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Investigation of Photoplethysmographic Signals in the Human Oesophagus

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Abstract

The continuous monitoring of blood oxygen saturation in patients with compromised peripheral perfusion is often difficult or impossible, since conventional non-invasive techniques such as pulse oximetry fail. Measurements of oxygen saturation are unreliable when patients are peripherally cool with low cardiac output and poor peripheral circulation. These clinical situations commonly occur after major surgery including cardiopulmonary bypass. We suggest that the above difficulties might be overcome if the sensor were to monitor a more central part of the body. It is proposed to use the oesophagus as measurement site and reflection techniques on the hypothesis that this site should be better perfused. A new probe was constructed utilising miniaturised opto-electronic devices designed to fit into a transparent oesophageal stomach tube. One infrared wavelength was used in this study at 880 nm and a circuit to analyse the photoplethysmograph (PPG) signal was developed. The output PPG signals were sampled and recorded by a data acquisition system and a laptop personal computer. Initial measurements were carried out to investigate the amplitude of the pulsatile signal in the oesophagus and preliminary results are presented.

1. Introduction

Non-invasive continuous monitoring of arterial blood oxygen saturation by pulse oximetry is widely acknowledged to be one of the most important technological advances in clinical monitoring (BOWES *et al.*, 1989). Pulse oximeters have become common as patient monitors in anaesthesia, operating theatres, recovery rooms and intensive care units (ICU), but they have some severe limitations. The vascular bed to be monitored must be pulsatile, therefore pulse oximeters require adequate peripheral perfusion to operate correctly. When peripheral perfusion is poor, as in states of hypovolemia, hypothermia, vasoconstriction, low cardiac output and low mean arterial pressure, oxygenation readings become extremely unreliable or cease altogether. In addition, the administration of vasoactive medications may have an adverse effect on the circulation making pulse detection difficult at peripheral sites (PALVE and VUORI, 1989; PALVE, 1992). Pulse oximeters become unreliable in these circumstances because conventional transmission sensors are usually placed on the most peripheral parts of the body such as the finger, the ear lobe or the toe, where pulsatile flow is most easily compromised. Reflection pulse oximeter sensors, which have been introduced recently, enable the measurement of oxygen saturation in more central parts of the body such as the forehead and nose, however these sites give no improvement in poorly perfused patients (ROSENBERG and PEDERSEN, 1990; CLAYTON *et al.*, 1991).

Hence, pulse oximetry becomes unreliable in a significant group of patients at just the time when the measurement of blood oxygen saturation would be most clinically valuable. In particular, it can fail in patients undergoing prolonged procedures such as, cardiac, vascular, reconstructive or neuro- surgery, which may lead to cooling and poor peripheral perfusion. There is, therefore, a need to find a means of solving this frustrating and serious clinical problem. This paper describes the development of a system for the measurement of the amplitudes of photoplethysmographic (PPG) signals from the human oesophagus and presents preliminary results. The aim is to develop techniques to facilitate measurements on patients with severely compromised peripheral circulations. No previous PPG measurements appear to have been reported for the human oesophagus.

2 Materials and methods

2.1 Probe design

A basic reflectance PPG probe consists of a red or an infrared emitting diode and a suitable photodetector, usually a silicon photodiode. The wavelength of the infrared emitter is usually chosen to be in the spectral region between 800 nm and 940 nm where the penetration into the tissue is relatively large and leads to a good signal-to-noise ratio. In practice, the choice of wavelengths of the emitters is limited to those readily available from manufacturers. Satisfactory PPGs can be obtained using wavelengths in the red region of the spectrum but signal amplitudes tend to be smaller than when using near infrared radiation. The spectral response of the photodetector must overlap the emission spectrum of the emitter. The radiation from the emitter in the reflectance probe is diffused by the skin and most other soft tissues.

The new oesophageal probe developed in this study uses two infrared emitting diodes (IREDs) with peak emission at 880 nm. A silicon diode photodetector is mounted between the IREDs to detect radiation back scattered by the tissue. A separation of 5 mm between the IREDs and the photodetector provides good signal-to-noise ratio and adequate pulsatile signals. The IREDs and the photodetector are mounted on a thin board. A four-core cable carries the power to the IREDs in the probe from the PPG driver unit and also the detected PPG signal from the photodetector (Figure 1). This cable is electrically screened to minimise electromagnetic interference but is flexible and light so that reasonable movement does not induced significant artefacts. The probe with the cable attached is inserted into a plastic oesophageal tube which is sealed at the distal end.

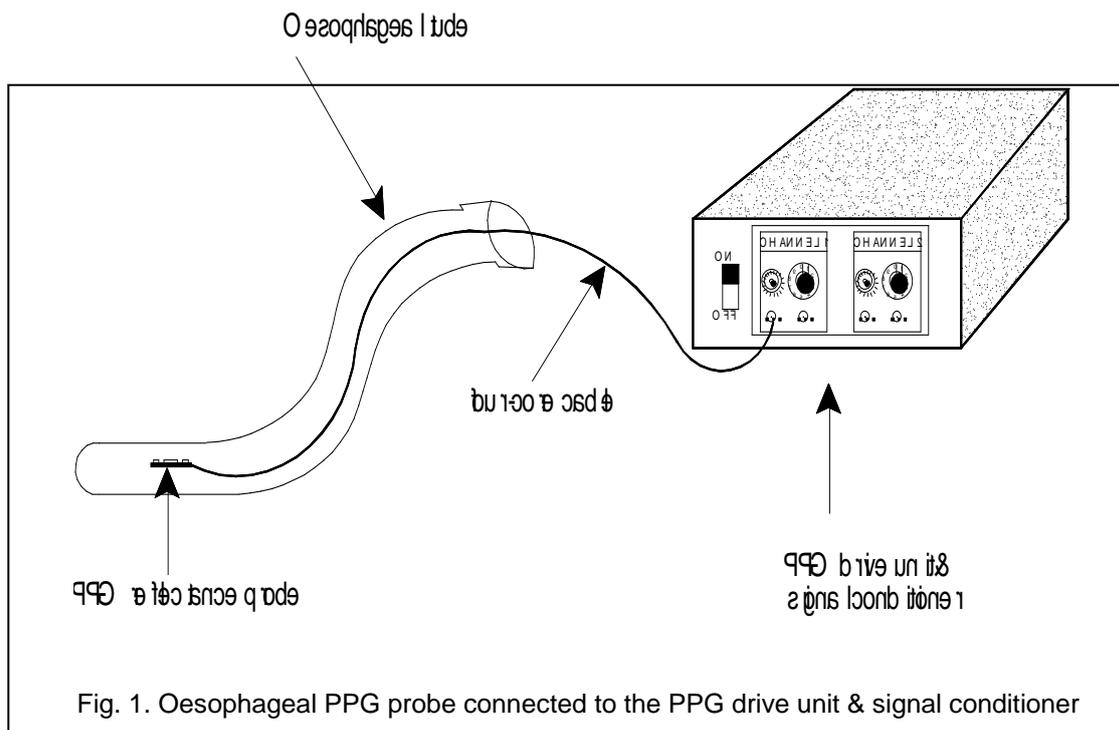


Fig. 1. Oesophageal PPG probe connected to the PPG drive unit & signal conditioner

2.2 PPG Signal Conditioning Circuit

The new reflectance probe is interfaced to a PPG signal conditioning circuit. A block diagram of the circuit is shown in Figure 2. The circuit allows the monitoring of two PPG signals simultaneously. The IREDs in each channel are driven by an IRED driver unit which is a constant current source comprising an operational amplifier and a series transistor. The output intensity depends on the forward current flowing through the IREDs which is maintained at 40 mA by the constant current source. The IREDs were operated well below their maximum rated current of 75 mA. Although the operating current was relatively low, it was still necessary to investigate the possibility of the IRED sources causing direct thermal damage to the oesophagus. Temperature tests, both *in vitro* and *in vivo* (see below), were conducted to verify that any temperature rise in the oesophagus during PPG measurements would be insignificant. The photodiode detects the energy back scattered by tissue from both infrared emitters and gives an output current proportional to the detected radiation level. The photodiode I-V amplifier is

an operational amplifier, connected in a transresistance configuration, that converts the photodiode current into a signal voltage. This signal is then passed to a band-pass filter and pre-amplifier circuit. The PPG pre-amplifier and filter circuit consists of a first order high-pass active filter and a Butterworth 2-pole low pass active filter. The frequency response is 0.1 Hz to 20 Hz (at -3dB) with a gain of 2.32 in the pass band. The low-pass cut-off was chosen to be 20 Hz because the PPG signal does not extend much beyond 12 Hz. After the signal passes through the PPG pre-amplifier filter circuit it is amplified using a variable amplification stage with gain in the range 1 to 100. The final stage comprises a DC level shifting circuit which gives an output signal compatible with the unipolar (0 to 2.5 volts) input range of the analogue-to-digital converter (ADC). The whole PPG signal conditioning circuit is battery driven (± 9 V).

2.3 Data Recording System for Short Term Measurements

The PPG signals at the output of the conditioning circuit are sampled and recorded using a 10-bit data acquisition system (type ADC11, Pico Technology Ltd., Cambridge, UK) and a laptop personal computer. The signals recorded correspond to infrared AC photoplethysmographs.

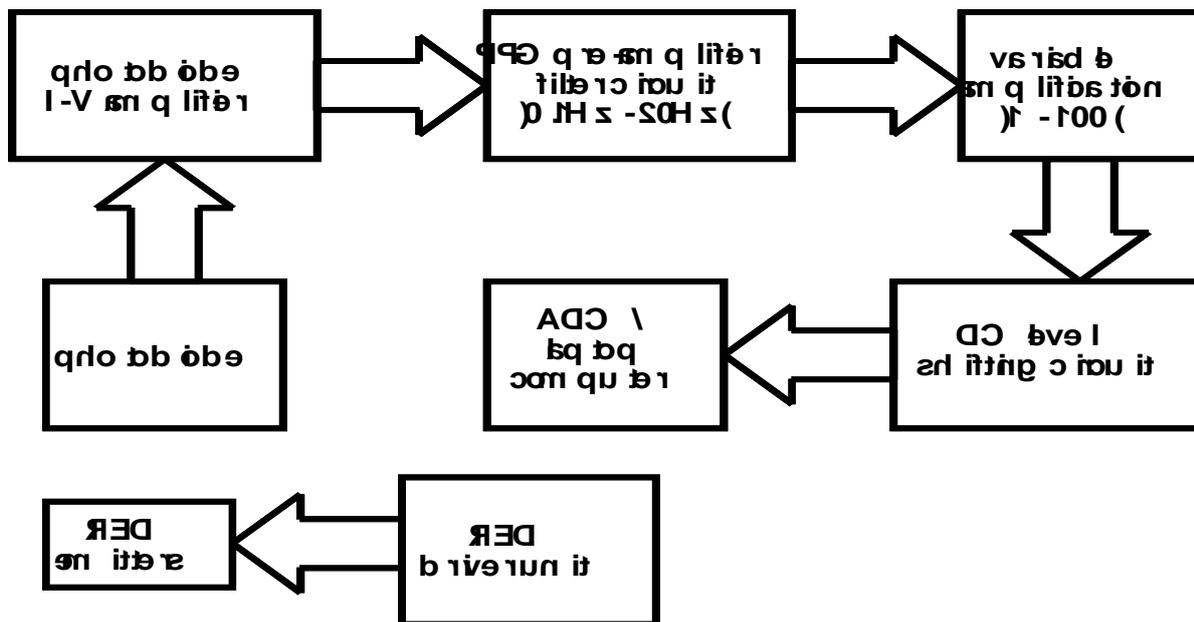


Fig.2. Block diagram of the PPG signal conditioning circuit

2.4 In vitro and in vivo temperature tests

The rise in temperature at the outside of the oesophageal tube immediately adjacent to one of the emitters was measured using a thermocouple. In order to simulate conditions in the oesophagus the tube was immersed in a static water bath at 37 °C as water has thermal properties similar to those of soft tissue. An *in vivo* test was also carried out. The oesophageal tube was placed in contact with the mucosa of the cheek inside the mouth. The temperature at the surface of the tube immediately adjacent to an emitter was measured before and after the emitters were switched on and after steady state conditions had been achieved, usually after approximately 20 minutes.

2.5 Clinical methods

The following procedure was adopted in measuring the healthy oesophagus. The airway was prepared with lignocaine spray (10 mg per spray) and benzocaine lozenges each containing 10 mg of benzocaine. Ten minutes was allowed to ensure maximum effect. The nasopharynx was sprayed with lignocaine spray and also left for ten minutes. A French 18 gauge bore oesophageal stomach tube containing the PPG probe was lubricated on its outside surface with aqueous and lignocaine gel. The tip was softened with warm water and introduced into the oesophagus via the nasopharynx to a length of 36 cm from the nose. During the oesophageal PPG measurement a PPG signal was also obtained from a finger using a similar reflection probe. Nothing was taken by mouth for three hours following the procedure and there were no complications.

3 Results

The results of the *in vitro* temperature measurements showed that the rise in temperature at the outside of the oesophageal tube, immediately adjacent to one of the emitters, was no more than 0.2 °C in the water bath. The results for the *in vivo* measurements in the mouth showed that the temperature rise outside the tube, immediately adjacent to one of the emitters, was always less than 0.6 °C. Therefore, it was concluded that there would be negligible risk of thermal injury to the oesophagus when using the probe.

A typical section of PPG traces obtained is presented in Figure 3. The measurements on the finger and in the oesophagus were all made using IRED currents of 40 mA. The electrical characteristics and gain of the PPG signal conditioning circuit for the oesophageal channel and the finger channel were identical for all the measurements. This facilitated realistic comparisons between the two signals. As can be seen from Figure 3, the AC PPG amplitudes from the oesophagus are at least a factor of two greater than those obtained from the finger. The oesophageal signal appears to be artefact free with a high signal-to-noise ratio.

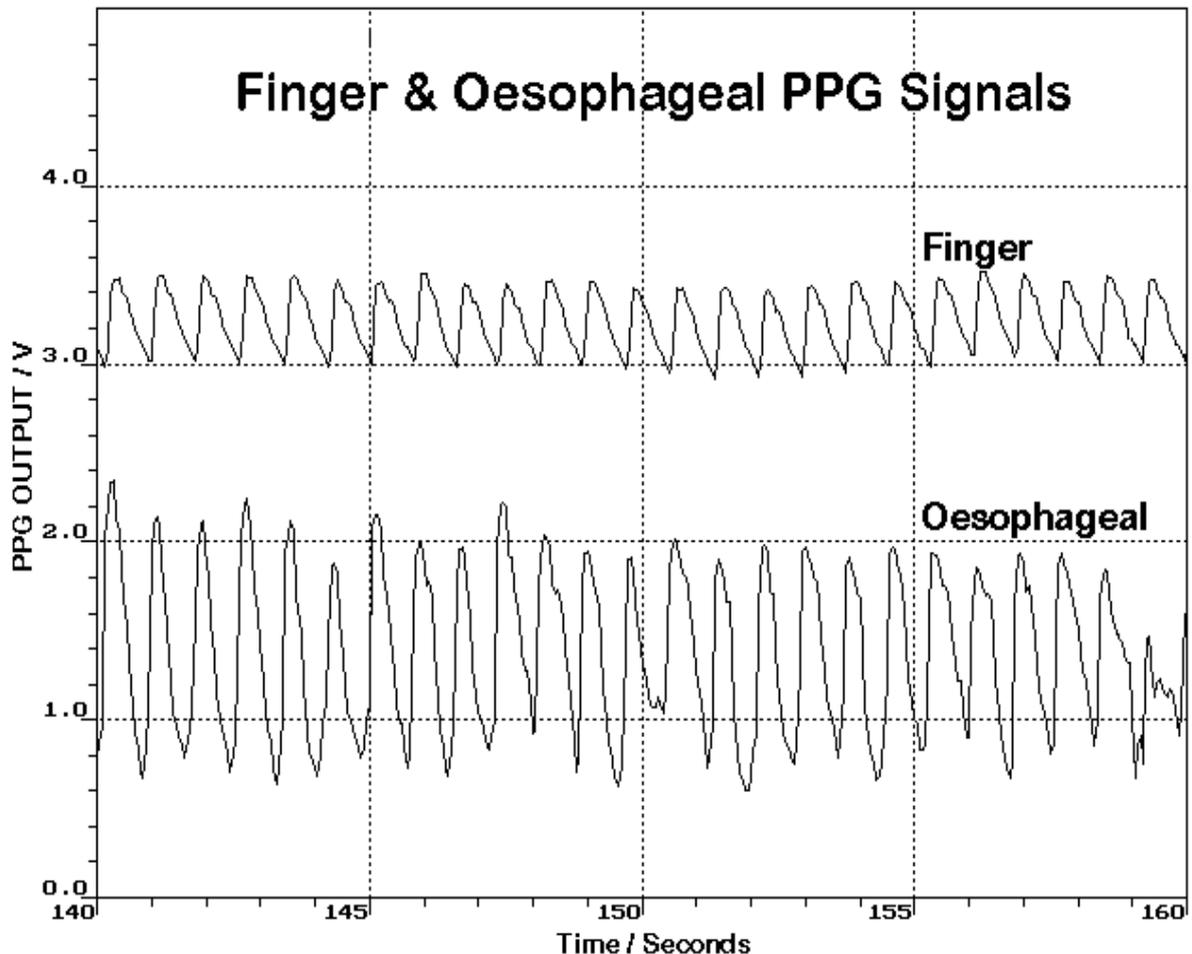


Fig. 3. Oesophageal and Finger PPG signals from a healthy oesophagus

Discussion and Conclusions

In this study it has been shown that good quality photoplethysmographic (PPG) signals can be measured in the human oesophagus. Simultaneous infrared PPG signals from identical reflectance probes in the oesophagus and on a finger were recorded and compared. On the basis of the data obtained, we conclude that the oesophageal PPG signals are significantly larger than the finger PPG signals. The PPG amplitudes measured from the oesophagus are at least a factor of two greater than those obtained from the finger.

Further studies are needed to investigate the possibility of measuring PPG signals in the oesophagus at wavelengths other than 880 nm. If other wavelengths, such as red (660 nm), produce satisfactory PPG signals then the oesophagus might be considered as a suitable alternative site for monitoring oxygen saturation (SpO₂) in patients with poor peripheral perfusion.

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