

# Continuous and noninvasive recording of cardiovascular parameters with the Finapres finger cuff enhances undergraduate student understanding of physiology

Yvonne Hodgson and Julia Choate

Department of Physiology, School of Biomedical Sciences, Monash University, Melbourne, Victoria, Australia

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**Hodgson Y, Choate J.** Continuous and noninvasive recording of cardiovascular parameters with the Finapres finger cuff enhances undergraduate student understanding of physiology. *Adv Physiol Educ* 36: 20–26, 2012; doi:10.1152/advan.00097.2011.—The Finapres finger cuff recording system provides continuous calculations of beat-to-beat variations in cardiac output (CO), total peripheral resistance, heart rate (HR), and blood pressure (BP). This system is unique in that it allows experimental subjects to immediately, continuously, and noninvasively visualize changes in CO at rest and during exercise. This study provides evidence that using the Finapres system improves undergraduate student engagement, understanding, and learning of how the cardiovascular system responds to exercise. Second-year science students undertaking a physiology practical class in 2009 ( $n = 243$ ) and 2010 ( $n = 263$ ) used the Finapres system to record CO, BP, and HR during graded exercise on a cycle ergometer. Student experiences with the Finapres was evaluated with a survey (a 5-point scale from strongly disagree to strongly agree). This indicated that students appreciated the immediacy of the recordings (88% of students agreed or strongly agreed, average for 2009 and 2010), gained an understanding of how to record physiological data (84%), enjoyed the practical (81%), and would recommend the Finapres to other students (81%). To determine if the practical enhanced student learning of cardiovascular physiology, identical tests were given to the students at the beginning (pretest) and end (posttest) of the class. There was a significant improvement from the pretest to the posttest (4% in 2009 and 20% in 2010). In summary, the ability of the Finapres to continuously display CO, BP, and HR during experimental protocols provides students with immediate feedback and improves their understanding of cardiovascular physiology.

laboratory class; cardiac output; blood pressure; heart rate

CARDIOVASCULAR PHYSIOLOGY is one area of the physiology curriculum that many students find challenging (3, 7, 8). Practical laboratory classes demonstrating how the cardiovascular system functions play an important part in student understanding and learning as they provide opportunities for active learning and consolidation of theoretical concepts (3). Animal models are frequently used in practical classes to demonstrate cardiac and vascular measurements and responses (6, 9, 18). These practical classes, while time consuming and expensive, are important for illustrating how the cardiovascular system functions and how it is regulated. They can also provide real-time experiences of the complexity of the interactions in the system as well as an opportunity for students to collect and evaluate data. Over the past 2 decades, there has been a shift away from the use of animals in practical classes to classes that

use computer simulations (12, 15, 17, 18), videos (18), problem classes (11, 12, 16), or human subjects (2, 5, 19). One advantage of using human subjects is that students can collect and measure cardiovascular parameters, such as arterial blood pressure (BP) and heart rate (HR), on themselves. Furthermore, most students enjoy doing these types of practical classes, so there can be a higher level of motivation and engagement with these types of activities.

Simple cardiovascular parameters, such as BP and HR, can be measured by students on each other using relatively inexpensive equipment that can be found in most university physiology laboratories. For example, the palpatory and auscultatory methods can be used to calculate the pulse rate. The measurement of more complex cardiovascular parameters, such as cardiac output (CO), stroke volume (SV), and total peripheral resistance (TPR), are not easily performed or demonstrated to students, yet these are critical measures of how the cardiovascular system is functioning in different situations of homeostatic imbalance (e.g., exercise or heart failure). CO is one of the most important cardiovascular parameters that physicians use to estimate cardiovascular well being and to determine the extent of cardiac disease or deterioration. The methods available to demonstrate CO are generally invasive and are not readily available to students in university practical laboratory settings. A study by Song et al. (19) used echocardiography to demonstrate the cardiovascular responses to changes in posture and during graded exercise. The use of echocardiography required the employment of a qualified echocardiographer, a luxury that many university teaching laboratories do not have. Such novel approaches for the teaching of cardiovascular physiology are rare.

The Finapres finger cuff is a recording system that provides continuous and concurrent calculations of CO, BP, SV, TPR, and HR (1, 13, 14). It is traditionally used in research settings. We report here, for the first time, the use of the Finapres finger cuff in an undergraduate physiology practical class. It is ideal for this use because it does not require specialized staff to operate the system and it is not prohibitively expensive. The practical class was developed over a 2-yr period (2009–2010) for students undertaking a science degree. The Finapres system was used on student subjects to demonstrate continuous calculations of BP, HR, and CO at rest and during moderate-intensity graded exercise on a cycle ergometer. To encourage student participation and learning, students worked in small groups to calculate SV and TPR. The learning objective of the practical class was that on completion, the students should be able to describe and explain the cardiovascular adjustments to exercise.

Address for reprint requests and other correspondence: Y. Hodgson, Dept. of Physiology, School of Biomedical Sciences, Monash Univ., Clayton, Victoria 3800, Australia (e-mail: Yvonne.Hodgson@monash.edu).

The aims of this study were 1) to determine if viewing the immediate changes in CO, HR, and BP during exercise (using the Finapres system), together with completing an associated practical worksheet, helped students to understand how exercise alters cardiovascular parameters and 2) to optimize the worksheet and logistics of the practical class for improved student learning.

## METHODS

*The Finapres fingercuff recording system.* Arterial BP can be continuously and noninvasively recorded using a Finapres finger cuff, which uses Finapres Medical Systems Finometer MIDI hardware and Beatscope software. The Finometer MIDI data-acquisition box and an analog-to-digital converter were connected to a computer. Signals were recorded and sampled with Beatscope software for Windows 98. Noninvasive continuous arterial BP and HR were measured beat-to-beat using the Finapres finger cuff on the index finger and a height correction system (see Fig. 1). The system is straightforward to set up following the manufacturer's instructions and can be easily used by both staff and students after a simple demonstration.

The Finapres finger cuff uses the volume-clamp technique to measure finger arterial pressure. The volume-clamp technique maintains the diameter of the artery under an inflated finger cuff at a set point, thereby determining with time changes in arterial pressure. Diodes located in the finger cuff, on either side of the finger, detect changes in artery diameter and change the inflation of the cuff (so that the diameter remains at the set point). The cuff is inflated or deflated

via an air bladder connected to an air hose and pump. For more detailed information about the volume-clamp technique for measuring arterial pressure, see Bogert et al. (1).

The Finapres finger cuff, together with Beatscope software, calculates left ventricular SV and uses this with HR to provide a calculated measure of CO. The software, using a mathematical model, generates an aortic pulse waveform from the finger arterial pressure wave. This computation takes into account changes in the pulse pressure and waveform shape as the pressure pulse is transmitted down the brachial arteries to the finger arteries. Parameters such as age, sex, height, and weight are also included in the computation for each individual subject. A fluid-filled tube attached between the top of the finger cuff and the subject's heart includes the positioning of the cuff relative to the heart in the computation (13).

*The cardiovascular physiology practical class.* A practical class investigating the effects of exercise on the cardiovascular system was introduced in 2009 to a group of second-year science students enrolled in a physiology unit at Monash University (called "The Physiology of Human Health"). Students study digestion, reproduction, endocrinology, and exercise within this unit. At Monash University, science students commence the study of physiology in the second year of their degree. There is no prerequisite for this unit (apart from passing the first year of the Science degree), and, in the past, up to 50% of the students have not previously studied cardiovascular physiology. In 2009, the class consisted of 243 students, took 1.5 h, and was run over 10 sessions to groups of ~25 students. There were six Finapres setups and six demonstrators for each class (demonstrators are PhD students that are paid to lead groups of students through a practical class). The demonstrator-to-student ratio was ~1:4. The practical class involved students working in groups of four or five, with one student performing graded levels of exercise on a cycle ergometer. For the duration of the exercise, the hand with the finger cuff was kept static on the handlebars. The exercise workload was increased every 3 min by increments of 50 W, until the subject reached 75% of their maximum HR [calculated from 220 beats/min – age (in years)]. The Finapres finger cuff, together with Beatscope software, was used to continuously measure and record BP. HR was triggered from the pulse rate, and a mathematical estimate of CO was calculated from the pulse waveform. Each member of the student group performed a role: there was a voluntary experimental subject (who performed graded exercise on the cycle ergometer), a computer operator (who was responsible for adding comments to the recordings and ensuring that high-quality recordings were maintained), a manager (who coordinated the experiment and the group members, especially the experimental subject, e.g., by providing water), and a recorder (who kept the laboratory notebook up to date, wrote down details of the experimental protocols, and calculated parameters). The responsibilities of the group members were allocated at the beginning of the practical class. After the experimental data had been acquired, students worked together as a group to calculate SV and TPR and to complete a worksheet; this included a table of cardiovascular parameters before and during exercise and some short-answer questions about the factors that cause cardiovascular parameters to be altered during exercise. Before the end of the practical class, demonstrators marked these worksheets and gave their student group written and verbal feedback.

Since this study occurred over two successive teaching cycles (2009 and 2010), student feedback from 2009 was taken into consideration in making amendments to the practical class in 2010. In 2010, the practical class was taken by 263 students. The time course was extended from 1.5 to 3 h, and it was repeated over 6 sessions and used 10 Finapres setups. The demonstrator-to-student ratio was ~1:10. The worksheet was modified so that it involved more group discussion of cardiovascular parameters at rest and during exercise. For example, students were asked to write down definitions and explanations of CO and TPR. Students were also asked to graph their data (exercise workload plotted against CO, HR, and mean BP).

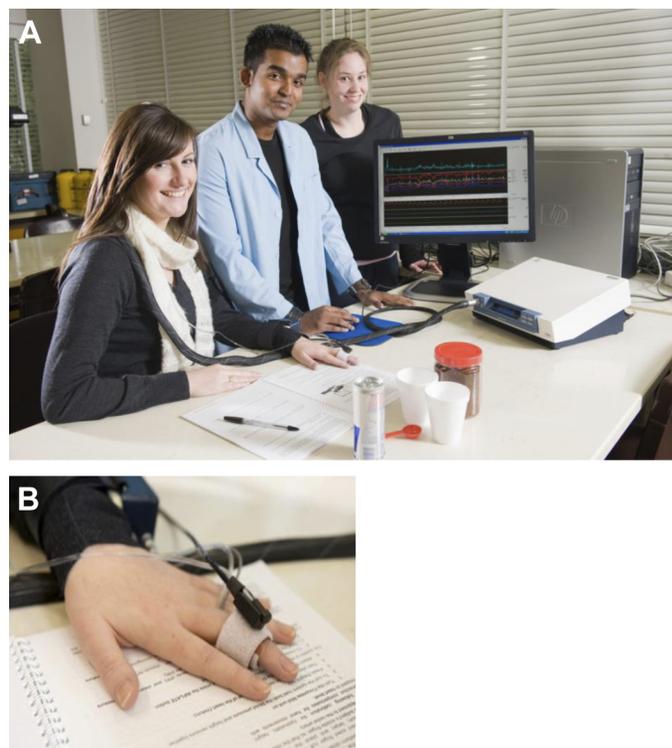


Fig. 1. A: photograph showing the practical setup of the Finapres finger cuff, which uses Finometer MIDI hardware. The calculated recordings using Beatscope software are visible on the computer screen. The white data-acquisition box contains electronic and pneumatic parts (which are enclosed in a black tube and are connected to a box worn on the wrist of the experimental subject). B: positioning of the finger cuff on the middle finger, with a height detection device attached on top of the finger (this is connected via a fluid-filled tube to another sensor on the subject on the thorax at the level of the heart). Differences in height from the heart are taken into account in the calculations of the cardiovascular parameters.

*Survey to determine student experiences with the Finapres recording system.* A survey to gauge student experiences with the Finapres equipment was given to students at the end of the practical class. This survey was administered to the class on each day by an independent administrator and was completed individually by the students. The survey questions, using a 5-point Likert scale, were based on those of Rodrigues-Barbero and Lopez-Nova (17). Students responded to questions or statements by ticking boxes corresponding to strongly agreed, agreed, neutral, disagreed, or strongly disagreed. For data analysis, these responses were registered as 5, 4, 3, 2, or 1 points, respectively. The quantitative data obtained from the survey were analyzed using Kruskal-Wallis one-way ANOVA for independent samples of ordinal data. At the end of this survey, students were asked to provide written comments on the “best aspect of the practical class” and “how the practical class could be improved.” These written comments were themed and collated.

*Student understanding and learning of the Finapres practical class; identical pre- and postpractical tests.* Identical pre- and postpractical class tests were given to the students by an independent administrator (see the APPENDIX for test questions). These were completed individually by the students. The multiple-choice, calculated, or matching answer questions on the tests evaluated the student knowledge of cardiovascular physiology. The prepractical test was administered as soon as the students arrived for the practical class. The postpractical test was administered once the students had completed their practical worksheet and it had been corrected and returned with written and verbal feedback. McNemar’s test was used to determine whether there was a statistical difference between the pre- and posttest results for each question in the test. This is a nonparametric statistical test for data with a binomial distribution; in this case, the student got the answer to the question correct or incorrect. Questions 1–4 (one question calculated and three multiple-choice questions) were the same for 2009 and 2010. The subsequent questions (matching answer questions) differed in 2009 and 2010 (questions 5–9 in 2009 and questions 5–10 in 2010); in 2009 the students were given scenarios involving changes in SV and in 2010 students were asked to match levels of fitness and cardiovascular health with changes in CO. Overall student performance on the tests was analyzed with a paired t-test for each year (2009 and 2010).

*Student performance on the end-of-semester exam.* Two multiple-choice questions about cardiovascular physiology on the end of semester exam were identical in 2009 and 2010. Student performance in these questions was statistically compared using McNemar’s test for nonparametric data with a binomial distribution (answer correct or incorrect).

*Human ethics and statistical analysis.* All student tests and surveys were approved by the Committee for Human Experimentation of Monash University. All data were analyzed using PASW Statistics 18 software (Polar Engineering and Consulting). Unless specified, results are expressed as means ± SE.

**RESULTS**

*Recording of cardiovascular parameters with the Finapres recording system.* Figure 2 shows a typical Finapres recording trace from an exercising student, which was recorded during a practical class in 2010. This trace clearly shows how CO, HR, and systolic BP increased as the workload of the exercise increased.

*Student experiences with the Finapres recording system.* The response rate for the survey was 91% (n = 222) in 2009 and 93% (n = 244) in 2010. The survey questions and results are shown in Table 1. The highest rating survey questions in both 2009 and 2010 were “my group discussed the questions on the worksheet” (question 3.4, 89% and 90% of students agreed or strongly agreed in 2009 and 2010, respectively) and “I worked well with my group members to set up and record with the Finapres system” (question 1.3, 87% and 91% of students agreed or strongly agreed). Importantly, the results of this survey indicate that the students appreciated the immediate recording and feedback of the Finapres system (question 1.4, 86% and 89% of students agreed or strongly agreed), enjoyed the practical class (question 3.1, 84% and 77% of students agreed or strongly agreed), gained a better understanding of how to record physiological data (question 2.4, 83% and 85% of students agreed or strongly agreed), and would recommend

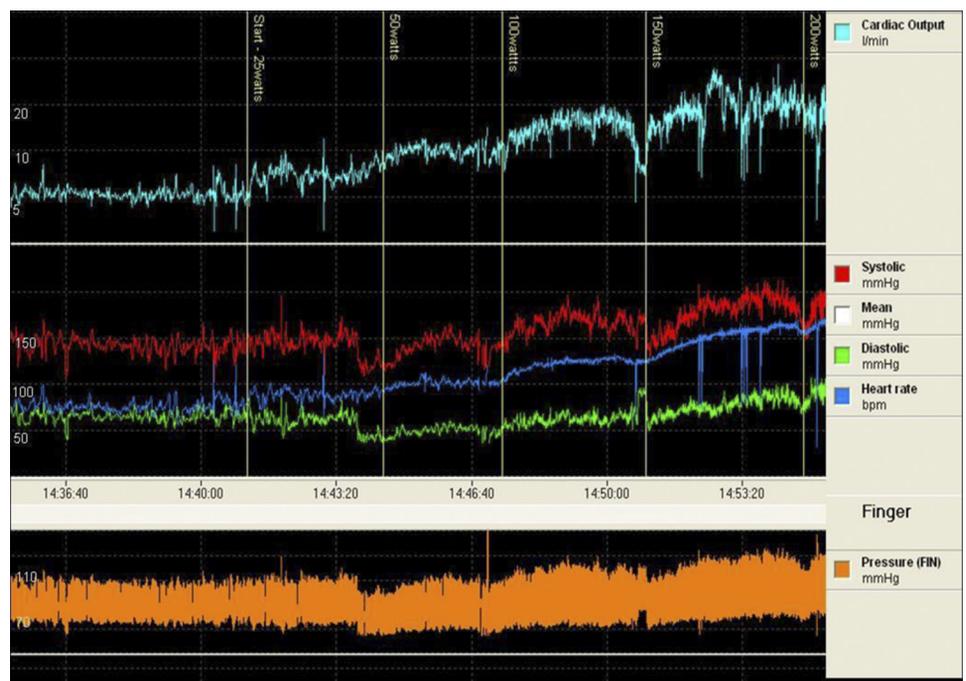


Fig. 2. Example of a Finapres recording from a student undertaking exercise. Finger arterial pressure [Pressure (FIN); bottom trace] as well as the blood pressure and heart rate (middle traces) and cardiac output (top trace) are shown. The vertical lines across the traces show the increase in exercise workload from 25 to 200 W. Please note that the vertical axis for the middle trace shows heart rate [in beats/min (bpm)] and the horizontal axis shows time (in min:s.ms).

Table 1. Student experience survey results (2009 and 2010)

	2009	2010	P Value
<i>Question 1. Using the apparatus</i>			
<i>Question 1.1. Using the Finapres equipment was easy.</i>	3.76 ± 1.10	4.01 ± 0.93	0.108
<i>Question 1.2. I was easily able to record and find values of heart rate, blood pressure, and cardiac output at rest and during exercise.</i>	3.94 ± 1.06	4.29 ± 0.77	0.004*
<i>Question 1.3. I worked well with my group members to set up and record with the Finapres system.</i>	4.25 ± 0.92	4.33 ± 0.77	0.804
<i>Question 1.4. I appreciated the immediate recording and feedback of blood pressure and heart rate provided by the Finapres system</i>	4.17 ± 0.85	4.31 ± 0.77	0.224
<i>Question 2. Student evaluation of the learning achieved by the use of the Finapres in the practical classes</i>			
<i>Question 2.1. After using the Finapres apparatus, I now have a much better understanding of how heart rate is altered during exercise.</i>	3.80 ± 0.93	3.99 ± 0.77	0.007*
<i>Question 2.2. After using the Finapres apparatus, I now have a much better understanding of how mean arterial pressure is altered during exercise.</i>	3.76 ± 0.92	3.96 ± 0.77	0.003*
<i>Question 2.3. After using the Finapres apparatus, I now have a much better understanding of how cardiac output is altered during exercise.</i>	3.88 ± 0.88	4.09 ± 0.77	0.001*
<i>Question 2.4. The Finapres allowed me to gain a better understanding of how to record physiological (cardiovascular) measurements.</i>	4.06 ± 0.89	4.10 ± 0.81	0.453
<i>Question 2.5. Using the Finapres enhanced my understanding and ability to synthesize and integrate physiological data.</i>	3.96 ± 0.90	3.99 ± 0.91	0.263
<i>Question 3. Student satisfaction with the practical class and the worksheet</i>			
<i>Question 3.1. I enjoyed the practical class.</i>	4.17 ± 0.96	4.01 ± 0.94	0.006*
<i>Question 3.2. I would recommend the use of the Finapres in practical classes for future students.</i>	4.12 ± 0.97	4.16 ± 0.86	0.217
<i>Question 3.3. Completing the worksheet for this practical was easy.</i>	4.15 ± 0.86	3.98 ± 0.85	0.039*
<i>Question 3.4. My group discussed the questions on the worksheet.</i>	4.27 ± 0.86	4.36 ± 0.77	0.555

Data are expressed as means ± SD; n = 221 students in 2009 and 244 students in 2010. \* $P < 0.05$  (as determined by an independent-samples Kruskal-Wallis test).

the Finapres practical class to future students (*question 3.2*, 81% and 80% of students agreed or strongly agreed). There was a significant increase (from 2009 to 2010) in the student ratings of *question 1.2* (easily able to record) and *questions 2.1–2.3* (after using Finapres, I now have a better understanding of how HR, BP, and CO are altered during exercise). There was a significant decrease for *question 3.1* (enjoyed the practical class) and *question 3.3* (completing the worksheet was easy).

The individual written student comments about the best aspect of the practical class and how the practical class could be improved are summarized in Table 2. For the best aspect of the practical class, in 2009 the demonstrators (i.e., their help and guidance) were the most highly rated comment. In 2010,

students rated most highly that the practical class helped them to understand the underlying theory. For both years, the area of the practical considered in most need of improvement was the accuracy of the equipment (theme: technical problems with the equipment). Of interest, in 2009 four students commented that the practical should be longer (than 1.5 h) and in 2010 nine students commented that the practical should be shorter (than 3 h).

*Learning achieved during the Finapres practical class.* The pre- and postpractical class test results for each question for the 2009 and 2010 student cohort are shown in Figs. 3 and 4. As shown in Fig. 3, student performance was significantly improved after the practical class (i.e., in the posttest compared with the pretest) for *questions 1* and *3* (2009 and 2010) and

Table 2. Individual student comments on the “best aspects of the practical” and “how the practical class could be improved” (organized by theme)

	2009		2010	
	Number of student comments	%	Number of student comments	%
The best aspect of the practical class was:	62 total		138 total	
Viewing the instant measurements	14	23	26	19
The equipment	11	18	18	13
Working with a group	10	16	21	15
The demonstrators	16	26	27	19
It helped me to understand the underlying theory and/or relevant lectures	4	8	29	21
Studying or participating in the exercise	5	6	12	9
No use of animals	1	1.5	0	0
Fun/enjoyable practical class	1	1.5	5	4
The practical class could be improved by:	31 total		51 total	
Fewer technical problems with the recording equipment	17	55	27	53
More detailed practical notes	3	9.5	7	14
Smaller groups	2	6.5	3	6
Newer exercise bicycles	4	13	2	3
More time for the practical class	4	13	0	0
Less time for the practical class	0	0	9	18
Individual worksheets	1	3	3	6

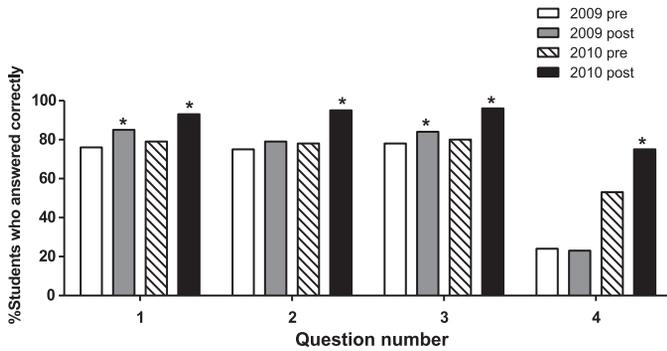


Fig. 3. Student performance on the identical pre- and postpractical test questions (questions 1–4) for 2009 ( $n = 180$ ) and 2010 ( $n = 205$ ). \* $P < 0.05$  for the pre- vs. postpractical test. In 2009,  $P < 0.001$  (question 1) and  $P = 0.013$  (question 3). In 2010,  $P < 0.001$  (questions 1–4).

questions 2 and 4 (2010). In 2010, student performance also improved in questions 5, 7, and 8 (see Fig. 4). Overall student performance in the pre- and posttest was compared. In both 2009 and 2010, student performance on the posttest was significantly higher than on the pretest. In 2009, the average pretest score was  $69 \pm 1\%$ , and the posttest score was  $73 \pm 1\%$  ( $n = 180$ ,  $P < 0.001$ ). In 2010, the pretest score was  $45 \pm 1\%$ , and the posttest score was  $65 \pm 1\%$  ( $n = 205$ ,  $P < 0.001$ ).

**Student performance on the end-of-semester exam.** Student performance on the two cardiovascular multiple-choice questions in the end of semester exam appeared to improve from 2009 to 2010, but this was not statistically significant. For question 1, 63% of the students got the answer correct in 2009 and 72% of the students got the answer correct in 2010 ( $n = 244$ ,  $P = 0.412$ ). For question 2, 57% of the students got the answer correct in 2009 and 68% of the students got the answer correct in 2010 ( $n = 263$ ,  $P = 0.137$ ).

**DISCUSSION**

This study demonstrated, for the first time, that the Finapres finger cuff recording system can be used to help second-year physiology students to gain an understanding of how the cardiovascular system responds to exercise. Calculations of CO, which normally require invasive techniques, were easily and continuously viewed by the students using the Finapres finger cuff recording system and Beatscope software. This meant that the students were able to observe the changes in these parameters during the exercise protocol. The students found the Finapres easy to use and were able to obtain direct measurements on a beat-to-beat basis, which were then used for calculations of TPR and SV in the accompanying worksheet. In addition to observing, calculating, and graphing these changes, students discussed and explained the mechanisms behind the exercise-induced changes. The active involvement of students in discussion and reflection increases their learning (8) and is likely to have contributed to the enhanced student engagement and understanding of cardiovascular physiology in this present study.

The efficacy of the Finapres as a teaching tool can be measured by 1) the ease with which students are able to use the equipment, 2) the reliability of the data they obtain, and 3) any improvement in answers and grades obtained in relevant assessment questions. Results from the student survey indicated that the students found the equipment easy to use, appreciated

the immediate feedback, and were able to easily analyse and interpret the data obtained. According to the student experience survey, in 2010 the students found the equipment easier to use than in 2009. This may reflect the increased time available to them and also that the teaching staff were more experienced with the use of the equipment. There was some frustration (for both staff and students) with the reliability of the apparatus. Most of the student comments about how the practical class could be improved in 2009 and 2010 related to technical problems with the Finapres. It was difficult to get measurements from students if their fingers were cold due to vasoconstriction of the finger arteries. This was a minor problem and was remedied by increasing the room temperature slightly or by asking the exercising subject to rub their hands together. There was also an issue with the accuracy of the recordings. The Finapres system sometimes produced different measurements of BP compared with an ambulatory Omron blood pressure cuff. The manufacturer (Finapres Medical Systems) and findings from other authors (1, 4, 14) indicated that the Finapres is suitable in situations where changes in BP are more important than absolute values. To obtain accurate absolute values for recordings of BP and CO, the Finapres equipment must be calibrated at each use (14). This is not practical in a teaching laboratory setting. In our experience, the equipment was able to provide realistic changes in BP and CO during exercise, which is sufficient for the needs of our laboratory classes in second-year physiology.

Results from the 2009 pre- and posttests indicated that there was only a modest effect on learning. In 2010, the practical time was extended, and the worksheet and test questions were modified. In this year, student performance in the posttest was markedly increased, and more students felt that the Finapres helped them to understand how HR, BP, and CO are altered during exercise. The 2010 students found the worksheet harder to complete; this suggests that the questions were more challenging and may have also enhanced their learning. Although there was improved student performance in 2010 on the postpractical test, this cohort of students had the same performance as the 2009 students for the two cardiovascular multiple-choice questions on the end of semester exam. The two exam questions are a smaller question sample size than the pre- and postpractical tests, which contained 9 and 10 questions, respectively. It should be noted that there were some questions on the pre- and posttests for which there was no significant difference. Furthermore, the concepts tested in the two exam questions were either not covered in the pre- and posttests or they

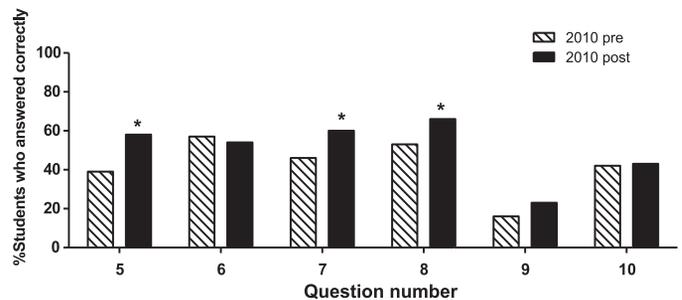


Fig. 4. Student performance on the identical pre- and postpractical test questions (questions 5–10) in 2010 ( $n = 205$ ). \* $P < 0.05$  for the pre- vs. postpractical test. Exact  $P$  values were as follows:  $P < 0.001$  (question 5),  $P = 0.017$  (question 7), and  $P = 0.003$  (question 8).

Table 3. Questions 5–9 for 2009

Scenario (Questions 6–10)	Answer With One or More of A–H
<i>Question 5.</i> Brandon is a 25-yr-old recreational long-distance runner. Today he ran 10 km in 35°C heat. His time was unusually slow.	
<i>Question 6.</i> Kasey's stroke volume while lying down was 75 ml. Her resting stroke volume in an upright position was 55 ml. Why is her stroke volume different when lying down?	
<i>Question 7.</i> After swimming five laps, Kasey's stroke volume increased to 90 ml. While running on a treadmill, her stroke volume increased to 100 ml. Why did her stroke volume increase more while running compared with swimming?	
<i>Question 8.</i> Ben is a competitive weightlifter at his university. His blood pressure immediately after performing the clean and jerk was 250/120 mmHg.	
<i>Question 9.</i> Amber is a swimmer on her high school swim team. She consumed a burger and fries 30 min before a race. To her surprise, she finished a distant sixth, instead of her usual top-three finish.	

Please match questions 5–9 with one or more of the following answer options (A–H). A: blood was diverted to the system that was placing a high demand and less blood was available to supply oxygen to muscles. B: blood does not pool in the lower legs, allowing for easy blood flow return to the heart and resulting in a higher resting stroke volume. C: in the upright position, stroke volume must increase to compensate for the force of gravity. D: use of the Valsalva maneuver caused an enormous increase in intrathoracic pressure, which led to increased blood pressure. E: gravity caused blood to pool in the legs, reducing the volume of blood returning to the heart. Stroke volume responded by increasing to maintain cardiac output. F: resistance training and exercise caused large increases in both diastolic and systolic blood pressure. G: aerobic training and exercise caused a large increase in both diastolic and systolic blood pressure. H: total peripheral resistance decreased during exercise.

covered the same concepts as those for which there was no significant difference on the pre- and posttests. Future research will examine the effects of the Finapres practical on short- and longer-term learning and will reuse the practical test questions on the end-of-semester exam.

The top rating responses in the survey related to group work, supporting the notion that this was an important aspect of the practical class. Group work involves active learning, which has been shown to enhance student engagement and improve student learning (8). As described in METHODS, the group work in this practical class allowed all of the group members to participate in the experiment, by allocating each member of the group a responsibility as a member of the experimental team.

A survey of undergraduate physiology students across eight United States institutions confirmed that they find some of the concepts underlying cardiovascular physiology difficult to understand (8). This present study highlights how a human practical class examining how the cardiovascular system functions during exercise can play an important part in student understanding and learning of these challenging concepts. A previous study (10) using the conscious unrestrained rat to demonstrate the baroreflex control of HR also reported enhanced student engagement and perceived understanding of cardiovascular physiology. This previous study and our own results demonstrate that practical classes that involve active learning and student-centered approaches can enhance student engagement and learning of cardiovascular physiology.

In summary, this is the first report of the Finapres finger cuff recording system being used to help undergraduate science students learn cardiovascular physiology. The equipment was easy to use and improved student learning of the underlying concepts. Positive student feedback about the Finapres practical class and improved student outcomes on the test questions support the idea that the Finapres provides a valuable laboratory teaching and learning experience for students. More recently, we have used the Finapres system for teaching more complex physiological scenarios, such as the diving reflex. In this way, the Finapres is an effective teaching (or research) tool that could be used to enhance the understanding and learning of cardiovascular physiology for medical, physiotherapy, or final-year science students.

#### APPENDIX: QUESTIONS ON THE PRE- AND POSTPRACTICAL TESTS FOR 2009 AND 2010

##### Questions 1–4

Questions 1–4 were the same in 2009 and 2010.

*Question 1.* Given a SV of 50 ml and a HR of 70 beats/min, the CO would be \_\_\_\_ l/min.

*Question 2.* Arterioles play an important role during exercise because of their ability to

A. store large volumes of blood in the arterial side of the circulation.

B. control blood flow by varying their length.

Table 4. Questions 5–10 for 2010

Scenario	Cardiac Output at Rest	Cardiac Output With Maximal Exercise
Amber is a 30-yr-old high school biology teacher. She is an amateur swimmer. For the last 6 mo, she has been training by swimming laps at the local public pool for 60 min each morning before work.	<i>Question 5</i>	<i>Question 6</i>
Kasey is a 38-yr-old university lecturer. She has two children in primary school and has no spare time for any structured physical activity.	<i>Question 7</i>	<i>Question 8</i>
Hayley is a 35-year-old physiotherapist. She has been experiencing high blood pressure, chest pains, and breathlessness with exercise. Her General Practitioner referred her to a cardiologist. The cardiologist performed an echocardiograph of her heart, which indicated that she has a stenosis (narrowing) of her main left coronary artery.	<i>Question 9</i>	<i>Question 10</i>

For the three scenarios, please indicate the most likely cardiac output at rest and with maximal exercise, selected from the following options (A–E). A: 19 l/min. B: 11 l/min. C: 5 l/min. D: 27 l/min. E: 3 l/min.

C. allow more blood to flow through them as a result of the squeezing action of the contracting muscles on them.

D. change the resistance to blood flow by changing their diameter.

*Question 3.* During exercise:

A. The increase in CO is unrelated to the intensity of the exercise.

B. Parasympathetic stimulation to the heart causes an increase in CO.

C. A decrease in venous return to the heart causes an increase in CO.

D. Sympathetic stimulation to the heart causes an increase in cardiac contractility.

*Question 4.* During intense exercise, CO increases significantly more than does mean arterial BP. This can be explained by the fact that:

A. CO has little influence on mean arterial BP.

B. the increase in CO is due to an increase in TPR.

C. there is a large fall in TPR.

D. the increased HR accelerates blood flow, thereby preventing pressure buildup.

*Questions 5–9 for 2009*

*Questions 5–9 for 2009 are shown in Table 3.*

*Questions 5–10 for 2010*

*Questions 5–10 in 2010 are shown in Table 4.*

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#### AUTHOR CONTRIBUTIONS

Y.H. and J.C. conception and design of research; Y.H. and J.C. performed experiments; Y.H. analyzed data; Y.H. and J.C. interpreted results of experiments; Y.H. and J.C. drafted manuscript; Y.H. and J.C. edited and revised manuscript; Y.H. and J.C. approved final version of manuscript; J.C. prepared figures.

#### REFERENCES

1. **Bogert LWJ, Erol-Yilmaz A, Tukkie R, van Lieshout JJ.** Varying the heart rate response to dynamic exercise in pacemaker-dependent subjects: effects on cardiac output and cerebral blood velocity. *Clin Sci (Lond)* 109: 493–501, 2005.
2. **Brunner M, Moeslinger T, Spieckermann P.** Echocardiography for teaching cardiac physiology in practical student courses. *Adv Physiol Educ* 13: 2–9, 1995.
3. **Carroll RG.** Cardiovascular pressure-flow relationships: what should be taught? *Adv Physiol Educ* 25: 8–14, 2001.
4. **Dyson KS, Shoemaker JK, Arbeille P, Hughson R.** Modelflow estimates of cardiac output compared with Doppler ultrasound during acute changes in vascular resistance in women. *Exp Physiol* 95: 561–568, 2010.
5. **Eblen-Zajjur A.** A simple ballistocardiographic system for a medical cardiovascular physiology course. *Adv Physiol Educ* 27: 224–229, 2003.
6. **Gupta S, Westfall TC, Lechner AJ, Knuepfer MM.** Teaching principles of cardiovascular function in a medical student laboratory. *Adv Physiol Educ* 29: 118–127, 2005.
7. **Michael J, Wenderoth M, Modell H, Cliff W, Horwitz B, McHale P, Richardson D, Silverthorn D, Williams S, Whitescarver S.** Undergraduates' understanding of cardiovascular phenomena. *Adv Physiol Educ* 26: 72–84, 2002.
8. **Michael J.** Where's the evidence that active learning works? *Adv Physiol Educ* 30: 159–167, 2006.
9. **Moore WA, Noonan AC.** Using live tissue laboratories to promote clinical reasoning in doctor of physical therapy students. *Adv Physiol Educ* 34: 54–58, 2010.
10. **O'Donoghue T, Resta T, Walker B.** Laboratory demonstration of baroreflex control of heart rate in conscious rats. *Adv Physiol Educ* 26: 309–316, 2002.
11. **Patil R, Snageeta K, DiCarlo S.** Integrated cardiovascular physiology; a laboratory exercise. *Adv Physiol Educ* 10: 20–31, 1993.
12. **Prakash E.** What is the ultimate goal in neural regulation of cardiovascular function? *Adv Physiol Educ* 28: 100–101, 2004.
13. **Ramat R, Jagomagi K, Mager TI.** Finger beat-to-beat blood pressure responses to successive hand elevations. *Med Eng Phys* 31: 522–527, 2009.
14. **Remmen JJ, Aengevaeren WR, Verheugt FW, Jansen RW.** Detection of elevated pulmonary capillary wedge pressure in elderly patients with various cardiac disorders by the Valsalva manoeuvre. *Clin Sci (Lond)* 111: 152–162, 2006.
15. **Ribaric S, Kordas M.** Teaching cardiovascular physiology with equivalent electronic circuits in a practically oriented teaching module. *Adv Physiol Educ* 35: 140–160, 2011.
16. **Richardson D.** Using situational physiology in a didactic lecture setting. *Adv Physiol Educ* 16: 61–67, 1996.
17. **Rodriguez-Barbero A, Lopez-Nova JM.** Teaching integrative physiology using the quantitative circulatory physiology model and case discussion method: evaluation of the learning experience. *Adv Physiol Educ* 32: 304–311, 2008.
18. **Samsel RS.** Cardiovascular physiology teaching: computer simulations vs. animal demonstrations. *Adv Physiol Educ* 26: 36–46, 1994.
19. **Song S, Burleson PD, Passo S, Messina EJ, Levine N, Thompson CI, Belloni FL, Recchia FA, Ojaimi C, Kaley G, Hintze TH.** Cardiac structure and function in humans: a new cardiovascular physiology laboratory. *Adv Physiol Educ* 33: 221–229, 2009.