Photoplethysmography Imaging of Microvascular Responses to Local Skin Heating Using a Custom-Designed Heating Unit

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***Abstract*—A custom-designed heating unit was integrated with photoplethysmography imaging (PPGI) to investigate microvascular responses to controlled local skin heating. Tissue temperature and spatial perfusion were recorded in parallel, and the perfusion index (PI) and continuous wavelet transform (CWT) were evaluated. Local heating produced measurable PPGI-derived perfusion changes in both subjects. Using the normalized perfusion-map signals as a common endpoint, the observed response peak occurred at approximately 14 min of the recording in Subject 1 and 15 min in Subject 2, corresponding to about 12 and 13 min after heating onset, respectively. During these periods, tissue temperature was within the stabilization ranges reported for each subject. Because only two subjects were studied and their thermal trajectories differed, the observations are treated as individual responses rather than evidence of smoking-related or endothelial differences. The results support the feasibility of combining PPGI with a custom heating unit for non-invasive assessment of local microvascular reactivity.**

Keywords—photoplethysmography imaging, PPGI, local hyperthermia, microcirculation, microvascular reactivity, non-contact monitoring, perfusion index, thermal response

I. Introduction

Photoplethysmography (PPG) is a non-invasive optical technique for detecting blood-volume changes in the microvascular bed [1]. Its imaging extension, photoplethysmography imaging (PPGI), uses a camera to record spatial and temporal variations in light reflected from the skin, enabling contactless monitoring of perfusion over larger tissue areas. Early work by Blazek demonstrated the feasibility of camera-based PPGI for contactless and spatially resolved assessment of dermal perfusion [2], while Verkruysse et al. showed that plethysmography signals can be remotely extracted from video using ambient light [3]. Subsequent studies have further demonstrated the applicability of PPGI for non-contact monitoring of skin perfusion and cardiovascular dynamics [4], [5].

Assessment of vascular and microvascular reactivity can provide information about alterations in vascular regulation, including those associated with endothelial dysfunction [6], [7]. While established approaches such as flow-mediated dilation (FMD) are widely used for vascular assessment, optical methods offer the possibility of investigating local microvascular responses non-invasively and over a spatially resolved tissue area [6], [7]. In this context, local skin heating represents a useful physiological stimulus for evaluating changes in cutaneous microcirculation.

Local heating produces a characteristic microvascular response consisting of an initial rapid vasodilation predominantly associated with sensory nerve activity, followed by a slower sustained phase influenced by local vascular mechanisms, including a substantial contribution of endothelial nitric oxide (NO) [8]. Consequently, the temporal and spatial characteristics of the perfusion response can provide information about microvascular regulation. Since the magnitude and dynamics of this response depend on the applied thermal stimulus, the measured tissue-temperature trajectory should also be considered when interpreting individual responses.

The combination of PPGI with local thermal stimulation enables spatial and temporal characterization of heating-induced perfusion changes without direct contact with the optically monitored tissue. Kamshilin et al. demonstrated that microvascular responses to local heating can be monitored non-invasively using PPGI [9]. Mizeva et al. further investigated microcirculatory dynamics during local heating using PPGI, with particular attention to low frequency vasomotion [10]. These findings support the use of PPGI together with controlled thermal stimulation and time-frequency analysis for characterizing microvascular responses to local skin heating.

Reliable investigation of these responses requires controlled and repeatable thermal stimulation while maintaining compatibility with optical monitoring of the investigated skin region. In this work, a custom-designed heating unit was developed and integrated with a PPGI measurement setup for controlled local skin heating. The system was experimentally evaluated in two subjects as a feasibility study. The analysis focused on the temporal and spatial evolution of PPGI-derived perfusion, the measured tissue-temperature response, and low-frequency microvascular activity assessed using continuous wavelet transform (CWT). The study was designed to characterize individual microvascular responses to local heating rather than to perform a group-level comparison between the subjects.