehensive and distant, but gradually they moved closer to the simulator, asked questions, and became involved with the workshop and “patient.” It seemed as though a “light was turned on” for many, resulting in a new sense of confidence in their understanding of cardiovascular physiology as a whole.

Physiology is considered one of the most clinically relevant basic sciences; yet, the interrelationships of
the various systems make it one of the most difficult
to master. Understanding physiological principles and
developing accurate and workable mental models are
fundamental goals of the preclinical years. Whereas
cadaver dissection is considered essential to learning
the static information of anatomy, teaching the func-
tional science of physiology is relegated more and
more to lectures and discussions. This unfortunate trend
has generated much discussion recently, with calls for
alternative methods of “active learning” (5, 7).

Demonstration of physiological principles in a labora-
tory exercise typically requires the use of live animals.
Their use has been criticized on ethical grounds, and
recent surveys have found an increasing number of
students opting out of these valuable learning expe-
riences (1).

Laboratory exercises and workshops offer significant
advantages over lecture-style teaching. First, the small
group size necessary for such teaching encourages
discussion both between faculty and students and
amongst students. Often, misunderstandings can be
corrected before they become the basis for incorrect
mental models. Of course the downside of the small-
group model is the increased requirement for faculty
time. Use of teaching assistants may be a solution, but
the model depends on congenial, enthusiastic instruc-
tors with excellent communication skills.

Second, the active, hands-on learning of these exer-
cises encourages application and elaboration of the
concepts introduced in lecture and independent
study. The information-processing approach to learn-
ing (9) theorizes that acquisition of new information
requires 1) activation of prior knowledge, 2) elabora-
tion of knowledge, and 3) encoding specificity. The
first two of these are achieved by revisiting and ex-
anding on concepts introduced in lecture and reading
assignments. But in addition, the simulator allows
teaching in a clinically realistic environment that, ac-
cording to the encoding specificity principle (10),
may increase the likelihood that information will be
retrieved at the appropriate time in the future. This
clinical correlation reinforces the importance of phys-
iology as a foundation for all of medicine.

Finally, cooperation in a laboratory exercise is ex-
cellent training for the student’s future role as a
member of the patient-care team. Such skills are not
usually taught elsewhere in medical school and may
not be well developed in this typically highly com-
petitive student population. The students helped
each other collect data during the scenario. When
an intervention was recommended by a student,
they were invited to explain the rationale to their
colleagues. Inevitably, questions and requests for
clarification followed, often answered by other stu-
dents.

Recognizing the value of these laboratory exercises
then, the existing alternatives to animal-based lab-
oratories are inadequate. Although valuable as ad-
juncts, videotapes and independent study cannot
substitute for the interactive learning of a labora-
tory exercise; computer simulations (2, 8) run in-
dividually lack both faculty interaction and team
work; and small-group discussions do not provide
the hands-on excitement of managing a “real” clin-
ical problem in real time. The simulator workshop
closes the void by providing a realistic, clinically ori-
tented, interactive venue, presenting information in
an active format conducive to discussion and indi-
vidual self-evaluation of mental models. Of course
successful teaching, even with a simulator, depends
on a dynamic, enthusiastic, skilled facilitator who is
able to engage the students and challenge those
who appear confused. In the author’s experience,
the simulator provides a valuable backdrop and
springboard for physiology instruction.

Limitations of Simulation
The cost of full-scale simulators looms as an obstacle,
carrying a price tag of approximately $150,000. To-
gether with costs of a facility and maintenance, this
investment clearly must be shared. Currently, more
than 150 medical schools and community colleges
worldwide have established simulator programs, giv-
ing evidence that many have found the investment
into simulation cost effective. In addition to teaching
medical students, at our institution the simulator is
used to teach veterinary students, nurses, resident
physicians, practicing physicians, physician assis-
tants, emergency medical technicians/paramedics,
and engineering and marketing personnel from indus-
try. We foresee a natural expansion of simulator-
linked teaching in such areas as pharmacology, ad-
vanced cardiac life support, and even the teaching of biology in high schools.

The limitations of the currently marketed simulators are primarily related to the physical mannequin itself, which clearly feels like plastic and does not move in a realistic way. In addition, as with all computer-based simulators, there are weaknesses in some of the physiological and pharmacological models. Despite the current drawbacks, most students and physicians working with the simulator are capable of the “willful suspension of disbelief” and soon forget the artificial circumstances of the system, becoming so involved with the clinical challenges that they become quite anxious when things go wrong. Improvement in the technology is an area of active research, providing educators with ever new and innovative teaching tools.

In conclusion, physiology is a difficult body of knowledge for medical students to assimilate. Laboratory exercises of the functional science are helpful in developing and validating workable mental models; yet, for various reasons, laboratory exposure is declining. Workshops using a full-scale patient simulator provide a valuable alternative. Cost constraints can be overcome with a multidepartmental sharing approach.

APPENDIX

Cardiovascular Physiology Survey

1. Draw a Starling curve for a normal healthy heart (please label the x and y axes).

2. Draw a Starling curve for a patient with congestive heart failure.

3. Explain the physiology of the Valsalva maneuver (bearing down).

How well do you feel you understand the following concepts?

- the effect of venous return on cardiac output?
- Starling curves?
- the clinical relevance of Starling curves?
- electrical-contraction coupling?
- the physiology of the Valsalva maneuver?
- the cardiac cycle?
- the baroreceptor reflex?

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