Remote photoplethysmography for assessment of oral mucosa

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ABSTRACT

The present study is devoted to the assessment of oral mucosa perfusion using remote photoplethysmography (rPPG) technique. The alterations of mucosal perfusion were evoked by regional infiltration anesthesia containing adrenaline. Simple rPPG setup comprising white LED light source, video camera and narrowband optical filter (CWL=540nm), are able to detect subtle microcirculation changes in gingiva. Results demonstrate substantial decrease of rPPG waveform amplitude and subsequently perfusion index in affected gingiva region, following administration of anesthetics. The present study emphasizes clinical advantages of remote photoplethysmography and perfusion index mapping as a simple and cost-effective technique for assessment of oral mucosa function.

Keywords: blood microcirculation, tissue perfusion, perfusion monitoring, imaging photoplethysmography, remote photoplethysmography, oral mucosa, gingival microcirculation, dental anesthesia

1. INTRODUCTION

Oral mucosa is a unique tissue, with a complex structure and diverse functions and therefore can manifest different systemic and local pathologies at early stages, such as diabetes[1], neuropathy[2], sepsis[3], potentially serving as a diagnostic indicator. Due to contemporary advancements in dentistry, neurology and surgery manipulations with mucosa has become a routine procedure, demanding novel techniques for mucosa function assessment, as the clinical aspects of the mucosa do not always reflect the underlying morphofunctional features and can mask alterations.

It is well known that microcirculation is a reliable indicator of tissue functioning and is deranged in pathological conditions. In this regard, what is particularly promising are contactless optical methods due to measurement site accessibility as mucosa is well exposed and high sensitivity for contact compression, which can produce irritation and because of rich population of intraoral bacteria[4] which might causes infection concerns during contact diagnostic procedures.

The potentially valuable field in dentistry for mucosa assessment is monitoring of local anesthesia as it is a routine procedure used in order to avoid discomfort for the patients during various dental manipulations[5]. Conventionally the patient is asked to confirm numbness and loss of perception and is then tested by pricking [5]. However, some patients may have difficulties reporting this adequate situation due to fear, stress or various other factors, which may lead to repeated injection of anesthesia and a larger cumulative dose which might cause some side effects or even complications, such as allergenic sensitivity to anesthetic components, temporal disturbances of gingival and pulpal blood supply, neurotoxicity etc.[6]. Thus reduction of dosage is crucially important, but without causing discomfort for the patient.

The formulation of anesthetic solution usually consists of two substances- the local anesthetic and a vasoconstrictor. The vasoconstrictor is added to negate the vasodilatory attribute of the amide anesthetics which are mild vasodilators. The vasoconstrictor causes the blood vessels to constrict and leads to a lower absorption rate, reduction of systemic toxicity, longer activity time, and increased hemostasis [7].

Early studies utilizing contact manner Laser Doppler flowmetry technique reported the reduction of oral mucosa perfusion in response to administration of adrenaline containing anesthetic lidocaine. However, application of contact methods is not convenient for the patient.

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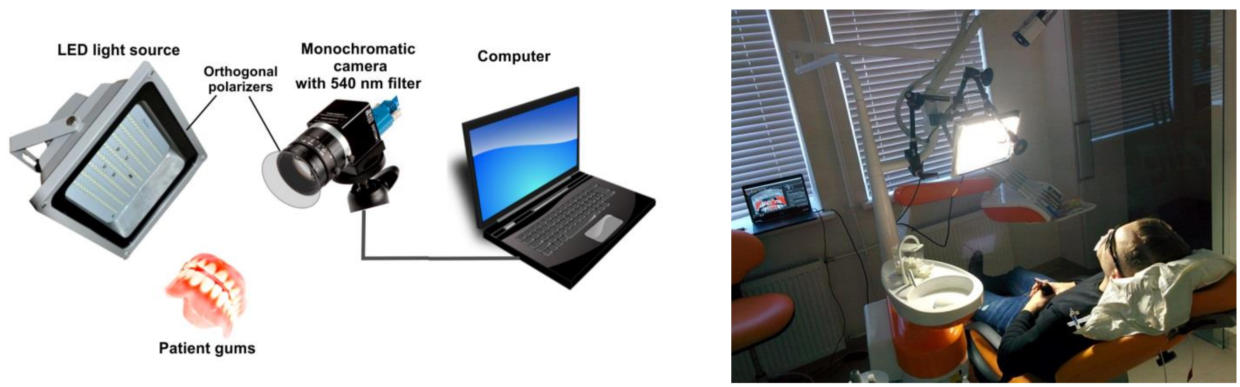
A simple and cost-effective technique for contactless microcirculation monitoring is remote photoplethysmography (rPPG)[8–10]. This technique provides information on tissue microcirculation, using simple instrumentation: light source and video camera, which allows detecting back-reflected light pulsations modulated by pulsatile blood flow. Hence, there are no studies evaluating reliability of rPPG for oral mucosa perfusion monitoring.

The aim of the present study was to assess the use of rPPG for gingival perfusion monitoring during the dental local infiltration anesthesia.

2. METHODS

2.1. The hardware

The rPPG setup was developed for contactless acquisition of gingival perfusion. The setup comprises of a white LED light source (100W electric power), industrial camera (Ximea-xiQ USB-3.0, ADC 8-12-bits, resolution 648x488 pix.) with mounted lens (Edmund Optics, C-mount f=25mm) and 540nm CWL 10nm FWHM narrow-band filter (Edmund Optics), see Fig.1.A. The light source was powered by a stabilized power supply and provided uniform illumination of the measurement site. To reduce glare of gingiva, crossed polarizers were placed in front of the camera lens and light source. Camera exposure was adjusted optimally to fit camera dynamic range and avoid pixel saturation of area of interest. Video acquisition was performed at 25 frames per second and data stored in AVI container as sequence of uncompressed grayscale frames.



A B

Figure 1. A-The major components of remote photoplethysmography system, B- Measurement setup during rPPG registering in Dental clinics

2.2. Examination protocol

The study comprised 12 subjects undergoing routine dental procedures in the Dental clinics of the Medical faculty. Before all procedures, subjects were informed about possible risks of local anesthesia and gave their written informed consent. All procedures were approved by University local Ethics committee, and were in accordance to the Declaration of Helsinki.

The subject was comfortably reclined in the dental chair in supine position and the head was fixed in a vacuum support pillow. A soft dental disposable rubber dam cheek retractor was placed so that the anterior maxillary gingiva was exposed, Fig.1.B. The light source and camera were focused on the recording site, and a video was continuously recorded for 12 minutes consisting of a 6-minute baseline and a 6-minute post administration of local anesthesia. In order to produce alterations of gingival perfusion, buccal infiltration of 0.85 ml (half a cartridge) of 4% articaine-hydrochloride with 1/100.000 adrenaline (Septodont UK Ltd, Units R & S - Orchard Business Centre - St Barnabas Close -Allington, Maidstone, KentME16 0JZ - UK) was performed on each subject. The injection was administered with a 30 gauge 12 millimeter short needle. The buccal infiltration was executed by placing the needle sub-gingival into the alveolar mucosa close to the mucogingival margin over the estimated root of the right lateral incisor (D12). The local anesthetic solution was infiltrated after negative aspiration.

2.3. The algorithm of rPPG processing

The video file was processed offline using custom-developed dedicated Matlab software[10,11]. The processing consisted of several stages (Fig. 2): 1) the video was stabilized, to compensate motion artifacts, and the region of interest (RoI) was manually selected; 2) the rPPG signal was computed from video and the fast-varied (AC 0.7-4 Hz) and slow-varied (DC 0-0.3 Hz) components were obtained, 3) the amplitudes of AC and DC components were calculated from rPPG signal.

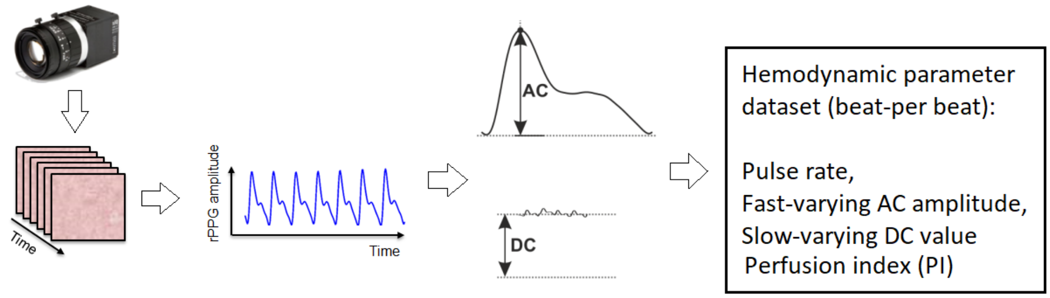


Figure 2. Remote PPG signal processing

To obtain perfusion parameters, a single-period rPPG waveform was computed in beat-per-beat manner. The feet of *AC* signal were detected in every *n-th* beat, and the corresponding values of pulse rate, *DC* and *AC* amplitudes were calculated. Perfusion index (*PI*) is related to both *AC* and *DC* signals, and can be foud in following way:

$$PI_n\ [\%] = 100\, AC_n / DC_n \tag{1}$$

To obtain perfusion map, the *PI* was calculated as time-averaged value (30 sec time window) in every pixel of the video, using algorithms described in our previous work[10,11]. The *PI* map was normalized, using an equation: $PI_{norm}=(PI_i-PI_{min})/(PI_{max}-PI_{min})$, where PI_{min} is obtained from baseline (where perfusion is not obtained), PI_{max} is obtained from the site having maximum circulation.

2.4. Statistical analyses

In order to assess anesthesia evoked perfusion changes in the subject group, each subjects individual PPG perfusion index values were selected during baseline (30 sec time period), first, second, third and fourth minute following administration and at the end of recording, where values did not change (plato phase). Arithmetic mean and standard deviation was calculated and group mean perfusion values were compared in different stages using Kruskal-Wallis One Way ANOVA with Tukey post-hoc test for multiple comparison at the significance level $p<0.05$. The data is expressed as mean±standart deviation.

3. RESULTS AND DISCUSSION

3.1. Gingiva baseline perfusion

Relatively high amplitude rPPG waveform was observed in all subjects during baseline conditions, indicating adequate basal perfusion, which substantially exceed the so called “biological zero” signal (Fig. 3a). As depicted in rPPG PI maps, perfusion in the gum anterior region exhibited symmetrical bilateral distribution of perfusion.

The perfusion values moderately varied (3.7-1.4 a.u.) across the subjects (see Fig. 4b), possibly due to other influencing factors such as different levels of emotional stress and arterial blood pressure differences during registering procedure, although similar variance of gingival perfusion has been previously observed in studies of Ahn et.al and Ketabi et al. during Laser Doppler measurements[12,13]. The comparison of obtained gingiva baseline perfusion is rather difficult as several principal differences exist between Laser Doppler Imager obtained perfusion, which is a product of red blood cell velocity and concentration and photoplethysmography derived perfusion index which is determined mainly by magnitude of AC component.

Still debatable is interpretation of rPPG AC component as there is no unified consensus regarding reflection mode photoplethysmogramme genesis and its provided information. It has been proposed that rPPG AC signal registered at green light illumination, partly reflect complex dynamics of red blood cell orientation and changes in RBC aggregation in small caliber vessels[14], partly on viscoelastic properties of the dermis (dermal deformation) as the dominant mechanism of rPPG signal formation[15], and depends on pulsatile transmural pressure of the arteries, which mechanically compress capillaries in the dermis, thus modulating the blood volume in the capillary bed, which in turn modulates the power of remitted light[16]. Thus photoplethysmography signal largely depends on tissue structure and may exhibit differences between gingiva and skin.

However, present observations (unpublished materials) indicate some similarities between cutaneous rPPG and rPPG signal acquired from gingiva despite tissue differences. However, in contrast to cutaneous, gingival rPPG has lower AC amplitude, and larger distortions, probably due to non-uniform illumination of gum surface and due to artefacts, produced by patient motions, which cannot be reduced by motion-compensated algorithms.

3.2. Perfusion changes during anesthesia

In the moment of anesthetic administration, gums slightly moved, producing sharp and short artefact in the signal for 1-4 seconds, therefore this fragment was excluded from offline analyses. Rapid and statistically significant ($p<0.05$) decrease of perfusion (approx. 50% from baseline) was observed adjacent to injection site one to three minutes post administration. Low perfusion region gradually spread in lateral direction reaching the midline and remained low for the entire recording time, as seen in the map acquired at the end of recording during plato phase (Fig. 3b). The same trend is depicted in RoI-averaged perfusion curve recorded from one subject (Fig. 4a).

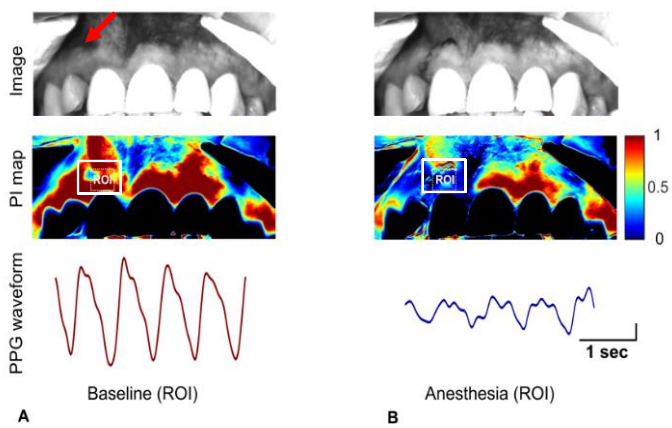


Figure 3. The image of gingival, perfusion map and waveforms, obtained from region of interest (RoI) during the baseline (A) and 5 minutes following administration of adrenaline containing local anesthetics (B).

In the first minute following administration, group mean perfusion decreased by 36.66±16%, at second 51.88±11.56%, at third 56.80±12.39% and at fourth minute 59.57±11.06% from the baseline. While the largest perfusion was observed during plato phase 62.16±12.96%, five to six minutes after injection, although due to the variance in subject group statistically significant differences were observed only between baseline perfusion and second, third and fourth minute (Fig. 4b).

Substantial alterations were noticed in rPPG waveform, the amplitude diminished, and distortions increased during plato phase, where gum perfusion in the anesthetized region was substantially reduced reaching nearly "biological zero" level as hemoglobin absorption decreased due to eliminated functional capillary density, produced by arteriolar vasoconstriction at the anesthetic affected site (Fig. 3b).

Similar perfusion alterations were observed by Laser Doppler Imaging, after administration of adrenaline containing anesthetics[12,13]. Nevertheless, in this study, the effect of lidocaine and lignocaine containing adrenaline on gingival blood flow has been evaluated but effect of articaine with adrenaline has not been studied. The comparison of the present data is challenging as to the best of our knowledge, this is the first pilot study exploring use of remote photoplethysmography for assessment of gingiva perfusion in human subjects during local infiltration anesthesia and in particularly during infiltration anesthesia administrating articaine with adrenaline.

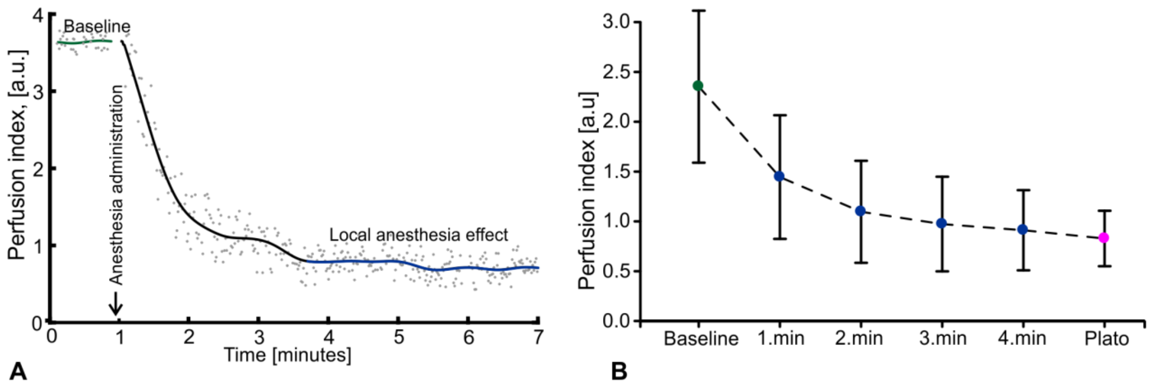


Figure 4. Characteristic trend of gingiva perfusion index at the baseline and following anesthesia, (A), data from one subject. Group mean perfusion values during baseline, and following anesthesia (mean±std) (B).

Previous remote PPG studies on cutaneous circulation demonstrate close similarities between rPPG perfusion and Laser Doppler obtained perfusion trend[11], advocating perfusion measurement similarities, which is rather speculation. As direct comparison of perfusion obtained by these two photonic techniques is problematic in the framework of the present study because mucosal and cutaneous structure differs.

We could conclude that in the light of present knowledge, the observed decrease of perfusion during infiltration anesthesia seems consistent, as adrenaline produces substantial vasoconstriction at the injection site which prevents further spread of anesthetics prolonging its action[15].

Taken together, the present pilot results provide an initial insight in the use of remote photoplethysmography technique for oral mucosa assessment however further studies are required to assess reliability of this technique using different provocation tests.

4. CONCLUSION

Preliminary results suggest that the local infiltration anesthesia substantially decrease the amplitude of rPPG pulsatile signal and its waveform at the affected site, emphasizing clinical advantages of remote photoplethysmography and perfusion index mapping as a simple and cost-effective technique for assessment of oral mucosa function.

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