Electro-optical techniques for the investigation of photoplethysmographic signals in human abdominal organs

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Abstract: There is a need for reliable continuous monitoring of abdominal organ oxygen saturation (SpO_2). Splanchnic ischaemia may ultimately lead to cellular hypoxia and necrosis and may well contribute to the development of multiple organ failures and increased mortality. A new reflectance electro-optical photoplethysmographic (PPG) probe and signal processing system were developed. PPG signals from abdominal organs (bowel, liver, and kidney) and the finger were obtained from 12 anaesthetised patients. The amplitudes of the abdominal organ PPGs were, on average, approximately the same as those obtained simultaneously from the finger. These observations suggest that pulse oximetry may be a valid monitoring technique for abdominal organs such as the bowel liver and kidney.

Introduction

Measurement of blood oxygen saturation (SpO_2) from an extremity such as the finger may not accurately reflect splanchnic oxygen saturation values. In many critically ill patients, poor tissue oxygenation is due to disordered regional distribution of blood flow, despite high global blood flow and oxygen delivery. Splanchnic ischaemia may ultimately lead to cellular hypoxia and necrosis and may well contribute to the development of multiple organ failure and increased mortality [1]. Rapid detection of a significant change in tissue oxygenation could enable earlier and more successful intervention and restoration of splanchnic blood flow and should improve survival in critically ill patients [1].

Techniques used to measure tissue oxygenation such as polarographic oxygen electrodes, luminescent oxygen probes, magnetic resonance spectroscopy and positron emission tomography remain research tools [1]. Manual fluid tonometry for estimating intestinal hypoxia, is expensive, intermittent, operator dependent and time consuming; the recently introduced automatic device is more convenient but is even more expensive [1]. Methods such as laser Doppler, Doppler ultrasound, and intravenous fluorescein have been previously explored to assess intestinal ischaemia in animals [2-5]. Many of these techniques are complex and expensive and none of them directly measures oxygenation. Therefore there is a need for a simple, reliable, and continuous method for estimating abdominal organ SpO_2. Animal studies have also shown that pulse oximetry could be used to monitor intestinal oxygen saturation [2]. The feasibility of estimating blood oxygen saturation in humans has been demonstrated by a study using a commercial transmission pulse oximeter on the colon [6]. However, there are difficulties in applying commercial pulse oximeters to measurements in abdominal human organs because the probes are unsuitable and are not easily sterilizable. Moreover, none of the currently available probes could be left in the abdomen for prolonged postoperative monitoring.

Pulse oximetry relies on the presence of adequate arterial pulsations, which are detected as photoplethysmographic (PPG) signals. As a preliminary to constructing a suitable pulse oximeter for monitoring abdominal organ SpO_2, this paper describes the development and application of a system for the measurement of PPG signals from the surface of the bowel, liver and kidney. The aim is to develop techniques to facilitate measurements on patients with compromised splanchnic circulation which will be useful both intraoperatively and in intensive care.

Materials and Methods

A reflectance electro-optical abdominal organ PPG probe comprising miniature infrared (880 nm) and red (655 nm) emitters and a photodetector has been constructed (Figure 1). The silicon diode photodetector is mounted between the red and infrared emitters to detect radiation back scattered by the tissue. A separation of 5 mm between the emitters and the photodetector provides good signal-to-noise ratio and adequate pulsatile signals. The emitters and the photodetector are mounted on a thin board (20 mm x 3.5 mm x 1.0 mm). A six-core cable carries the power to the emitters in the probe from the PPG processing system and also the detected PPG signals from the photodetector. This cable is electrically screened to minimise electromagnetic interference. The probe was designed to fit into a conventional disposable transparent gastric tube, 20 French gauge, which is sealed at the distal end [7]. A reflectance finger PPG probe, identical to the abdominal organ probe, was also constructed to facilitate comparisons between the two sites, abdominal organ versus finger.

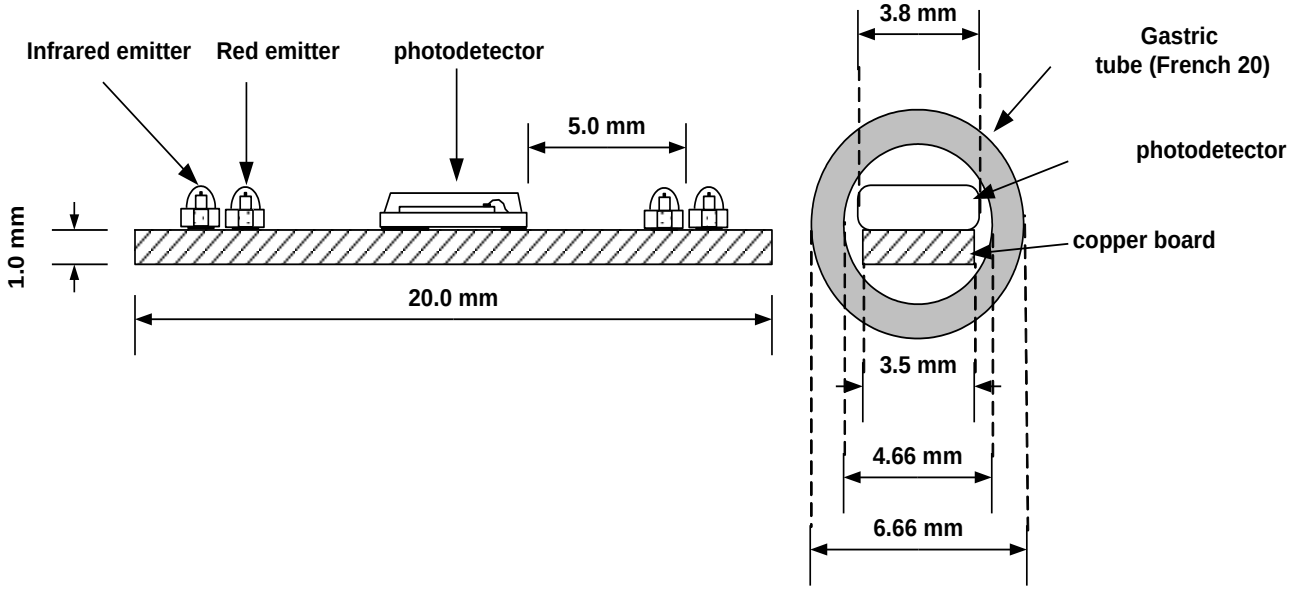


Figure 1: Side and cross sectional view of the reflectance electro-optical abdominal organ PPG probe. In the cross sectional view the probe is shown inserted in the gastric tube

An isolated data acquisition and processing system, comprising two identical channels has been developed to detect, process, record and display the red and infrared AC and DC PPG signals fromthe abdominal organs and the finger. A block diagram of one of the two identical channels is shown in Figure 2.

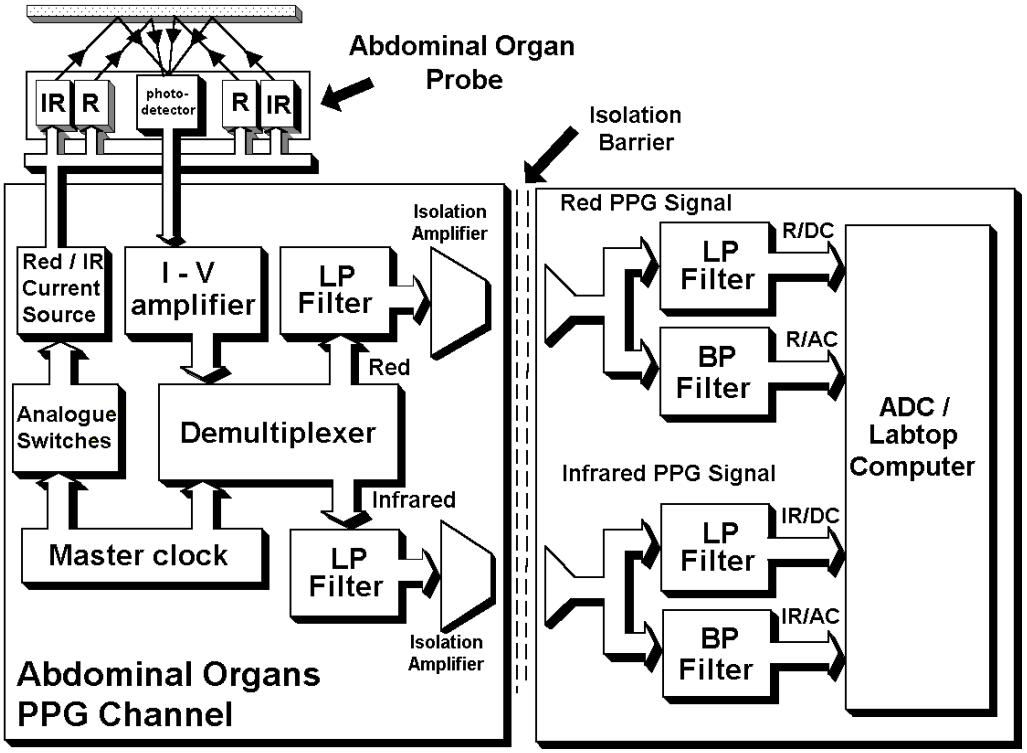


Figure 2: Block diagram of the abdominal organ PPG channel

The emitters, red (R) and infrared (IR), are driven by constant current sources which are controlled by analogue switches which turn the red and infrared emitters on and off at 75 Hz. The photodetector detects the energy backscattered by the tissue and gives an output current proportional to the detected light intensity. The output of the current-to-voltage (I-V) amplifier contains multiplexed PPG signals corresponding to red and infrared wavelengths. The signal from the current-to-voltage amplifier passes to a demultiplexer synchronised to the master clock, which separates the red (R) and infrared (IR) signals. The two signals (R and IR) are then passed through low pass filters to eliminate high-frequency switching transients and are then transmitted across an isolation barrier. Two isolation amplifiers (Burr-Brown ISO122) are used to isolate the patient side of the PPG channel from the output side. The signals on the output side are then filtered to extract the AC and DC PPG components for each wavelength. The output signals are digitised using a 16-bit analogue-to-digital card (ADC) (National Instruments DAQCard-AI-16XE-50) and further analysed by a virtual instrument implemented in *Labview* on a laptop computer. PPG traces corresponding to infrared and red wavelengths from the abdominal organs, together with PPG traces from the identical finger probe, are obtained simultaneously and displayed on the laptop screen.

Twelve adult patients (five male and seven female, average age 52) undergoing elective laparotomy under general anaesthesia were studied. The abdominal organ PPG probe was inserted into a sealed and sterilised disposable size 20 French gauge gastric tube. The gastric tube containing the probe

was then applied gently to the surface of each abdominal organ so that the emitted light was reflected from its surfaces (Figure 3). General theatre and operating lights were switched off. The probe was kept in place until a stable PPG signal was achieved. The identical reflectance finger probe was placed on the finger of the patient. A commercially available transmission type pulse oximeter probe was also used on an adjacent finger to record finger SpO_2. Simultaneous AC and DC PPG traces from each abdominal organ and the finger were recorded for approximately two minutes.

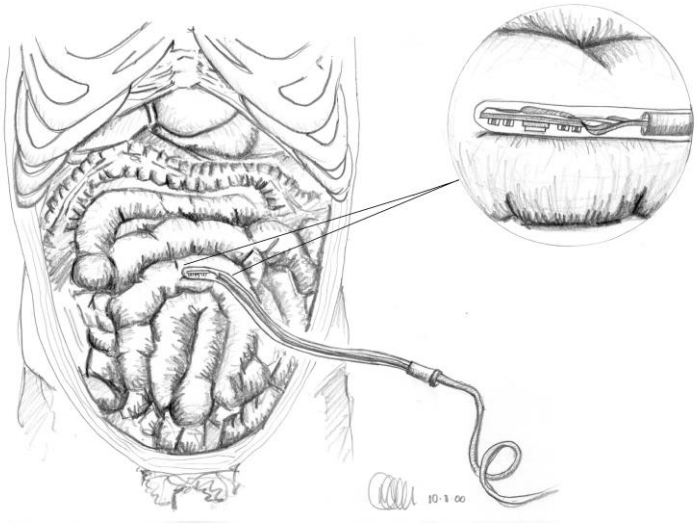
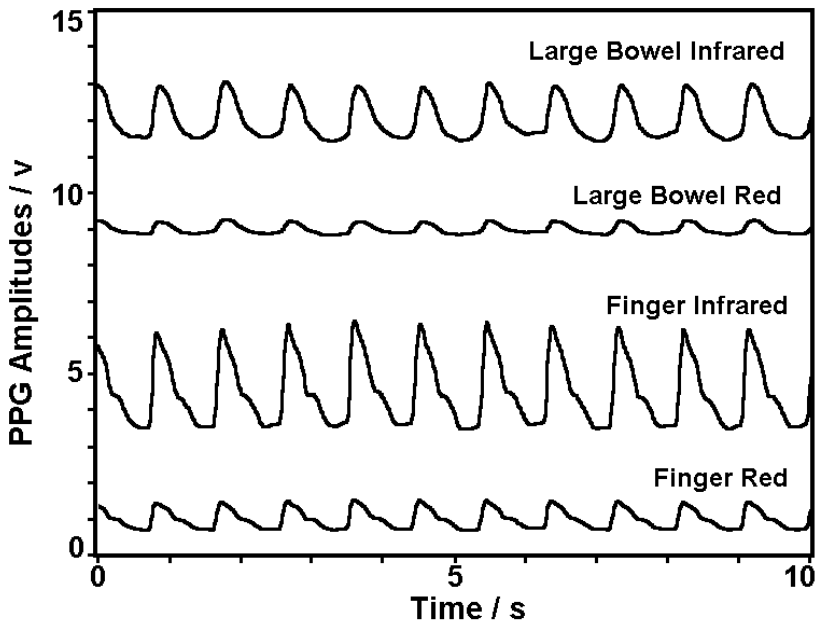


Figure 3: Reflectance abdominal organ PPG probe placed on the surface of the human bowel

Results

Measurable PPG signals were always obtained from the surface of the bowel in all twelve patients, and depending on intra-operative accessibility, also from the liver (eight patients) and the kidney (six patients). PPG signals with similar amplitudes and reasonably high signal-to-noise ratios were obtained from all investigated abdominal organs (Figure 4). The low frequency artefact present on the liver and kidney traces was due to movement of the handheld probe.



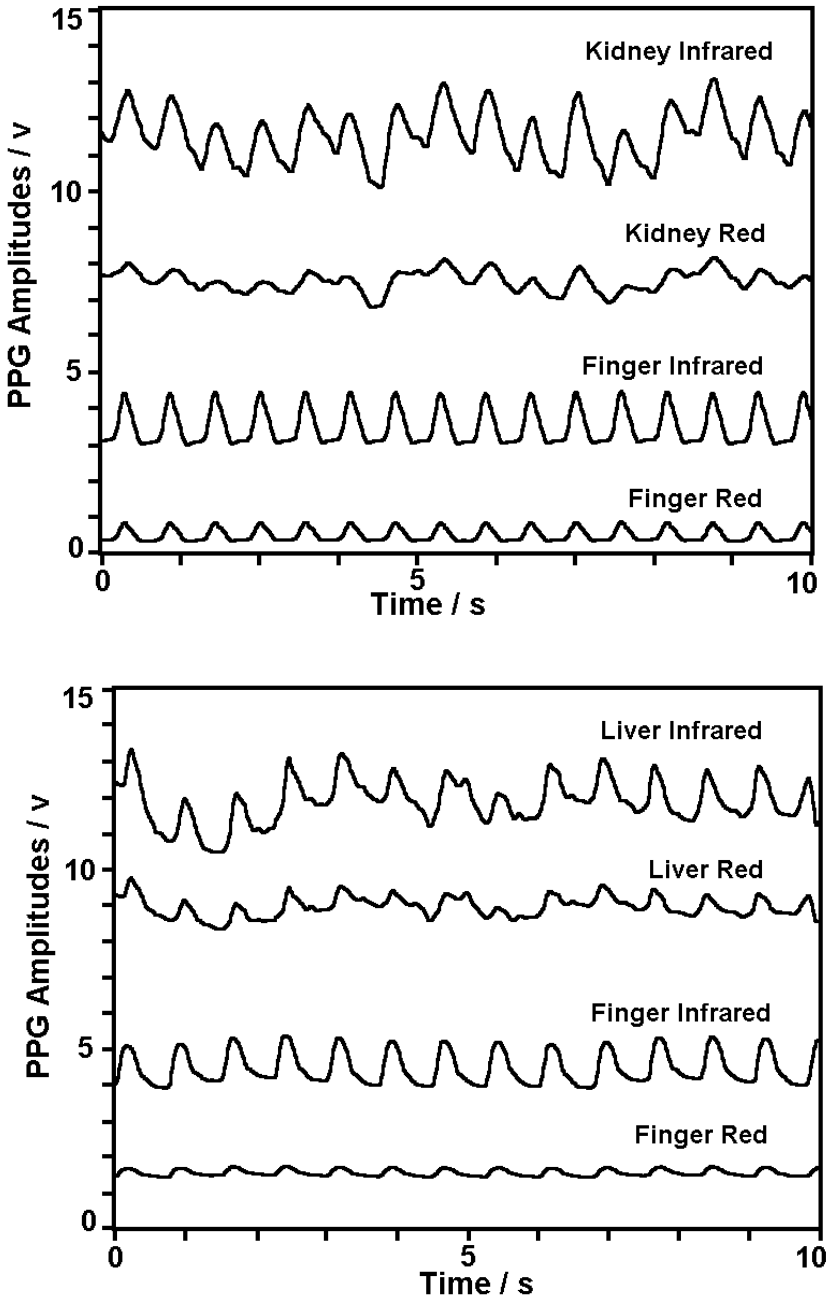


Figure 4: AC PPG traces from simultaneous measurements at various abdominal organs (bowel, kidney, and liver) and the finger.

Mean peak-to-peak PPG amplitudes and standard deviations from all investigated abdominal organs and the finger are shown in Figure 5.

Paired t-tests showed that there were no statistically significant differences between the PPG amplitudes recorded from the abdominal organs and those from the finger.

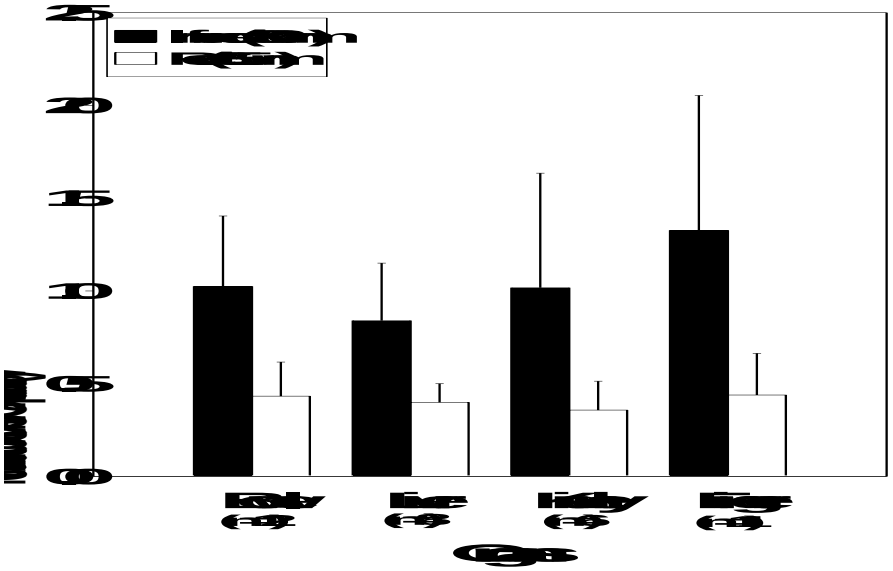


Figure 5: AC Peak-to-Peak Amplitudes, Mean (± S.D.), at two wavelengths from the three abdominal organs and the finger

Conclusions and Discussion

Abdominal organ PPG signals at red and infrared wavelengths have been obtained with adequate signal-to-noise ratio. This appears to be the first quantitative report of PPG signals from human abdominal organs. The PPG amplitudes from both hollow and solid abdominal organs are on average, approximately the same as those obtained simultaneously from a finger for both wavelengths, although there is considerable variability. The primary objective of this work was to measure the amplitude of PPG signals from various abdominal organs. However, some random comparison of online estimation of SpO_2 from the abdominal organs showed good agreement with SpO_2 values obtained simultaneously from the commercial finger pulse oximeter. This observation supports the hypothesis that pulse oximetry may be used as a monitoring technique, for abdominal organs such as the bowel, liver and kidney. Further work needs to be carried out to validate this hypothesis.

Acknowledgements

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