Simple and convenient remote photoplethysmography system for monitoring regional anesthesia effectiveness

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Abstract— **Simple and inexpensive remote photoplethysmography system for monitoring the effectiveness of regional anesthesia was developed and tested. The system involves surgical lamp as light source, compact video camera and computer with custom developed software. Data from eight patients were processed and the effectiveness of regional anesthesia was calculated. The results showed that the standard surgical lamp can be used as a light source together with camera for remote monitoring of regional anesthesia effectiveness.**

Keywords— **Remote photoplethysmography, photoplethysmography imaging, regional anesthesia, blood flow, skin perfusion.**

I. Introduction

Remote photoplethysmography imaging (rPPG) is a non-contact optical diagnostic technique detecting blood volume changes in the microvascular bed of tissue [1-13]. The principle of rPPG is based on the light absorption in the tissue. Due to the cardiac activity, the blood volume is periodically changing in tissue, which leads to modulation of backscattered light intensity. Weak backscattered intensity changes can be detected by video camera and special video processing algorithms performing visualization of the amplitude of blood pulsations in each pixel of the skin image. The main advantages of this technique are simplicity and ability of contactless monitoring of skin blood perfusion. RPPG is mainly used for remote monitoring of cardiac pulse [4-7], but it also can be used for monitoring the blood circulation parameters, such as pulsatile amplitude changes [1-3,8-13].

Previously our group developed prototype devices and software for skin microcirculation monitoring under different physiological tests, such as occlusion [12], thermal provocations [9,12], linament application [12] and regional anesthesia (RA) procedures [8,10-13]. As the blood hemoglobin absorbs the light mainly in the green spectral range, it is better to use the green light for illuminating or to use green optical filters for detecting blood absorption changes from the skin. For practical clinical applications, it is a good choice to use a surgical lamp as a light source, because it is widely available in most operation theatres and can be conveniently located in the room.

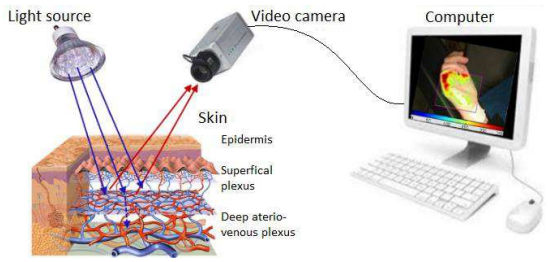

Fig. 1 The principle of rPPG technique.

In this study, we have developed a simple and convenient rPPG system for contactless monitoring of the effectiveness of regional anesthesia before the surgical procedures of the human palm. The developed system has been successfully tested in clinical environment, and can be used as a tool for continuous monitoring of RA.

II. Methods

A. The rPPG device

The rPPG system involves compact lightweight industrial camera (Ximea-xiQ, CMOSIS, ADC-8/10/12-bits, resolution 640x480, 502 frames/s), equipped with low-distortion lens (Edmund optics 3.5mm f/2.4), optical band-pass filter (half-bandwidth 520-580nm), both placed in custom designed 3D-printed case, which is adapted for handle attachment on the surgical lamp (Fig.2). Illuminator comprises warm-white-light surgical lamp (ALM Prismalix PRX800). The camera is connected via USB-3 cable to laptop computer, which is also served as the power supply of camera.

Fig. 2 The rPPG device attached to surgical lamp.

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B. The rPPG video processing

The rPPG processing algorithm was developed in order to visualize the blood volume pulsation amplitude in every pixel of the skin image. We used improved version of previously developed rPPG algorithm [13]. The proposed algorithm was adapted for real-time clinical measurements of skin microcirculation, using non-stabilized white illumination source (surgical lamp).

The main steps of rPPG processing are the following: during the video acquisition, the images are stored in the computer memory as an image cube of size H×W×B (H-height, W-width, B-video buffer length). The next step is temporal processing of image cube. The intensity of skin image changes from frame to frame due to blood induced changes of backscattered illumination. As the fast varying rPPG component is related to the cardiac blood volume pulsations, we assume the heartbeat range of 40-180 bpm. This signal was extracted by applying bandpass filter within the frequency range 0.7-3.0 Hz. The filtered signal and its amplitude was calculated in every pixel of image through the frame buffer to get rPPG amplitude (PPGA) maps. Finally, the PPGA map was visualized on the computer screen which allows to monitor blood circulation in different skin zones. During the acquisition, processing steps are repeated infinite times.

We have optimized our algorithm for speed and changed the sequence of calculations described in [13]. We moved spatial filtering to the tail of the algorithm. This does not affect spatial resolution of map, but increases the computational speed. During the RA procedure subject's hand moved a few times, which can lead to big artefacts in the registered signal. To avoid the motion artifact noise from the signal, we applied modified iterative median filter, which replaces signal values, exceeding the local median value, with the median value of signal.

The electric current in the network is pulsating (in Europe the standard is 50 Hz), so the lamp produces pulsed light with the double value of the current frequency. To avoid this interference induced by non-stabilized light, video acquisition was performed with the frame rate equal to the blinking frequency i.e. 100 Hz. Although the power supply is not stable, slow variations of intensity do not affect the PPGA signal, due to the filtering in the frequency range 0.7-3.0 Hz.

To achieve higher quality of rPPG signal acquired from the skin surface at different lighting conditions, the dynamic range of camera was extended to 10-bit mode. This takes two bytes of memory needed for one video frame. To reduce 16-bit 100-fps data amount, the live video was compressed by custom algorithm, before saving it in standard *avi* format.

C. Measurement procedure

The measurements were performed in the Hospital of Traumatology and Orthopedics (Riga, Latvia) under approval of the local Ethics Committee. Eight patients (aged 30-78 years) undergoing hand surgery received ultrasound guided axillary brachial plexus blocks. During the recording, patients were in a supine position. The dorsal aspect of hand was comfortably adjusted in a custom-made foam rubber hand support. Room temperature was 23.0±0.5°C. The block was produced by administrating a combination of Sol.Lidocaini 2% 10 ml and Sol.Bupivacaini 0.5% 10 ml. After the measurement, the anesthesia level was controlled with "conventional" methods e.g. skin touch with ice.

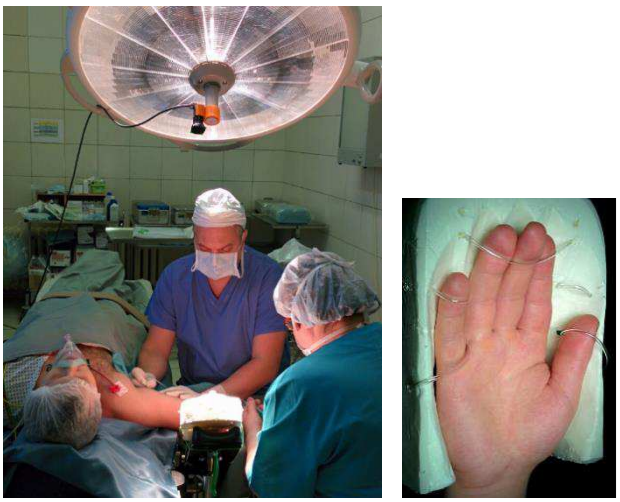

Fig. 3 RA procedure and the measurement setup.

Before each measurement, the surgical lamp was adjusted to reach uniformed illumination of the palm. The distance between lamp and the skin surface was approximately 1 meter. Then the camera was attached to lamp's holder and connected to the laptop computer with a 3-meter long USB-3 cable. This kind of setup is very easy to install and does not interfere with the doctor-anesthesiologist and medical staff to perform their standard RA manipulations.

Video acquisition and real-time processing was performed by custom designed Matlab (Mathworks) software, described in [13]. To reduce large amount of video data, smaller region of interest (RoI) with image resolution of 240x160 pixels was chosen. Such resolution was enough to get quality PPGA maps that can visualize innerved areas of palm skin supplied by single nerve (dermatomes) which were affected by RA. The video from the palm surface was acquired before and during the all stages of RA procedure, 10 minutes after the RA manipulation.

III. Results and Discussion

Local anesthetic affects the sympathetic vascular tone by resulting in vasodilation and subsequent rising of microcirculation intensity in the palm skin. This leads to the increase of amplitude of fast-varying rPPG signal detected by our system. Fig.4 shows signal waveforms recorded from the middle part of the palm before and after the anesthesia procedure. The rPPG signal is weak at baseline (before RA) for most of patients. In some cases, this signal is near to camera noise level. After the successful administrating of local anesthetic, the signal amplitude becomes high enough to detect effect of RA.

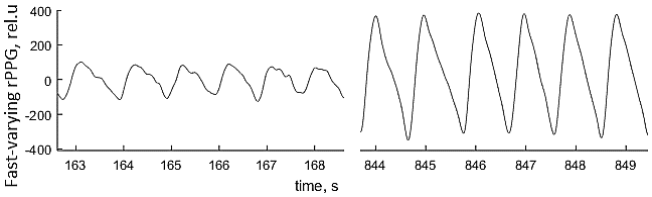

Fig. 4 The palm rPPG signal waveforms before (left) and after (right) the administrating of local anesthetic.

Fig. 5 shows the rPPG signal dynamics during the measurement of patient's palm. The graph above shows the beat-to-beat amplitude dynamics while the graph below shows the slow-varying rPPG component. The gradual increase of perfusion and subsequent rPPG amplitude was observed few minutes after the administration of local anesthetics (6th minute), where the plateau phase was reached approximately 10 minutes later.

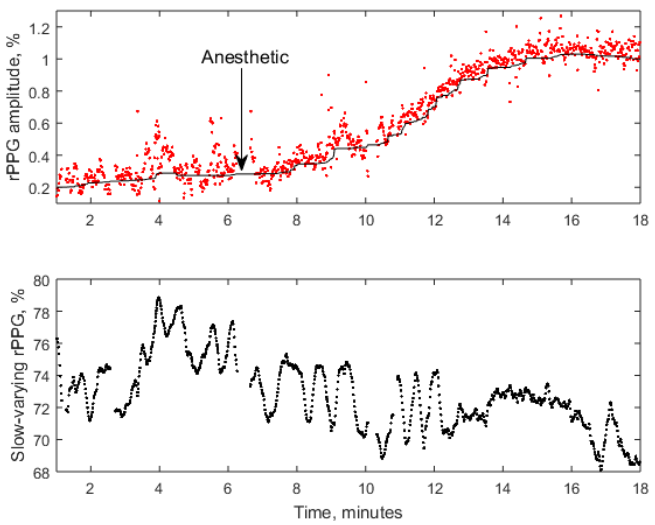

Fig. 5 The RoI-averaged amplitude of fast-varying rPPG signal (above) and slow-varying signal (below) during the RA procedure. The signals show % values of full dynamic range of camera.

Variations of slow-varying rPPG signal was affected mainly by non-stabilized light which reached 9% from full dynamic range of camera. Although the power supply was not stable, slow variations of light intensity did not affect the fast-varying rPPG signal in the near-heartbeat frequency range, because the high dynamic range camera allows to capture video frames with wide range of light intensities.

Fig. 6 shows screenshots of palm video fused with thresholded PPGA maps in the different time moments, before and after the RA procedure. The maps represent the spatial distribution of microcirculation intensity in the palm skin. As the local anesthetic affects four different nerves, subsequent microcirculation changes of four different skin zones (dermatomes) should be observed [14]. The PPGA maps showed increase of microcirculation in dermatomes, and the intensity of maps increased immediately after the administering of local anesthetics (Fig 6 stages 2-6).

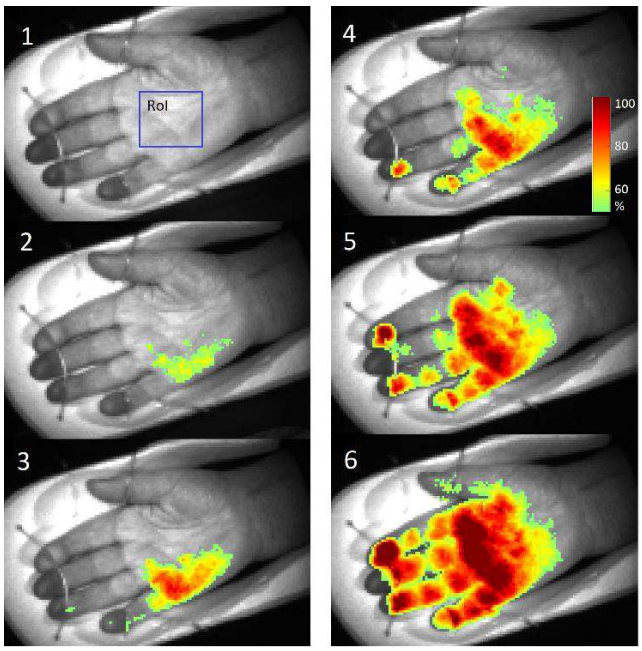

Fig. 6 PPGA maps before (1) and after the administration of local anesthetics, after 1 (2), 3 (3), 5 (4), 6 (5) and 7 minutes (6).

The perfusion response slightly differs across the patients, depending on the heterogeneity of the group of patients and the variance of anesthetic procedure. The PPGA maximum value (100%) was found empirically: from the subject having best RA effect, and 50% of PPGA maximum value was suggested as the threshold of a successful anesthesia. The effectiveness of RA was expressed by PPGA signal maxima/minima ratio, which is different from subject to subject. The results of RA effectiveness are summarized in Table 1.

Table 1 The effectiveness of RA

Subject	PPGA ratio (maxima/minima)	Cold sensitivity (positive/negative)
1	1.3	Negative
2	5.4	Negative
3	2.9	Negative
4	1.5	Positive
5	4.0	Negative
6	1.1	Positive
7	4.5	Negative
8	1.4	Negative

The current study does not answer the following question: how is it possible to detect the minimum signal level, when the local anesthetic affects peripheral microcirculation and what is the maximum level of such signal? Nevertheless, the effectiveness of RA could be expressed through the rPPG signal changes at different stages of RA.

The advantage of proposed system is the simplicity and ease to use in a clinical environment. Every operating room has a surgical lamp as a light source that is suitable for rPPG illumination. This simple system consisting of the surgical lamp, video camera and computer can be adjusted for non-contact monitoring of microcirculation for any application, including regional anesthesia. Future plans include designing a wireless rPPG device for more convenient using in clinical environment.

IV. Conclusions

Simple and inexpensive remote photoplethysmography system for monitoring the effectiveness of regional anesthesia was successfully tested in this study. The rPPG system was approved in clinical environment during regional anesthesia procedures. The results showed that the standard surgical lamp can be used as a light source together with the high dynamic range camera for remote monitoring of skin microcirculation.

Acknowledgment

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Conflict of Interest

In this paper the authors declare that they have no conflict of interest.

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