Novel use of a noninvasive hemodynamic monitor in a personalized, active learning simulation

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Zoller JK, He J, Ballew AT, Orr WN, Flynn BC. Novel use of a noninvasive hemodynamic monitor in a personalized, active learning simulation. Adv Physiol Educ 41: 266–269, 2017; doi:10.1152/advan.00185.2016.—The present study furthered the concept of simulation-based medical education by applying a personalized active learning component. We tested this novel approach utilizing a noninvasive hemodynamic monitor with the capability to measure and display in real time numerous hemodynamic parameters in the exercising participant. Changes in medical knowledge concerning physiology were examined with a pre-and posttest. Simply by observation of one’s own hemodynamic variables, the understanding of complex physiological concepts was significantly enhanced.

THE USE OF ACTIVE LEARNING via simulation is an established method of medical education (10). Active learning strategies specifically aim to promote a deeper understanding of concepts through learner-based participatory activities and in-depth discussions, as opposed to more traditional passive learning approaches, such as an instructor-led lecture (5). Evidence suggests that active learning facilitates more conducive attitudes toward learning and is associated with both a deeper understanding of content material as well as improvements in educational objectives (11, 13). Active learning promotes both active discussion and critical thinking to solve complex problems and improve comprehension of complex topics (6).

Newer technology has now afforded students the opportunity to utilize not only active learning, but also personalized simulation. Traditional simulation training has become a standard in medical education, resulting in the requirement for simulation testing for completion of certain American Medical Board Examinations. Furthermore, students who engage in active learning simulations report that such an environment allowed ease of participation and understanding of material (3).

Active learning strategies and simulation technologies have been successfully incorporated into physiology education. Previous authors reported medical students’ performance over the course of four semesters utilizing active learning strategies was significantly higher on a cognitive monitoring test of physiology topics than those who did not engage in active learning (9). Similarly, another study tested the utility of a high-fidelity patient simulator in an active learning environment to enhance learning of cardiovascular physiology concepts and develop treatment strategies (7). This study identified a significant increase in knowledge from pre- to posttest, suggesting that simulation technologies can promote learning outcomes. While there is copious literature suggesting that simulation technologies can promote active learning, limited studies have been conducted utilizing new noninvasive technologies in a “self-simulation” approach.

Real-time, active learning, whereby learners participate in a simulation experience using their own physiological data, has not yet been validated as an effective educational tool. We sought to extrapolate the philosophies of active learning and simulation experiences by allowing participants to learn from their own unique physiological and hemodynamic data during exercise. Traditional medical education of physiology focuses on diagrams and equations to teach the complex physics that occurs on a beat-by-beat basis inside the human body. However, by actually witnessing these parameters in human subjects, the level of understanding escalates dramatically. Furthermore, we wished not only to evaluate real-time active learning and simulation, but also to utilize the learner’s own physiological data to aid the learning experience and to provide a more intense and meaningful understanding of complex concepts in medical education.

The present study focused on real-life and real-time application of hemodynamic monitoring. We chose to evaluate this modality in an exploratory study by recording stroke volume (SV), cardiac index (CI), systemic vascular resistance (SVR), and heart rate (HR) during intense physical stress in the form of Burpee exercises, both in the dehydrated and then in the hydrated state, using a noninvasive cardiac pulse contour analysis monitor (Clearsight, Edwards Lifesciences, Irving, CA). Figure 1 depicts the body positions of the Burpee exercise. Specifically, we were introducing the physiological concepts of pulse pressure, pulse pressure variation changes during exercise, and changes in SVR, CO, and SV during a rest phase, an exercise phase, and a recovery phase. We hypothesized that by simply “using” the monitor on one’s self, understanding of complex cardiovascular physiological principles would be enhanced in the form of improvement in test scores.

METHODS

After institutional review board approval, 10 study participants were recruited with flyers and word-of-mouth solicitation for this exploratory study. All participants had to be registered nurses in an intensive care unit to standardize the knowledge base of the partici-
pants. Other inclusion criteria included age 20–45 yr old and capability of performing strenuous activity. Exclusion criteria included pregnancy and non-English speaking. Five women and five men entered and completed the study. Written and informed consent was obtained from all subjects for this study.

The Burpee exercise was chosen as the strenuous exercise based on previous findings that the Burpee exercise elicits a relatively higher acute metabolic demand than traditional resistance exercises (12). We used the Clearsight monitor to measure hemodynamic variables, as it had been previously shown to correlate with inert gas rebreathing and respired gas analysis measurements of cardiac output during exercise (1). There are no previous studies utilizing the Clearsight monitor for cardiovascular physiological education.

All participants were administered a 10-question pretest written examination encompassing the previously identified physiological and hemodynamic concepts. The examination is shown in Fig. 2. Purposefully, no education concerning physiology or hemodynamics was given. The noninvasive cardiac monitors were then placed on each participant using the adhesive finger blood pressure cuffs that fit

Fig. 1. The five parts of the Burpee exercise are as follows: 1) from a standing position, the participant jumps straight into the air with arms straight up overhead; 2) squats with both hands and feet on the floor; 3) kicks legs back to table-top position and performs a push up; 4) jumps forward to squat position with both hands and feet on the floor; and 5) stands up and jumps straight into the air with arms straight up overhead. [With permission from Dr. T. Carter.]

1. What is not a determinant of cardiac output?
   a. Heart rate
   b. Preload
   c. Stroke volume variation
   d. Stroke volume
2. Cardiac output is affected by tissue oxygen demand
   a. True
   b. False
3. What does a large stroke volume variation indicate in a patient?
   a. Increased contractility
   b. Fluid responsiveness
   c. Low blood pressure
   d. High blood pressure
4. A pulmonary artery catheter is required for measurement of cardiac output
   a. True
   b. False
5. Cardiac output is always proportional to ejection fraction
   a. True
   b. False
6. Which of the following can provide an estimate of cardiac output?
   a. Thermodilution via pulmonary artery catheter
   b. Fick equation
   c. Clearsight system
   d. Angiography
   e. All of the above
7. What do the vertical lines represent in the picture below?
   a. Blood pressure
   b. Stroke volume
   c. Heart rate
   d. Stroke volume variation
8. What do the horizontal lines represent in the picture below?
   a. Blood pressure
   b. Stroke volume
   c. Heart rate
   d. Stroke volume variation
9. What does the fluctuation in the horizontal lines (see arrows) represent in the picture below?
   a. Stroke volume
   b. Heart rate
   c. Mean arterial pressure
   d. Stroke volume variation
10. What is the equation for maximal heart rate?
    a. $220 - \text{age}$
    b. $200 + \text{age}$
    c. $150 + \text{weight in kg}$
    d. $150 + \text{weight in lbs}$
snugly onto one finger. Each participant was connected via a loose wire to his or her own monitor showing numerical and waveform data. All participants were able to visualize their monitor as they exercised. Baseline data hemodynamic variables (SV, CI, SVR, HR) were obtained at rest.

Hemodynamic parameters were continuously recorded during the initial Burpee exercise of 90-s duration while the participant was in a dehydrated state, as defined as a minimum 8-h fast of food and water. Then each participant drank 500 ml of water and rested for 30 min to achieve the hydrated state. The 90-s Burpee exercise was then repeated in the hydrated state, and hemodynamic variables were again recorded. There was no requirement as to the number of Burpees each participant did. Participants were openly encouraged to do as many as possible. Hemodynamic variables were recorded after the variables had equilibrated, as assessed by waveform stability.

Throughout the exercise portions of the study, the participants watched in real-time their own personal hemodynamic data recordings, both in numerical form and waveform. Participants were allowed to make vocal observations and also allowed to ask directed questions to the study proctors during this portion of the study. Questions were answered concisely without additional education. Afterwards, participants were allowed to rest, consume food and water, and take a repeat written examination, which was identical to the pretest.

Statistical Analysis

All demographics and hemodynamic variables for each individual participant were recorded and provided. The outcome variable of knowledge test score at baseline and after exercise was summarized using descriptive statistics; the change scores (post-pre) were calculated, and Wilcoxon signed-rank test was used to test whether the change was significant. Due to the exploratory nature of the study, no control of multiple tests was considered. The significance level is 0.05, and all analyses were conducted in STATA 13.1 (StataCorp LP, College Station, TX).

RESULTS

Baseline characteristics and hemodynamic variables for the female and male study participants were recorded. The five men and five women were between the ages of 26 and 42 yr. All participants’ body mass indexes were within a healthy range (17–28 kg/m²). HRs ranged from 58 to 102 beats/min, and CI ranged from 2.7 to 4.4 l·min⁻¹·m⁻². SVR ranged from 778 to 1403 dyn·cm⁻⁵, with men having a lower average SVR. As expected, the women had lower SV than the men (54–79 vs. 81–115 ml).

We found a significant increase (P = 0.006) in written test scores when comparing test results before using the hemodynamic monitor to after using the hemodynamic monitor. Pretest scores ranged from 5/10 to 10/10 (in one subject). Posttest scores ranged from 6/10 to 10/10. Among the 10 participants, 8 participants had improved their tests score by 1–3 points, and 2 participants had no change (Table 1).

DISCUSSION

The present study gives credence to a novel process of active learning whereby medical caregivers engage in a learning style that diverges from traditional simulated medical education. Participants in the present study were tested on acquisition of new knowledge concerning personal physiology and hemodynamic variables using a noninvasive pulse contour monitor with real-time displays of their own physiological data. Participants in the present study demonstrated a statistically significant improvement in written test scores (P = 0.006).

Table 1. Pre- and postexperience examination scores for the 10 participants

<table>
<thead>
<tr>
<th>Participant No.</th>
<th>Pretest Score/10</th>
<th>Posttest Score/10</th>
<th>Change Score (Post-Pre)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>9</td>
<td>3</td>
<td>0.006</td>
</tr>
<tr>
<td>2</td>
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<td>9</td>
<td>1</td>
<td></td>
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<tr>
<td>3</td>
<td>10</td>
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<tr>
<td>10</td>
<td>6</td>
<td>7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>6.5</td>
<td>7.5</td>
<td>1</td>
<td>0.006</td>
</tr>
<tr>
<td>Mean</td>
<td>6.9</td>
<td>7.9</td>
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<td></td>
</tr>
<tr>
<td>SD</td>
<td>1.45</td>
<td>1.29</td>
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</tbody>
</table>

Wilcoxon signed-rank test was used for calculations. SD, standard deviation.

Our study is unique in that the active learning truly required activity in the form of exercise. The interactive learning environment allowed participants to realize gaps in knowledge, reflect on past knowledge, and to ask questions concerning the assimilation of new knowledge. Furthermore, this educational method provided more meaning to the reflection of ideas and thought processes involved in the learning process since the simulation experience involved participants’ own personal physiological data. Hence, the information gleaned by using a real-time physiological monitor was substantially more meaningful than viewing physiological data generated by a computer model. We feel personalized data acquisition may provide an extra value for individuals attempting to learn complex physiological concepts, and this may be something that medical education systems should employ.

Intensive care unit nurses in our institution are required to possess knowledge concerning hemodynamic variables such as SV, CI, HR, and SVR. They routinely manage patients with pulmonary artery catheters, thus understanding the definitions of each data point. However, interpretation of these data is not something they are required to do. Simply by using the monitoring device, the participants gained new knowledge that they did not possess before the exercise based on standardized pre- and posttest scores.

Active medical learning is an important educational concept in which learners are engaged in manipulating knowledge in real time. The authors feel a personalized simulation experience would enhance the educational process even further. While not all physiological objectives necessary for medical education can be safely simulated in a personalized experience, many of the basics can and perhaps should be. A learning experience as detailed in the present study could be easily translated not only into the advanced practice provider curriculum, but also to the medical student and resident curricula when attempting to understand important physiological concepts. While active learning is thought to be superior to traditional classroom learning, active learning on one’s own body takes on a whole new level of meaningfulness.

There is a paucity of data whereby active learning utilizing the learner’s own hemodynamics is examined. Johnson et al. (8) incorporated real-time cardiac ultrasonography imaging to enhance the understanding of Frank Starling’s law of the heart. The authors found that students subjectively improved their...
conceptualization of the effect of preload on cardiac output by comparing left ventricular dimensions before and after an exercise with real-time surface echocardiography. Outside of this report and the present study, “self-simulation” as an effective teaching and learning tool is not widely reported.

Other authors and educational instructors have utilized medical research instruments such as the Biopac (2) for biology and physiology education (4). Adjuncts such as this are likely useful; however, limited evidence exists to prove this. Lastly, while numerous monitoring devices may provide physiological data, it is necessary to choose the tool that is specific to the coursework being studied. In the case of the Clearsight, cardiovascular hemodynamic function should be the intended educational objective.

**Limitations**

The present study used an identical pre- and posttest to ascertain knowledge acquisition, which could create an exposure bias. The goal was not to identify specific baseline knowledge of the participants, but to identify improvements in knowledge with use of a noninvasive hemodynamic monitor. Another weakness of the study is the small sample size of participants. Additionally, a written test with a greater number and more educationally vetted questions would be worthy of a future study.

**Summary**

Personalized, active simulation experiences may be a unique and highly effective method of educating complex medical principles, as shown by significant improvements in written test scores. The real-time observation of one’s own physiological parameters during exercise likely gives enhanced meaning when attempting to understand new concepts and is perhaps the next step beyond simulation training for medical education. As the non-invasiveness of hemodynamic monitors continues to improve, the next logical adjunct is to practice the active learning experience on one’s own physiological data to enhance conceptual understanding of difficult topics.

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**DISCLOSURES**

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

**AUTHOR CONTRIBUTIONS**


**REFERENCES**