Comparison of cerebral blood flow auto regulation with peripheral blood flow autoregulation using photoplethysmography

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Background

Autoregulation is the general term used to describe the complex set of metabolic, myogenic and neurogenic processes involved in maintaining adequate and stable blood supply to an organ. While most organs demonstrate some degree of autoregulation, the brain however is thought to be hypersensitive and critical in the consistency of blood flow and oxygen delivered. This is primarily due to the inflexible structure of the skull, which does not allow for the expansion of extracellular fluid or tissue. Additionally, the vascular resistance of large arteries in the brain plays a significant role in providing constant blood flow and defending the microcirculation against surges in blood pressure. Hence, making the cerebral autoregulation distinctive from the peripheral autoregulation.

In an effort to understand these differences in peripheral and cerebral blood flow auto regulation, a study was carried out in 9 healthy volunteers using dual-site, multi-wavelength photoplethysmography (PPG). Perfusion Index (PI) and oxyhaemoglobin concentrations (HbO_2) were estimated from the PPG signals acquired from both peripheral and central location (finger and the ear canal). PI and HbO_2 were calculated as they represent the strength of blood flow at the respective area and may provide an assessment of its autoregulation. The ear canal being closer to the trunk and being supplied with the same arteries as the brain is expected to reflect changes in cerebral circulation.

Methods

A reflection based ear canal PPG sensor was built along with an optically identical finger probe and multi-wavelength PPG processing system. The peak emission wavelengths of the LEDs used in the probe design are 870 nm in the infrared region and 658 nm in the red region. During the study, volunteers were seated in a room maintained at 22 ± 1^{o}C for a minimum of 10 min to acclimatize. Baseline readings were then obtained for at least 2 min before they were moved into an air conditioned room maintained at 10± 1^{o}C. After which they were moved back to normal room temperatures. PPG signals were continuously acquired during all three phases.

The acquired signals were analysed to estimate PI using (1) and HbO_2 by applying and solving (2). In order to minimize inter-subjects variability, changes in the PI were expressed as normalized values with respect to 5 seconds baseline measurement.

1. $PI = \frac{AC_{IR}}{DC_{IR}} \times 100\ \%$
2. $\Delta A_\lambda = \ln(\frac{DC_{0_\lambda}}{DC_\lambda}) = (\Delta[HbO_2]\varepsilon_{HbO_{2_\lambda}} + \Delta[HHb]\varepsilon_{HHb_\lambda}) \cdot d$

The means of the estimated parameters from both locations were compared for the first min of baseline, last min of cold exposure, and last min of recovery.

Results

The box-plots in Figure 1 and 2 show the mean of the mean PI, and concentration changes of HbO_2 measured from both locations across all the volunteers. The PI, as expected has decreased across both locations due to profound vasoconstriction resulting from 10 min cold stimulus. However, the drop in PI was less profound in the ear canal, indicating the disparity between central and peripheral autoregulation. Similarly, the concentration of the HbO_2 varied during all phases of experiment in both finger and the ear canal. Although, the changes in both locations were variable, the greater decline in the finger demonstrates the weaker peripheral blood flow autoregulation.

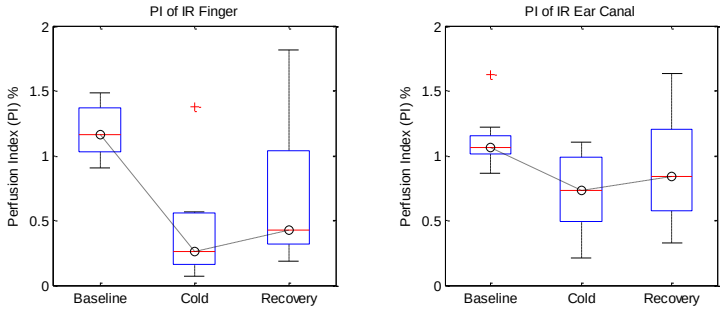

Figure 1: Mean PI of IR finger and ear canal PPG signals calculated from 1 min baseline, last min of cold exposure and last min of recovery.

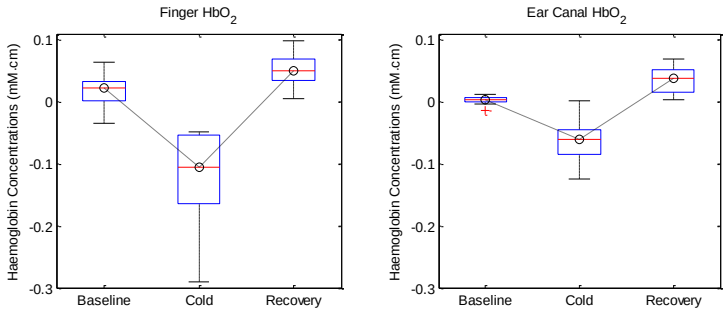

Figure 2: Mean HbO_2 of finger and ear canal calculated from 1 min baseline, last min of cold exposure and last min of recovery.

Conclusion

In this study, the differences in central and peripheral blood flow auto regulations were assessed using dual-site PPG. The PI and the concentration of HbO_2 measured from the PPGs demonstrated that the cerebral circulation is less affected by cold stimulus than the peripheral circulation. These results suggest that cerebral blood flow autoregulation can be assessed using PPG.