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Camera-based photoplethysmography (cbPPG) to measure the change in perfusion after local negative pressure therapy

Abstract: Camera-based photoplethysmography (cbPPG) allows the contactless measurement of various vital signs. Using this method, our goal is to evaluate the blood flow regarding an increase or decrease after applying local vacuum therapy on the thigh.

1 Motivation and background

The process of wound healing is still not fully understood [1]. Previous studies have shown that successful wound healing requires adequate tissue microcirculation and intact tissue metabolism [2]. Thus, monitoring the wound healing process by measuring the local *blood flow* (BF) and the regional *oxygen saturation* (SO_2) helps appraising the success of wound healing [3]. Therefore *camera-based photoplethysmography* (cbPPG) as a non-contact method for estimating different cardiorespiratory parameters could be promising with some potential advantages compared to conventional contact-based devices [4].

Cardiac pulsation causes an altering blood volume in the blood vessels. This alteration can be detected using a conventional camera. Two effects are assumed to contribute to the signal. The *blood volume effect*, i.e. the periodic change of blood volume within a *region of interest* (ROI), could either arise "directly" through the cyclical change in the cross-section of the vessel, or "indirectly" through the oscillating pressure changes in lower arteries, which cause a cyclical deformation of the connective tissue in the dermis, and thus cause a variation in capillary density in the papillary dermis [5]. *Ballistocardiographic effects* result from movements and have either a global (e.g., head movements due to the blood ejection of the heart) or local (e.g., movement of the skin surface due to the pulsation of a larger artery under the measured area) origin [6].

Different cardiovascular parameters, e.g., the heart rate (HR) or the HR variability, as well as the microcircular BF can be estimated from the pulsatile signal [4, 7].

2 Study design

Since most studies focus on facial regions, because of increased cutaneous perfusion [7], our study focuses on the thigh to evaluate the potential of detecting changes of BF in more distal regions. Thus, our study is based on previous work by Muenchow et al. [1], in which it could be shown that with constant negative pressure on the thigh's tissue for 30 minutes, the blood circulation in this area was increased even 60 minutes after the intervention. We propose a similar setup as used by Muenchow et al. but expand it by using cbPPG.

2.1 Measurement setup

Measurements on 10 healthy female subjects between the age of 22 and 28, simultaneously using an industrial camera (IDS UI-3370CP-C-HQ, IDS Imaging Development Systems GmbH, Obersulm, Germany, 100 fps, 600 x 600 pixels, RGB 3 x 12 bit) at a distance of ~60 to 100 cm and a near-infrared-spectrometry (NIRS) device (INVOS 5100C) by Somanetics Corp. (Troy, MI, USA) as reference. For intervention we used a vacuum-assisted-closure System® (VAC) by KCI Medizinprodukte GmbH (Wiesbaden, Germany), that creates a constant negative pressure for 30 minutes.

Two measurements at an interval of 4.5 minutes before and five measurements at an interval of 0, 15, 30, 60 and 90 minutes after the intervention lasting 90seconds each were acquired.

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2.2 Signal generation and processing

After manually defining the ROI in the video sequences, the values of the green colour channel were extracted for each pixel and the arithmetic mean was calculated for each value of the temporal dimension.

The generated signal was interpolated, normalized to its mean, linearly detrended and 0.5 Hz high-pass filtered (third-order Butterworth). Subsequently, 10-second sections were subjected to zero padding to 8192 points and a fast Fourier transformation. HR was assumed to be the maximum amplitude between 30 and 200 bpm. Corresponding to de Haan and Jeanne [8], the *signal-to-noise ratio* (SNR) was calculated as the ratio of the usable to the unusable part of amplitude spectrum $X(f)$ for every frequency f,

$$\boldsymbol{SNR = 10 * log_{10}\left(\frac{\sum_{f=30\ bpm}^{200\ bpm} BM(f)*X(f)^2}{\sum_{f=30\ bpm}^{200\ bpm}[1-BM(f)]*X(f)^2}\right)} \quad (1)$$

where the binary mask $BM(f)$ is either 1, if the respective frequency is less than or equal to the estimated heart rate or its first harmonic + / - 5 bpm, or 0 otherwise. The SNR as a quality measure of the HR estimation allows conclusions about the tissue blood flow [9].

3 Preliminary results

As it can be seen in Figure 1, the SO_2, measured by the INVOS system, rises after VAC intervention and keeps nearly constant for 90 minutes. An increase in the SNR can also be seen in the cbPPG data. Here, however, the values fall back to the level of the second measurement before the intervention (PreVAC2) after 60 minutes (VACOFF60). The rising SNR between the first two measurements (i.e., PreVAC1 to PreVAC2) is striking. Due to the small sample size, among other things, both the INVOS and the cbPPG data show high variance.

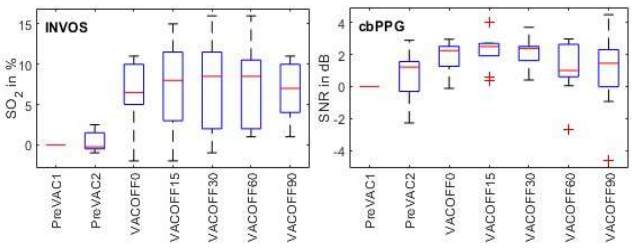

Figure 1: Results from cbPPG and INVOS normalized on first measurement before intervention (PreVAC1)

4 Lessons learned

The preliminary results indicate that an assessment of the tissue blood flow using cbPPG seems to be possible, however we identified two challenges that must be considered in our future study design.

(1) Due to the different measurement depths of INVOS and cbPPG, the two systems reach different tissue layers in which the increased blood flow that the VAC produces may turn out differently and last for different durations.

(2) The increase in SNR between PreVAC1 and PreVAC2 could be of physiological (e.g., shutdown of the cardiovascular system) and technical (e.g., camera warming) origin. These influences must be identified and mitigated.

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