Cold pressor test using strain-gauge plethysmography

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Feliciani G, Peron C, La Rocca A, Scuppa MF, Malavolta A, Bianchini D, Corazza I, Zannoli R. Cold pressor test using strain-gauge plethysmography. Adv Physiol Educ 40: 410–417, 2016; doi:10.1152/advan.00096.2015.—This laboratory activity is designed to teach students how to measure forearm muscle blood flow (FBF) to describe the mechanisms of peripheral blood flow thermal regulation in healthy subjects. The cold pressor test (CPT) is the clinical procedure used in the experiment to induce arterial vasoconstriction. Strain-gauge plethysmography is applied on the patient’s forearm to noninvasive monitor vasoconstriction effects on local blood perfusion and physiological parameters such as blood pressure (BP) and heart rate (HR). Patients with an altered peripheral vascular resistance (e.g., in hypertension) have different responses to the CPT from healthy subjects. To date, experimental evidence remains unexplained, as we do not know if the BP and HR increase is caused by a decrease in flow rate or an increase in peripheral vascular resistance during the test. To clarify this situation, we have to quantify the parameter we assume is being conditioned by the regulatory physiological intervention, i.e., peripheral vascular resistance. Peripheral vascular resistance quantification can be calculated as the ratio between muscle flow and mean arterial pressure. Students will learn how to apply the instrumental procedure to collect and analyze data before, during, and after the CPT and to describe the physiological responses of the peripheral vascular system to external stressors. They will also learn how to distinguish healthy from pathological responses on the basis of how sympathetic nervous system reactions influence the biomechanics of peripheral vessels.

Cold pressor test; hypertension; strain-gauge plethysmography; vasoconstriction

PAINFUL COLD is a minimally invasive sympathoexcitatory stressor used in clinical practice to induce changes in cardiovascular parameters such as heart rate (HR) and blood pressure (BP) (8). These changes are caused by sympathetic nervous system intervention and are usually used to screen diseases like hypertension by monitoring the effects on the heart (HR) and the vascular system (vascular resistance and venous tone) (6, 7, 14, 19). The cold pressor test (CPT) is performed by immersing the hand in ice water and measuring arterial BP and HR. The basic assumption is that the BP increase during the test is due to autonomic nervous peripheral arteriolar vasoconstriction. The patient’s test response might be clinically indicative of some functional (hypertension) or anatomical (5, 13, 18) vascular condition. A direct relationship between changes in BP and peripheral arterial vascular resistance is possible only if peripheral blood flow perfusion is constant. This situation is not guaranteed during the CPT when only HR changes are observed, so the assumption that the BP change is the consequence of arterial vasoconstriction is not obvious. If we want to describe the CPT scientifically, we must measure peripheral blood flow perfusion. This can be accomplished by forearm strain-gauge plethysmography. Furthermore, it is important for students to understand the difference between pain tolerance, which is the maximum level of pain that a person is able to tolerate, and the pain threshold, which is the point along a curve of increasing perception of a stimulus at which pain begins to be felt. Indeed, the pain threshold is a substantially subjective phenomenon.

The objective of the present study is to show students with a good background in cardiovascular physiology, thermoregulation principles, basic physics, and an interest in “hands-on” experiments the application of a scientific method to physiological procedures of signal monitoring and acquisition to:

1. Support the objectives of learning key vascular physiology concepts, integrating neural control, and thermoregulation concepts.
2. Develop essential diagnostic skills.
3. Develop scientific inquiry, data analysis, and reporting skills.

Our method is an improvement on the technique previously reported in Ref. 10 based on the use of strain-gauge plethysmography to noninvasive monitor the physiological response of the peripheral vascular system in healthy subjects undergoing a CPT (3, 20). Venous occlusion strain-gauge plethysmography is a technique to monitor forearm muscle blood flow (FBF) by measuring arm circumference changes during venous occlusion. It may also measure venous compliance and venous tone to monitor CPT-induced vascular regulation (3, 16). A description of the physical basis of strain-gauge plethysmography is given below, and other applications can be found in Refs. 4, 12 and 17. Data collected with this technique give a general overview of the behavior of the peripheral vascular systems and related underlying mechanisms that serve as examples to understand the basic physiology of cardiac and sympathetic nervous system reactions to external stimuli.

CPT and venous occlusion strain-gauge plethysmography were also chosen because they combine a straightforward physiological description with noninvasive monitoring and low-cost instrumentation. Arteriolar vasoconstriction is stimulated by painful cold to allow the body to preserve a physiological baseline temperature of 36–37°C.

Physiologically, arteriolar vasoconstriction is directly proportional to the frequency of impulses originating from the orthosympathetic nervous system, which releases norepinephrine on the α1-adrenergic receptors expressed on vascular smooth muscle cells. The peripheral stimulus, in this case cold,
is registered by afferent nerves and then communicated to the preoptic area of the anterior hypothalamus. This specific area of the brain will then modify the basal activity of the sympathetic nervous system situated in the spinal cord.

Background on the Strain-Gauge Plethysmography Technique

Venous occlusion strain-gauge plethysmography is a noninvasive practical and low-cost tool to assess FBF (in ml·100 ml⁻¹·min⁻¹) (1, 9, 15). The patient is placed in a supine position on a bed with the arm slightly elevated with respect to the body. Measurements can be performed by a thin water-, mercury-, or gallinstan-filled silicone tube (strain gauge). The underlying principle of the technique is that occluding venous arm drainage by applying a pressure lower than diastolic arterial pressure (i.e., 40 mmHg) in a cuff surrounding the raised arm for a short period of time (5–10 s), arterial inflow is almost unaltered and blood can enter the forearm but cannot escape, resulting in a linear increase in forearm volume. The volume increase rate can easily be monitored by applying a circumferential strain gauge to the arm. The slope of the circumferential signal change is proportional to FBF and can easily be measured.

Brief excursus on inflating the pressure cuff and patient setup. The inflatable cuff used to stop the venous return must be longer than the arm circumference to close all the venous drainage by applying a pressure lower than diastolic arterial pressure. The inflatable cuff used to stop the venous return must be longer than the arm circumference to close all the venous drainage by applying a pressure lower than diastolic arterial pressure (i.e., 40 mmHg) in a cuff surrounding the raised arm for a short period of time (5–10 s). The cuff must be inflated to a pressure lower than the diastolic arterial pressure in the arm. If we want to refer to the flow (in ml/min) for 100 ml of muscle, and we measure the closure time (in mm) on the graph with respect to baseline, by applying the following rule:

\[
\text{Cal}(V) = l - H(V) \times \Delta C(V)
\]

FBF is the arm volume change divided by the closure time. Hereafter, closure time is referred to as the time that elapses between the closure of venous return coinciding with the moment in which the strain gauge starts to elongate from baseline (as shown in Fig. 2) and the peak of the gauge variation slope that occurs in the instant of release of the pressure in the arm cuff. If we want to refer to the flow (in ml/min) for 100 ml of muscle, and we measure the closure time interval (\(\Delta t\)) on the graph in Fig. 2 in seconds, the final formula is as follows:

\[
\text{FBF} = \frac{\Delta V}{V} \times \frac{60}{\Delta t} = \frac{\Delta C \times 60}{C \times \Delta t} = \frac{H(\Delta t)}{C \times \text{Cal}} \times \frac{60}{\Delta t} = K \Delta t \text{ ml·100 ml}^{-1} \cdot \text{min}^{-1}
\]

From the above formula, it is obvious that changes in FBF are shown by a change in the signal slope, as shown in Fig. 3. With this setup, we can monitor FBF during a provocative test such as immersion of the contralateral hand in ice water. The hand immersion activates the response of the nervous system, resulting in arterial vasoconstriction. If we assume no central effect (constant HR and cardiac output), the BP changes detected are exclusively due to the mechanism of peripheral arterial regulation. This mechanism operates differently in normal subjects, borderline hypertensive subjects, hypertensive patients, and in some pathological conditions (heart failure syndrome). However, raised HR and BP are recorded during the CPT, and students should reason about the interaction of these three mechanisms operating simultaneously.

Objectives and Overview

Learning objectives. After the completion of this activity, students will be able to:

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Time required. Approximately 20 min is required for subject preparation, ECG electrodes, pressure cuffs, and forearm strain-gauge application. Computer connections as well as calibration and baseline physiological measurements will take 15 min. After that, the CPT can be initiated by immersing the subject’s hand in a pan containing ice and water for a maximum time of 5 min. During this time, the measurements performed in baseline conditions are repeated. An extra 10 min are required for the subject to return to basal physiological conditions. During this time, the measurements are repeated again. The data collected (~30 min of continuous recording) can be processed in an informatics laboratory in ~1 h, and another 30 min can be spent answering questions on the technical procedural, physical, or physiological aspects, depending on the number of students. The recommended time for the entire activity is ~3 h, depending on the number of students, and can be divided into two sessions, one session for data sampling and one session for data analysis.

METHODS

Equipment Required

The following equipment is required for this activity:

1. Any commercial equipment for BP and HR measurements (oscillometric or auscultatory). Oscillometric is preferred because it is operator independent.

2. A venous closure, low-pressure cuff of adequate length and width. This cuff may be inflated manually acting rapidly by a hand pump and reading the pressure on a manometer or using a rapid inflator (not mandatory for this activity), as shown in Fig. 3. In this case, pressure is generated by the laboratory’s oxygen or air source, connecting the cuff in parallel with an output pipe immersed in water. The air pushing against the column of water, whose hydrostatic pressure (P) is \( P = \rho gh \) (where \( \rho \) is the density of the liquid, \( g \) is the acceleration due to gravity, and \( h \) is the height of the column of liquid), fills the cuff at the same pressure, easily adjustable by changing the immersion depth of the pipe, as shown in Fig. 4.

3. A hand perfusion cuff closure, to be applied on the wrist, 250 mm long and 50 mm wide, connected to one hand.

4. An adequate volume container, half filled with water and ice (50%), to reach a temperature of ~41–46.4 °F (5–8°C).

5. Pressure transducers to monitor pressure values in the low-pressure inflatable cuff and in the wrist cuff. For this activity, an electronic pressure transducer is not necessary—a mechanical one is adequate—but for more accurate and future measurements, an electronic system with analog output is useful.

6. Strain gauges (homemade or commercial) channel and a signal acquisition chain for accurate forearm circumference measurements. This is the most delicate instrument, with a measurement range of 5 mm and a sensitivity of 0.1 mm. Further details on acquisition systems and venous occlusion strain-gauge plethysmography can be found in Refs. 2 and 16.

7. A multichannel workstation for strain gauge, ECG, and pressure analog signal acquisition, recording, and analysis.

Human Subject Approval

Every procedure described in this laboratory activity is considered noninvasive under Italian law. Adopters of an activity are responsible for obtaining permission for human or animal research from their home institution. For “Guiding Principles for Research Involving Animals and Human Beings,” please see www.the-aps.org/mm/Publications/Ethical-Policies/Animal-and-Human-Research.

Instructions

Subjects undergoing the test should not:

1. Be smokers

2. Have vascular diseases

3. Drink alcohol or caffeine during the hours before the experiment.
to include the hand circulation. Signal recording is activated, and the calibration line shifts are recorded. The venous closure phase is started by inflating the venous cuff at 40 mmHg, and deflection of the gauge signal is observed on the screen. The closure pressure lasts 10 s, and the arterial pressure is measured. The cuff is then deflated, and the gauge signal returns to baseline with an exponential decay. After waiting 20 s, the closure, pressure measurement, and opening are repeated twice. If the quality and slope of the gauge signals are acceptable, the procedure moves on; otherwise, the previous steps are repeated until a satisfactory condition is reached.

**Step 10.** Staying in the recording condition, the subject’s hand is immersed in the cold water reservoir, and the process of venous cuff inflation, arterial pressure measurement, and cuff deflation is repeated each minute for 5 min. Gauge, ECG, and pressure signals are continuously recorded.

**Step 11.** When the test phase is complete (maximum of 5 min), the hand immersed in cold water is extracted, wiped, and covered with warm tissue. The wrist cuff is deflated, and the subject is left calm for 5 min. The wrist cuff is then reinflated, and flow measurements are repeated to obtain signals toward the basal condition. Finally, calibration signals are recorded, the recording is stopped, the cuffs, electrodes, and gauge are removed, and the subject is discharged.

### Calculations (Steps 12–17)

**Step 12.** The recorded signal file is displayed on the computer screen to locate the calibration, basal, test, and recovery phases. The horizontal time base and vertical amplitude are regulated to have an optimal reproduction of the gauge signals on the screen.

**Step 13.** The calibration phase is centered on the screen and printed on paper. On the printout, the gauge signal (Cal deflection; in mm) is measured, and the constant of the FBF formula (K) is calculated.

**Step 14.** The basal signal phase is centered on the screen and printed on paper. On each gauge signal, the baseline is noted in pencil, and H(Δt) (in mm) is measured at an interval of Δt (in s) from the cuff closure. The measured values are introduced into the formula, and FBF is calculated. Maximal arterial pressure (Pmax), minimal arterial pressure (Pmin), and HR are noted in pencil on the paper. PM is calculated as PM = Pmin + (1/3)(Pmax − Pmin) and noted.

**Step 15.** Step 13 is repeated for the “test phase” and for the “recovery phase.”

**Step 16.** For each FBF measurement, the arterial vascular resistance (Mk) of 100 ml of muscle is calculated as the ratio of Pm and FBF. All measured and calculated values of HR, Pmax, Pmin, PM, FBF, and Mk are stored in a table.

**Step 17.** The stored values are then graphically depicted on a time basis.

### Safety Considerations

Some equipment used for the measurements is electric, so attention should be paid during the CPT acquisition phase due to the presence of water. To avoid problems, instruments should be battery operated.

### Troubleshooting

The main issue during the procedure is the correct and stable application of the strain gauge on the subject’s forearm, at an adequate distance from the venous closure cuff. The gauge must be slightly extended to be in contact with the skin surface and should not move during the arm volume change. Correct gauge operation can be ascertained by observing the signal on the screen during venous closure: it has to increase in a linear way, as in the examples shown in Figs. 2, 3, and 5. Especially at the start of the rising part of the curve, no artifacts or shoulders in the signal should be present. The main measurement errors are the strain gauge too tight or too loose, venous closure cuff of an inappropriate size, or venous closure cuff too tight or too loose. Even if the arm of the subject is approximated...
to a cylinder, it is appropriate to put the strain gauge in the widest part of the arm to maximize the signal coming from capillary compartment expansion. The measurement of the limb should be performed at the same time of the application of the strain gauge to avoid variations due to subject position or temperature differences among different rooms. Secondary errors may arise from the following causes: inter-individual differences in people with obesity, muscle tremor, lower ejection fraction, or lower limb swelling.

Students should always emphasize with the subject undergoing the procedure, asking about their sensation, in particular:

1. In case a subject reports intolerable pain at the immersed hand during the CPT, it is better to stop the procedure immediately and let the subject relax for some minutes. Even if every one of our healthy subjects were able to endure the pain related to the immersion of their hand in cold water for 5 min without major difficulties, for some susceptible subjects it might be useful to try to accelerate the procedures or stop them in case of complain.

2. Students should also pay attention to the tightness of the cuff to avoid sufferance by the patients during FBF acquisition.

RESULTS

During step 2 after the setup phase of the equipment (step 1), students are expected to observe the subject’s baseline parameters, noting their consistency within physiological variability. In particular, it is expected that no variation be present at rest in patient arm circumference except for involuntary movement. During FBF measurements, the same slope in circumference variation recordings is expected. Examples of FBF calculated from Eq. 3 are shown in Fig. 6.

After the subject’s hand is immersed in cold water (CPT start in Fig. 7, left), an evident decrease in arm ΔV due to peripheral vasoconstriction induced by the sympathetic nervous system is detected by the gauge and the signal baseline is shifted down until a new stable condition is reached (Fig. 7, bottom). FBF will decrease in the meantime, and the slopes of the gauge signal during venous closure will change. At the same time, students will notice a change in HR and BP from oscillometric or manual measurements.

Evaluation of Students’ Work

Students should process data as outlined in the RESULTS. In particular, they should measure the slope of the gauge signal during venous closure and calculate FBF using Eq. 3 for all phases of the experiment and plot results, as shown in Fig. 6. This allows them to check if the baseline measurements are accurate and follow their variations during the CPT and also to evaluate mean FBF and its SD. Hence, they apply the scientific method to decide if one FBF measurement (i.e., during the CPT) differs from another within experimental errors. Finally, they should calculate from FBF and pressure measurements the variation in MR.

Questions for the Laboratory Report

Question 1. Which venous cuff pressure should not be exceeded during FBF measurement? Why? Diastolic BP should not be exceeded; otherwise, an occlusion in the arteriolar compartment will occur, and blood flow will stop (even if temporarily). Moreover, occlusion pressure should be maintained at a value as low as possible to stop venous blood flow without changing arteriolar flow too much. Any cuff pressure reduces the arterial transmural pressure, but these effects can be considered negligible for low occlusion...
pressures. Students can determine the optimal occlusion pressure experimentally.

**Question 2. Why are FBF measurements in one condition repeated at least two or more times?** Students should recall the scientific method and describe strain-gauge plethysmography as a technique to measure blood flow perfusion. Result variability depends on the subject’s physiological instability, correct application of the technical procedure, and instrumental sensitivity. To evaluate this variability, the FBF measurement is performed at least four times in the basal condition to know the accuracy associated with the results and to evaluate its suitability to monitor FBF changes due to an external stressor, such as the CPT.

**Question 3. What conclusions can be drawn from the comparison of mean arterial changes, FBF, and vascular resistance changes?** Normally, the CPT is used as a stressor to activate peripheral arterial vasoconstriction, demonstrated by an increase in arterial pressure ($P_{\text{max}}, P_{\text{min}},$ and $P_m$). The direct relationship between arterial pressure and arterial vascular resistance is valid only for the $P_m$ value and under the assumption of stable cardiac output during the test. If HR changes, the assumption of a constant cardiac output is very questionable. The FBF measurement vascular arterial resistance calculation allows arterial vasoconstriction to be quantitatively correlated with the $P_m$ change and verify if there is a linear correlation or not.

**Question 4. How and why do different stimuli, for example, a thermal stimulus, change the diameter of blood vessels?** Your answer should take into consideration the nervous system’s anatomy and physiology and analyze the role of the hypothalamus preoptic area. Afferent nerves are in charge of communicating the specific information of the external stimuli to the preoptic area of the hypothalamus. Depending on the nature of the stimuli involved, the preoptic area of the hypothalamus is then able to modulate the activity of the orthosympathetic nervous system and therefore modulate its control on smooth muscle cells.

**Question 5. For which patients would you use strain-gauge plethysmography to monitor FBF and arteriolar resistances?** Strain-gauge plethysmography can be used to monitor borderline hypertension in healthy subjects but used with familiarity for cardiovascular pathologies.

**Inquiry Application**

This activity is designed for second-year medical students. It is advisable for students to follow a technical procedure protocol in the presence of a supervisor so as not to introduce too many biases.

To increase the inquiry level, students can:

- Repeat the activity by applying strain gauges to the lower limbs. This is done to observe if the same changes in vascular resistances occur in other peripheral districts under the same conditions during the CPT.
- Monitor FBF variations in rapid sequence during the CPT. The time required for peripheral resistances to respond to the external stressor can be monitored following the reduction in FBF after immersion of the hand into cold water. Using the ratio between $P_m$ and FBF, an estimation of peripheral resistance can be calculated during the CPT. By plotting resistance values against time and interpolating values with a curve, a time constant can be extracted for each patient. A comparison of time constants between healthy subjects and hypertensive subjects can be performed.
- Modify the stressor, for example, by using a hot source or switching temperatures between hot and cold. In fact, some pain threshold studies have suggested that the hot water immersion test might be a better suited model to study tonic pain (11).

**Conclusions**

The aim of this activity is to introduce medical students to the application of the scientific method in a simple clinical physiological test, the CPT, with procedural aspects, signal acquisition, processing, and interpretation of results. The procedure stimulates students to recall and use basic physiology principles of the vascular system, such as vasoconstriction and vasodilatation under stimulation of the sympathetic nervous system, leading to:

- Central HR and BP changes
- Arteriolar vasoconstriction or vasodilatation with consequent changes in peripheral perfusion

All these events can be quantitatively recorded and analyzed by the students. After the accomplishment of this exercise, students can be stimulated to go further and introduce the measurement of vessel compliances. This measurement introduces new variables inside the experiment using the very same setup. However, the decaption of the behavior of vessel compliances in the baseline condition and under the CPT is beyond the scope of the present report, and it will be discussed in detail in a further work.
Finally, this procedure can be applied in clinical research protocols to noninvasively monitor the progression of vascular disease.

APPENDIX: THEORETICAL EXCURSUS ON THE RELATIONSHIP BETWEEN STRAIN-GAUGE MEASUREMENTS OF FOREARM CIRCUMFERENCE AND FBF

As previously stated, strain gauges noninvasively register small variations in the circumference of a subject's arm (ΔC) during venous occlusion. To link these measurements to forearm volume changes and blood flow perfusion (FBF), some hypotheses should be stated:

1. The arm is approximated to a regular cylinder (Fig. 1) with no significant variations along the axis during the measurement.
2. Pressure in the cuff is rapidly raised to a value (Pv ≈ 40 mmHg) to occlude the venous return network. The relaxed arm is assumed to be a fluid-filled cavity, applying the Pascal principle, and the external cuff pressure is transmitted to the deepest tissues with no reduction.
3. The short-lasting venous return blockage does not reduce blood flow from the arteries and entering the capillary compartment, expanding the arm volume by a quantity (ΔV). (The hand circulation is excluded by a wrist cuff inflated to a pressure higher than the maximum arterial value.)

Under these conditions, to obtain the relationship between the arm circumference change and the volume change rate (FBF), we can refer to Fig. 1, which shows the complete setup.

Here, we have two cuffs: one cuff to close the venous return (40 mmHg) and the other cuff to exclude the hand circulation (>150 mmHg) as well as a strain gauge applied to the arm circumference. When the venous cuff is inflated, the volume of the forearm increases, as does the resistance of the gauge, and a graph is shown on a computer screen. Knowing that the arm volume change rate (muscle blood inflow) and the arm circumference change are proportional, and by applying a small calibration shortening on the gauge, the volume rate of change (muscle flow) can be calculated as follows:

\[
\Delta V = V_{\text{fin}} - V_{\text{in}} = \pi (r + \Delta r)^2 - \pi r^2 = 2 \pi r \times \Delta r \times l
\]

\[
\Delta C = C_{\text{fin}} - C_{\text{in}} = 2 \pi (r + \Delta r) - 2 \pi r = 2 \pi \Delta r
\]

\[
\frac{\Delta V}{\Delta C} = \frac{2 \pi r \times \Delta r \times l}{2 \pi \Delta r} = \frac{r \times l}{\frac{\Delta C}{C}}
\]

To correlate the readings on the graph to the change in arm circumference (ΔC), we can measure the arm resting circumference (C) in the position of the gauge and apply a known gauge lengthening (L; i.e., 2.5 mm), as shown in Fig. 2. The square-shaped calibration signal [Cal (in V)] related to the known elongation [L (in mm)] is used to convert forearm circumference variations from volts to millimeters. We can obtain the instantaneous circumference changes by reading the line shift (in mm) on the graph with respect to baseline, by applying the following rule:

\[
\frac{\text{Cal(V)}}{L} = H(V) \cdot \Delta C(mm)
\]

\[
\frac{\Delta C(mm)}{\text{Cal(V)}} = H(V) \cdot \frac{L(mm)}{\text{Cal(V)}}
\]

FBF is the arm volume change divided by the closure time. Hereafter, closure time is referred to the time that elapses between the closure of venous return coinciding with the moment in which strain gauge starts to elongate from baseline shown in Fig. 2 and the peak of the gauge variation slope that occurs in the instant of release of the pressure in the arm cuff. If we want to refer the flow (in ml/min) for 100 ml of muscle, and we measure the closure time interval (Δt) on the graph in shown Fig. 2 (in s), the final formula is as follows:

\[
\text{FBF} = \frac{\Delta V}{\Delta t} = 2 \frac{\Delta C}{C} \frac{60}{\Delta t} = 2 \frac{H(\Delta t) \times L}{C \times \text{Cal}} \frac{60}{\Delta t}
\]

\[
= \frac{KH(\Delta t)}{\Delta t} (\text{ml} \cdot 100 \text{ ml}^{-1} \cdot \text{min}^{-1})
\]

From the above formula, it is obvious that changes in FBF are shown by a change in the signal slope, as shown in Fig. 3.

With this setup, we can monitor FBF during a provocative test like immersion of the contralateral hand in ice water. Hand immersion activates the response of the nervous system, resulting in arterial vasoconstriction. If we assume no central effect (constant HR and cardiac output), the BP changes detected are exclusively due to the mechanism of peripheral arterial regulation. This mechanism operates differently in normal subjects, borderline hypertensive subjects, hypertensive patients, and in some pathological conditions (heart failure syndrome). However, raised HR and BP are recorded during the CPT, and students should reason about the interaction of these three mechanisms operating simultaneously.

DISCLOSURES

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

AUTHOR CONTRIBUTIONS


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