Observing and understanding arterial and venous circulation differences in a physiology laboratory activity

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Background

Cardiovascular physiology represents an important topic in medical and biological physiology courses, and its comprehension is essential to make the student understand the relevance of basic sciences to clinical management and to the development of treatment strategies (13). However, previous studies have reported that students have difficulties to understand cardiovascular concepts due to their complexity (1, 19).

In this sense, some authors have already proposed strategies to change the teaching-learning method of this content (1, 3). Despite these previous reports about strategies to facilitate the teaching of this content, it is essential to find new and additional ways to facilitate student comprehension of cardiovascular physiology. Proposals with mathematical and physical models (9), homework activities (25), group dynamics (7), and practical classes (5) have been done and showed benefits in the understanding of physiology and other basic health sciences. A practical class allows the student and the professor to work together (5) but, most importantly, is able to clarify concepts, relating them to day-to-day questions (17, 4).

Previous work has demonstrated that clinical and practical experiences may have positive effects raising the understanding of students in the beginning of health courses, especially because they make the student think critically about therapies, considering the physiological concepts that are being studied in basic health sciences (1). Misunderstanding of physiological and other basic sciences concepts has proven to make students perform worse in clinical practice (13), showing the importance of proposals aiming to improve the teaching-learning process in physiological sciences.

With these concepts in mind, in the present article, we describe one practical activity on arterial and venous blood circulation, considering the hypothesis that the experimental experience would help the students to better understand the issue of hemodynamics and the cardiovascular system. The color and temperature of the skin are directly dependent on the bloodstream as well as the caliber and surface area of the capillaries and nerve-subcapillary attachments, so this experiment has the aim of identifying visible changes in skin color due to changed or interrupted blood flow.

Blood flow control includes local, neural and hormonal mechanisms (22). The local mechanisms include the myogenic tonus, metabolic control, vascular endothelium factors, and release of other paracrine substances, such as histamine, serotonin, and bradykinin. The myogenic tonus is an important basic mechanism activated each time that the blood pressure in a region increases because a distension of the blood vessel occurs due to the increase of blood pressure. The metabolic control mechanism matches O2 availability and consumption, so in situations in which O2 consumption is increased, as in physical exercise, vasodilator factors are produced by the tissue and act in arteriolar vessels of this region. The main vasodilator substances are adenosine, CO2, H+, changes in osmolality, K+, and a decrease in O2. Local release of vascular endothelium factors that influence vessel tonus include vasodilators (nitric oxide and prostacyclin) and vasoconstrictors (endothelin, prostaglandins, ANG II, and ROS). Other local paracrine substances are released by different processes independent of vessel synthesis, such as histamine (promotes arterial vasodilation), serotonin (vasoconstriction after a lesion), and bradykinin (promotes arterial vasodilation).
Neural control occurs through the sympathetic nervous system (noradrenergic and adrenergic). Most vessels have both types of receptors (α-adrenergic and β-adrenergic), but the response of the receptors depends on the balance of norepinephrine and epinephrine actions in each moment. Hormonal control depends, mainly, on the actions of epinephrine, but ANG II, vasopressin, and atrial natriuretic factor also influence the vascular tonus (22).

In skin blood flow, the local mechanism seems to be important, as does sympathetic innervation (8, 11, 22). In addition, it is important to consider that cutaneous and tissue blood flow can be influenced by environmental and body temperatures (24).

Another important concept related to blood flow that could be observed in the following experiments is hyperemia. During hyperemia, local factors induce vasodilation and, consequently, increase blood flow to the tissue. Hyperemia can occur in two forms: active and reactive. Active hyperemia is related to the increase of blood flow to a tissue according to its metabolic activity. This occurs, for example, during physical exercise, when the metabolic activity of the exercised muscles increases and local metabolites induce vasodilation and increase local blood flow. On the other hand, reactive hyperemia is related to an increase in blood flow in response to a previous reduction in blood flow. In experiment 1 suggested here, we can see an example of reactive hyperemia after one temporary occlusion of the arterial flow, when the reduction of blood supply promotes nutrient and O2 deficits that generate vasodilators, minimizing the obstruction effects (22).

**Learning Objectives**

After completing this activity, the student should be able to:

1. Describe and explain how the anatomic and physiological differences between arterial and venous blood vessels influence blood flow when external compression is applied
2. Develop hypothesis to explain the different responses to the interruption of the arterial and venous blood flow
3. Understand and discuss hemodynamics and differentiate active and reactive hyperemia

Students will also gain general skills, such as how to observe, collect, and analyze physiology data, and can also learn how to design and prepare an experiment as well as a little about the ethical and experimental care that are necessary in human experiments.

**Activity Level**

This activity is suitable mainly for human physiology courses but can also be useful in anatomy, general physiology, animal physiology, general biology, human biology, and other science courses.

**Prerequisite Student Knowledge or Skills**

Before doing this activity, students should have a basic understanding of:

1. Anatomic and physiological differences between arterial and venous blood vessels
2. Heart function, including cardiac electrophysiology and blood pressure
3. Factors that affect blood flow, vascular resistance, and venous return

4. Reactive and active hyperemia and arteriolar smooth muscle control

Students should know how to:

1. Use a sphygmomanometer.

**Time Required**

At least 1 h in the laboratory is necessary to perform the experiments. First, the professor explains the idea and students then plan and design the experiments in small groups. During the performance of the experiment, the data should be collected from one volunteer subject from each group. In the end, students analyze and discuss the results. One strategy to reduce the time required to perform the experiment is to provide to students a practical guide before the class.

**METHODS**

**Equipment and Supplies**

In these experiments, the following equipment is required (1 set/group):

1. A sphygmomanometer
2. Rubber bands
3. A clock or watch or stopwatch

**Human Subjects**

This is a noninvasive experiment and is considered an exempt educational activity by our home institution. This proposal was approved by the Educational Committee of the Federal University of Pampa (Institutional Review Board no. 10.001.10). Adopters of this activity are responsible for obtaining permission for human subject research from their home institution. For a summary of Guiding Principles for Research Involving Animals and Human Beings, please see www.the-aps.org/mm/Publications/Ethical-Policies/Animal-and-Human-Research.

**Instructions**

**Preparation.** First, groups should gather equipment and material for notes. Each group should select a volunteer student that should keep their index fingers (experiment 1) and/or arms (experiment 2) visible (without garment sleeves) and do the procedures according the following instructions. Another student should be responsible for making notes about the observations. Models of the data sheets for experiments 1 and 2 are shown in Tables 1 and 2, respectively. No additional preparation is required.

Experiment 1: alterations in arterial blood flow. In experiment 1, students should think about how to use a rubber band applied to one finger to observe changes on arterial circulation.

Students could use the following procedures:

1. The rubber band should be used on the index finger, clamping the finger around the base to occlude arterial blood flow (~2 min). Students can observe the changes during the occlusion.
2. Students should remove the rubber band and immediately observe the changes compared with the rest hand.
3. Students can determine the time required for the sensibility of the finger and skin back to their normal aspects.

The professor should guide the students’ discussions, including concepts that can help them to understand the results, such as the reactive hyperemia concept.

Experiment 2: alterations in venous blood flow. In experiment 2, students can observe alterations on the venous circulation using a sphygmomanometer and a stopwatch, using the following steps:

1. Place the sphygmomanometer on the right arm. Observe the forearm and hand skin and veins.
2. Inflate the cuff placed on the right arm up to 40 mmHg and observe for 3 min the color of the fingers and fingernails and the contour of the veins.

3. Deflate the cuff and immediately observe the changes for 1 min.

4. Pause for 3 min to allow blood flow to return to normal.

5. Inflate the cuff placed on the right arm up to 90 mmHg and observe for 3 min the color of the fingers and fingernails and the contour of the veins.

6. Deflate the cuff and immediately observe the changes for 1 min.

7. Determine the time necessary for the fingers and fingernails and the contour of the veins to return to normal.

The professor should guide the students’ discussions, guiding them to observe the different results between experiments 1 and 2 and why they occur.

**Experiment 3: alterations on blood circulation after physical activity.** In experiment 3, one student from each group should be invited to perform a rapid outside running exercise in the university campus (or in another available space, such as a stairway). The other students should observe, describe, and explain the alterations observed in the runner’s skin on their face, but they should also think about the distribution of blood to different tissues (the viscera, muscles, and skin) during the run.

The professor should guide the students’ discussions, emphasizing the active hyperemia phenomenon and discussing the differences between active and reactive hyperemia.

**Troubleshooting**

Some students could not tolerate the blood flow block. In this case, we suggest a change of the volunteer. Other students could tolerate a shorter time than stipulated in the instructions in some steps of the experiments. This is not a problem, because normally the alterations in blood flow occur in less time than recommended in the instructions.

**Safety Considerations**

Students with any of the following conditions should not be the volunteer subject:

1. Cardiovascular disorders
2. Neurological disorders

Students should be advised that should the sphygmomanometer cuff/rubber band pressure become painful, they should deflate and remove it from the arm/finger immediately and not wait until the end of the experiment stop time.

**RESULTS**

**Expected Results**

In experiment 1, the pressure caused by rubber band use in the index finger should result in whiteness of the skin and the subject should report formication and coldness compared with the rest hand. After the elastic is removed, the finger will become ruddy and warm/hot (reactive hyperemia).

Reactive hyperemia occurs after the blood supply is blocked by external pressure to a particular tissue over a short period of time; after the obstruction is released, the flow for this tissue increases by one-quarter to seven times for a few seconds. This phenomenon occurs due to the accumulation of vasodilator metabolites near the tissue (12, 23). The additional blood flow during reactive hyperemia corrects the tissue O2 deficit and removes the accumulated vasodilator metabolites (12). In this case, some minutes may be necessary for the fingers to come back to their normal color and condition.

In experiment 2, a moderate pressure of cuff inflation should promote finger and arm cyanosis (bluish discoloration of the skin), whitish nails, and well-defined boundary veins. This pressure promotes these alterations because the cuff pressure does not occlude the arterial inflow but does occlude the veins, preventing blood from flowing out of the hand and arm. Venous vessels are nearer to the body surface. Trapping blood in these vessels promotes bluish skin (23). In the case of
In your opinion, the performance of these practical activities was ____. Did the questions proposed for discussion contribute to increase your learning? Yes/No/Partly.

Would you consider the proposed activities easy to perform? Yes/No/Partly.

With this practice I can understand better:

In your opinion, did the proposed experiments contribute to your learning of:

- the arterial circulation in the index finger
- the concept of hyperemia
- the differences between arterial and venous circulations

The differences between active and reactive hyperemia: Yes/No/Partly.

The concept of hyperemia: Yes/No/Partly.

The differences between arterial and venous circulations: Yes/No/Partly.

Would you consider the contents worked on in the classroom? Yes/No/Partly.

Table 3. Questionnaire used in the assessment regarding student opinions about the practical activities

<table>
<thead>
<tr>
<th>Question</th>
<th>Possible Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. In your opinion, did the proposed experiments contribute to your learning of the contents worked on in the classroom?</td>
<td>Yes/No/Partly</td>
</tr>
<tr>
<td>2. With this practice I can understand better:</td>
<td></td>
</tr>
<tr>
<td>A. The differences between arterial and venous circulations</td>
<td>Yes/No/Partly</td>
</tr>
<tr>
<td>B. The concept of hyperemia</td>
<td>Yes/No/Partly</td>
</tr>
<tr>
<td>C. The differences between active and reactive hyperemia</td>
<td>Yes/No/Partly</td>
</tr>
<tr>
<td>3. Would you consider the proposed activities easy to perform?</td>
<td>Yes/No/Partly</td>
</tr>
<tr>
<td>4. Did the questions proposed for discussion contribute to increase your learning?</td>
<td>Yes/No/Partly</td>
</tr>
<tr>
<td>5. In your opinion, the performance of these practical activities was ____ (select as many options as you wish).</td>
<td></td>
</tr>
<tr>
<td>6. Were the instructions provided in the scripts easy to understand?</td>
<td>Yes/No/Partly</td>
</tr>
</tbody>
</table>

Evaluation of Student Work

At the end of the class, we asked to students to answer a questionnaire to evaluate the effectiveness of the proposed activities and report their contribution to learning (Table 3). Forty undergraduate students answered the questionnaire (19 students from nursing undergraduate courses and 21 students from physiotherapy undergraduate courses).

We found that the majority of students [95% (n = 38)] considered that the experiments were easy to perform and contributed to their learning of the theoretical concepts. Additionally, 100% (n = 40) of students understood the differences between arterial and venous circulations and the concept of hyperemia after performing the experiments. Furthermore, 98% to the students (n = 39) declared that the proposed questions for discussion contributed to increasing their learning.

Regarding the use of practical activities to reinforce theoretical concepts, 80% of the students (n = 32) considered them
interesting, 35% \( (n = 14) \) found them fun, and 84% \( (n = 33) \) stated that they prompted their curiosity and desire to understand more about cardiocirculatory physiology.

After the practical activity, students presented their results in a brief report. The different groups shared and discussed their observations; it was a good opportunity to observe the variability that can be found in a population.

In our experience, we worked with classes with \( \sim 40 \) students and organized them into small groups with 5 students. Each group received a copy of Tables 1 and 2 to use, if they wanted. Once they finished with the practical activity, students were instructed to discuss some questions (see the questions below in Inquiry Application).

Inquiry Application

The described experiments can be adjusted to fit any level of inquiry. In addition, students may be asked to design and perform additional experiments that could provide additional evidence showing that blood flow can adapt according to homeostatic demands.

Questions that students could be encouraged to answer and can be added in the laboratory report include the following:

**Question 1.** Why did the limb (arm) acquire a cyanotic aspect when the cuff was inflated in experiment 2 and, on the other hand, why did the limb (index finger) acquire a pallid aspect in experiment 1?

**ANSWER.** Because the cuff pressure used in experiment 2 (40–90 mmHg) was sufficient only to occlude the venous vessels (more surface), preventing the venous return (not affecting the arteries), causing an accumulation of \( \text{O}_2 \)-poor blood in this area and, hence, the purplish color. On the other hand, in experiment 1, the pressure caused by rubber band, although did not directly measured, was larger and sufficient to occlude the arteries and prevent arterial blood flow, causing whiteness.

**Question 2.** What changes could be observed after the release of blood flow in experiment 1?

**ANSWER.** Redness and warmth of the skin could be observed as a result of the increased blood flow in response to a previous occlusion of the arterial circulation in that limb (reactive hyperemia; see **ANSWER in question 1**).

**Question 3.** Why in the case of a fight can our skin become pale?

**ANSWER.** This is the fight-or-flight response, mediated by the sympathetic nervous system. This response guarantees that the blood of superficial tissues can be redirected to more important places for this specific situation (skeletal muscles, for example).

**Question 4.** What is the purpose of the blood flow alterations perceived in the physical exercise practice (experiment 3)?

**ANSWER.** Redness in the skin of the face was observed, which is related to the thermoregulatory role of skin blood flow. In addition, active hyperemia occurs during exercise to promote a greater supply of \( \text{O}_2 \) to muscle tissue required during the activity and is mediated by local metabolites and sympathetic nervous system and hormonal responses (epinephrine).

Wider Educational Applications

Regardless of the inquiry level, this exercise allows students to perceive the presence of physiology in their daily lives, making students understand concepts related to the cardiovascular system that could be difficult for educators teach in theoretical classes (20).

According Wu et al. (26), the learning process should emphasize constructivism, i.e., students should have an active role and, together with the teacher/professor, should enhance their knowledge through experiences and interactions with the environment, building their own arguments and conclusions. In this sense, practical classes can help in the development process of scientific concepts and allow students to learn how to objectively approach their world and how to develop solutions to complex problems (16). When teachers involve students in the teaching-learning process, giving them an active role, students have more realistic views about what they are learning (15, 18).

Additional Resources

For additional information on this topic, please see Refs. 2, 12, 14, 21, 23, and 24.

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GRANTS

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DISCLOSURES

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

AUTHOR CONTRIBUTIONS


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