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Original Article

A Novel Practical to Demonstrate Systemic and Local Regulation of Circulation in A Human Subject

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Abstract

Purpose of the study: Systemic and local regulation of peripheral circulation is a vital concept to be taught to undergraduate medical students. There is lack of an effective practical module to demonstrate and reinforce the theoretical understanding of this concept.

Methodology: We designed a simple feasible novel practical using finger pulse recording coupled with hand grip test and reactive hyperemia protocol to elicit systemic and local regulation of peripheral circulation respectively.

Main findings: The reduction in finger pulse amplitude during hand grip contralateral to the exercising hand demonstrates systemic regulation while the isolated ipsilateral increase in finger pulse amplitude during reactive hyperemia demonstrates local regulation.

Conclusion: Here we propose a simple novel practical for effective demonstration of systemic and local regulation of circulation for under-graduate teaching in physiology.

Introduction

Physiology of cardiovascular system (CVS) constitutes an important portion of undergraduate teaching curriculum that comprises of about 17-25 didactic lectures dedicated to its understanding in most medical schools (1-3). However, practical sessions focusing on this system are limited. The purpose of practical teaching in medical schools is not only to impart new psycho-motor skills but also to reinforce the understanding of theoretical concepts (4). The cognizance of the concept of systemic and local regulation of circulation is a crucial component of MBBS teaching and additionally indispensable for its actual application in clinical setting by the medical graduate. Reviewing the course syllabus prescribed by Medical council of India and various health sciences' universities (1-3) across the country, we found that physiology practical teaching modules lack experiments that demonstrate systemic and local regulation of peripheral circulation.

Photoplethysmography (PPG) is a widely available, simple, cheap and sensitive optical measurement

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technique for recording blood volume changes in microvasculature (5). Additionally, it has been observed that the PPG pulse amplitude changes during reactive hyperemia (RH) mimic the flow mediated vasodilatation in the proximal conduit arteries (6, 7) and the reduction in PPG pulse amplitude during hand grip test (8) represents the sympathetically mediated vasoconstriction. Therefore, we aimed to design a comprehensible, feasible and instructive experimental paradigm based on combined usage of both these phenomena using PPG to demonstrate the important physiological principles underlying local and systemic regulation of cardiovascular system to undergraduate MBBS students.

Materials and Methods

Materials required

The equipments required for this practical exercise include at least one (preferably two) reflection or transmission type near- infra red photoplethysmography (PPG) probe for measuring blood volume changes, an analog or digital polygraph with an amplifier gain of 100 for recording, a sphygmomanometer to measure blood pressure of the subject and also to produce arterial occlusion during reactive hyperemia (RH) protocol and finally a hand grip dynamometer for isometric exercise during the hand grip test (HGT).

Experiment Protocol

I) **Specific learning objective 1:** To demonstrate the neurally mediated systemic control of circulation by recording the changes in PPG pulse amplitude from middle finger in response to contra-lateral hand grip at maximum voluntary contraction (MVC) for 30 seconds.

Principle: Central command associated with handgrip stimulates sympathetic outflow from vasomotor centre to systemic vasculature leading to vasoconstriction. Vasoconstriction in the digital vessels will be recorded as reduction in PPG pulse amplitude.

Procedure:

1. Make the subject sit down comfortably keeping both the forearms supported over the table in front. Measure MVC in the dominant hand using handgrip dynamometer. Mark the MVC value using a marker and instruct the subject to apply required grip force to maintain the pointer at this value when he is instructed to.

2. Attach PPG probe snugly to the contralateral middle finger without applying undue pressure to avoid compression of vessels.

3. After 5 minutes of rest, start acquisition of the baseline PPG signal for one minute duration. The experiment has to be performed in a temperature controlled environment (22-25°C) in sitting posture and the subject should be instructed to breathe spontaneously, refrain from taking deep inspiration and expiration to avoid baseline shifts in PPG signal and avoid movement of hand to which PPG probe is attached to prevent motion artifacts.

4. Ask the subject to apply the required amount of grip force to maintain the pointer at previously marked MVC value for 30s while continuing the acquisition of PPG signal.

5. Measure the average amplitude of PPG signal for consecutive 6 to 7 beats (to smoothen the respiratory induced fluctuations) (9, 10) at baseline and at the visually identified phase of reduced PPG amplitude following hand grip (Fig. 1). PPG pulse amplitude is estimated as the magnitude of the difference between signal voltage at the peak and signal voltage corresponding to the foot of each PPG pulse waveform (7).

6. Quantification of response can be done by calculating percentage change in amplitude from baseline. It can be computed by using the formula given below :

$$\frac{\text{(Minimum pulse amplitude during HGT} - \text{Baseline PPG pulse amplitude)} \times 100}{\text{Baseline PPG pulse amplitude}}$$

(EMG from forearm flexor muscles has been recorded along with PPG in the recordings presented here for showing temporal relationship between onset of contraction and changes in pulse amplitude)

II) Specific learning objective 2: To demonstrate the local regulation of circulation by recording the changes in PPG pulse amplitude from middle finger during ipsilateral post-arterial occlusion reactive hyperemia.

Principle: Arterial occlusion produces locally mediated vasodilatation through myogenic and metabolic mechanisms which translate into increased blood flow post release of occlusion and consequent changes in conduit vessel diameter which can be recorded as pulse amplitude increase in PPG signal.

Procedure:

1. Make the subject sit down comfortably with both upper limbs lying by the side of the body and forearms supported over the table in front. Apply PPG probes to the middle fingers of both right and left hand (apply to any of the hands in case of non-availability of 2 probes).

2. Measure the blood pressure by sphygmomanometry in the arm where the occlusion has to be performed and keep the cuff fastened to the arm after deflation.

3. Start the baseline recording of PPG signal after 5 minutes of rest in sitting posture following all precautions previously mentioned with the hand grip experiment.

4. After 1 minute of baseline recording, increase the cuff pressure to 50 mm Hg above the previously recorded systolic blood pressure (11). Complete arterial occlusion can be ensured by checking for the disappearance of pulse waveform and demonstrating this would be of additional instructive value for the students.

5. After 5 minutes of occlusion (11) release the cuff pressure and continue recording the PPG signal for a duration not less than 3 minutes.

6. Compare the averaged maximum PPG pulse wave amplitude (averaged for 6 to 7 consecutive beats as mentioned previously in hand grip experiment) during RH with the baseline of the same side. Similar comparison can be performed on simultaneously recorded values of the contralateral hand if available (Fig. 1).

7. Quantification of response can be done by calculating percentage change in amplitude from baseline. It can be computed by using the formula given below :

$$\frac{(\text{Maximum pulse amplitude during RH} - \text{Baseline PPG pulse amplitude}) \times 100}{\text{Baseline PPG pulse amplitude}}$$

Results

The representative records of PPG responses during hand grip and reactive hyperemia protocol are shown in Figure 1B and 1D respectively. PPG amplitude changes correspond to blood volume changes in finger microvasculature during the maneuvers.

The PPG responses recorded during both the maneuvers are consistent and reproducible. Average time required for setting up and demonstrating this experiment is expected to be around 1 hour 30 minutes and the remaining time can be utilized to interpret the results and discuss the underlying cardiovascular mechanisms.

Discussion

The present paper proposes an innovative teaching experiment to demonstrate the important concept of systemic and local regulation of peripheral circulation using finger pulse recordings. Using this simple practical demonstration module, students can easily understand and compare the systemic vasoconstrictor response during hand grip versus locally mediated vasodilatory response in ipsilateral occluded arm during reactive hyperemia. Quick vasoconstrictor response to hand grip reiterates the neural nature of

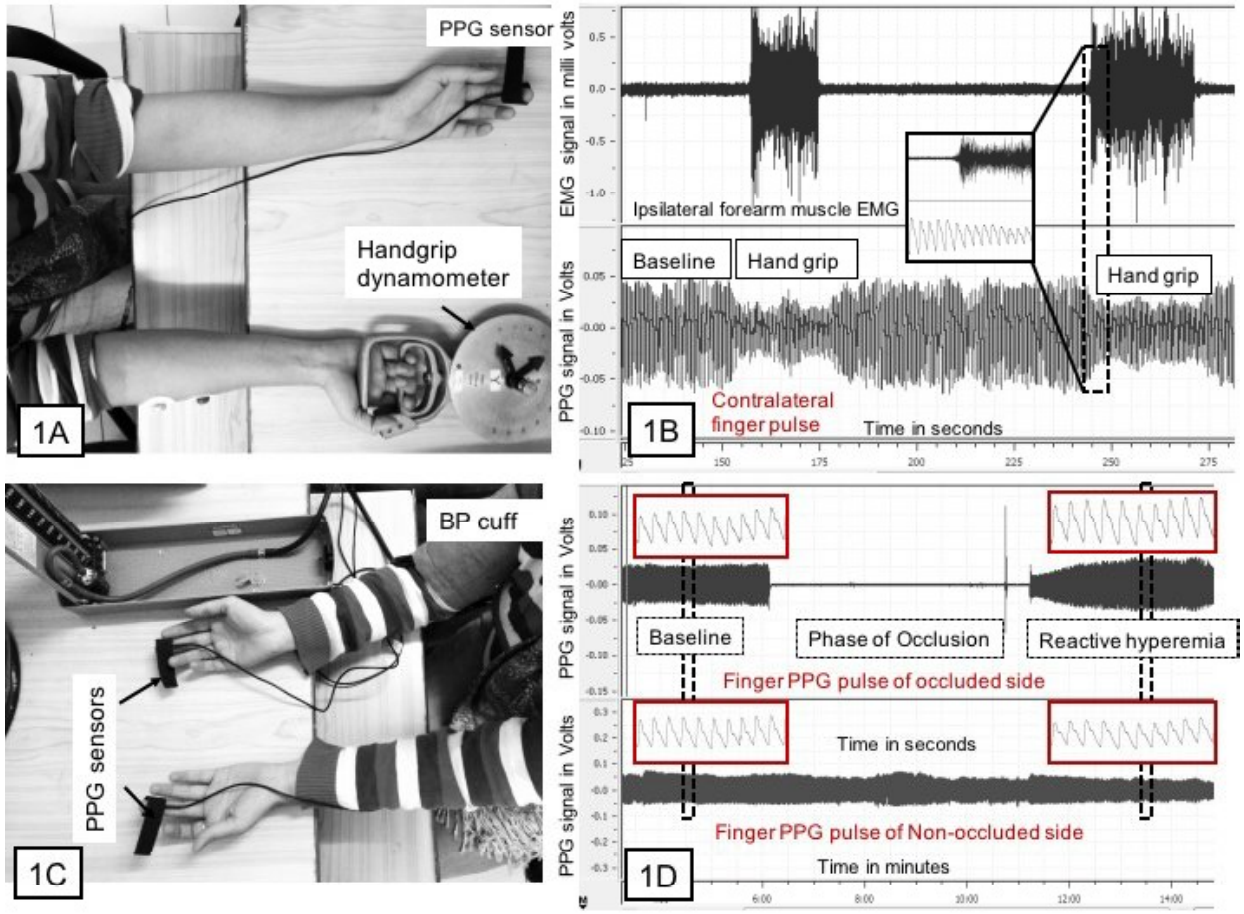

Fig. 1 : Depicts the procedure and recording of hand grip maneuver and reactive hyperemia protocol. 1A - depicts the set up for hand grip maneuver with MVC contraction of dominant hand using hand grip dynamometer and recording of PPG from contralateral middle finger. 1B - depicts the recording of two consecutive hand grip maneuvers with increase in EMG activity above the baseline on first channel during the hand grip. Second channel depicts the corresponding changes in PPG amplitude which decreases consistently during hand grip. 1C - depicts the set up for reactive hyperemia with BP cuff on one arm to produce arterial occlusion and bilateral PPG probes for recording. 1D - depicts the recording during RH. First channel is recording of PPG from ipsilateral occluded arm where there is disappearance of pulse during occlusion and an increase in PPG amplitude post-occlusion while the second channel depicts PPG from contralateral arm where these changes are not observed.

Abbreviations: MVC - Maximum Voluntary Contraction; PPG - Photoplethysmography; EMG - Electromyography; BP - Blood Pressure; RH - Reactive Hyperemia

response due to direct sympathetic excitation of vasculature and excludes mediation by the transport of any chemical mediator through circulation from the contralateral side. Similarly, absence of response in the contralateral non-occluded arm during RH recapitulates the strictly 'local' nature of regulation and clearly differentiates it from previously recorded systemic responses.

Assessment of student's learning of this demonstration practical can be done as a part of objectively structured practical examination (OSPE) with question stations based on the observed differences in the graphs obtained during the two maneuvers and their underlying mechanisms.

The only plausible limitation involves occasional difficulty in ensuring optimal quality of finger pulse recordings due to high amplitude baseline fluctuations in PPG signal if the filter settings are not appropriately set. However, this generally does not affect the responses which are clearly visible in terms of pulse amplitude changes during the maneuvers.

Further extension of the scope of this practical for post graduate teaching can be done by including the concept of pulse transit time (PTT) as a measure of vascular tone (7, 9) and comparing the changes in PTT during reactive hyperemia and hand grip protocols with reference to their baseline. Measurement of PTT will require an additional channel for ECG recording as PTT calculation uses R wave peak as the reference point (7, 9).

In conclusion, this novel practical proposal can be utilized for effective perceptible demonstration of systemic and local regulation of circulation for undergraduate teaching in physiology.

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