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Esophageal SpO₂ measurements from a pediatric burns-patient: A case study.

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Abstract — Pulse oximetry is being used in everyday clinical practice in anesthesia utilizing peripheral saturation sensors. However, it may be unreliable in certain clinical situations such as peripheral hypoperfusion. Similar situations occur in burns patients and more importantly burns to extremities which limit the sites available for measurement of peripheral oxygen saturation (SpO₂). To overcome these limitations, the esophagus has been investigated as an alternative measurement site, as perfusion may be preferentially preserved centrally. A miniaturized reflectance esophageal saturation (SpO₂) probe has been constructed utilizing infrared and red photodiodes and a photodetector. Our case study was aimed at evaluating the reliability of esophageal pulse oximetry in a major burns infant. Measurable photoplethysmographic (PPG) traces and SpO₂ values were obtained in the neonatal esophagus. It was found that the esophageal pulse oximeter results were in good agreement with oxygen saturation measurements obtained by a commercial ear lobe pulse oximeter. This study suggests that the esophagus can be used as an alternative site for monitoring arterial blood oxygen saturation by pulse oximetry in burned infants.

I. INTRODUCTION

Pulse oximetry is widely used in neonatal/pediatric anesthesia and intensive care monitoring. It is a valuable, non-invasive technique used for continuous measurement of arterial blood oxygen saturation (SpO₂) [1]. Although pulse oximeters generally give reliable

readings of blood oxygen saturation, there are significant limitations on the accuracy and availability of pulse oximeter data in some circumstances [2]. 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. Sites for pulse oximeter sensors are frequently difficult to find in patients with major thermal injury. Standard sites such as fingers or toes may be affected by the burn, unsuitable due to the use of tourniquets during surgery, or in some cases absent. Therefore, blood oxygen saturation readings are often unobtainable at just the time when they would be most valuable.

Pulse oximeters estimate arterial oxygen saturation by shining light at two different wavelengths, red and infrared, through vascular tissue. In this method the pulsatile photoplethysmographic (AC PPG) signal associated with cardiac contraction is assumed to be attributable solely to the arterial blood component. The amplitudes of the red and infrared AC PPG signals are sensitive to changes in arterial oxygen saturation because of differences in the light absorption of oxygenated and deoxygenated haemoglobin at these two wavelengths. From the ratios of these amplitudes, and the corresponding DC photoplethysmographic components, arterial blood oxygen saturation (SpO₂) is estimated. Hence, the technique of pulse oximetry relies on the presence of adequate peripheral arterial pulsations, which are detected as photoplethysmographic (PPG) signals [3].

Studies have shown that measurable PPG signals can be detected in the esophagus of adult patients, including adult burns patients, during anesthesia [4].

The present unique proof of concept case study was aimed at demonstrating the suitability and reliability of esophageal pulse oximetry in a major burns infant.

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II. METHOD

A. Instrumentation

A reflectance trans-esophageal PPG/SpO₂ sensor (TES) has been designed and manufactured utilizing miniature optical components. Two LEDs (red 660 nm and infrared 940 nm) were placed 5 mm either side of a broad-spectrum photodiode (TEMD7000X01, Vishay, PA, USA), with an active surface area of 0.23 mm². The sensor head was sealed with medical-grade epoxy resin (Dymax Corp, CT, USA). Figure 1 is a schematic and photograph of the TES. A second reflectance sensor (RFS) designed to be placed on either the hand, foot or head, with identical optical-electrical components, was also constructed.

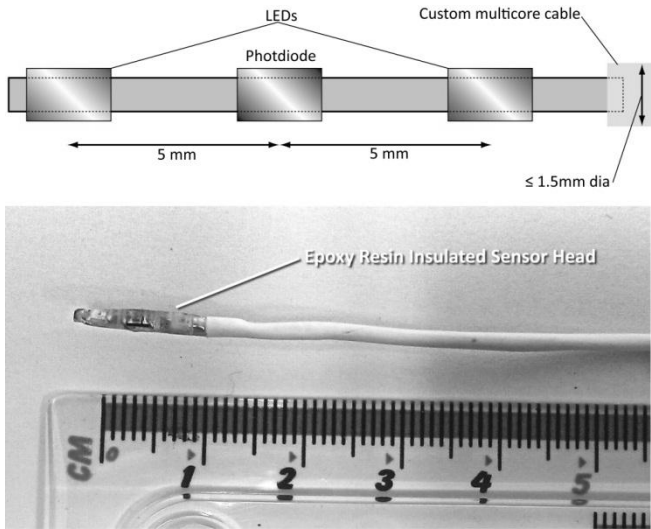


Fig. 1: TES sensor construction

A dual channel PPG processing system was also developed to detect and pre-process all acquired PPG signals (TES and RFS) simultaneously. The technology of the PPG processing system has been previously described [5]. All PPG signals were digitized using a 16-bit data acquisition card (USB-6212, National Instruments, USA). A Virtual Instrument (VI) implemented in LabVIEW (National Instruments, TX, USA) was developed to acquire, display (on a laptop computer) and archive all PPG signals. Algorithms were also developed for the real time estimation of SpO₂ from both sensors.

B. Clinical Measurements

A nine-month-old, 9 kg infant was admitted to the ICU at Great Ormond Street Hospital (London, UK) with 1st

degree burns covering approximately 40 % of its body. Due to the manner in which dressings were used in the treatment of the infant it was not possible to place the bed-side SpO₂ sensor on a hand or foot and was instead placed on the left ear.

Parental consent was obtained to use the TES PPG/SpO₂ sensor. Prior to sensor placement the RFS was placed into a clear sterile pocket constructed from two sheets of transparent film dressing (Tegaderm, 3M Corp, MN, USA), this was then placed on the right temple of the child's head. The TES was threaded into an F-14 nasogastric (NG) tube with the end blocked by fast-acting sterile skin adhesive (Dermabond, Johnson & Johnson, NJ, USA). The lead clinician then placed the NG tube, nasally, to a length of 23 cm, into the esophagus. By the clinicians' judgment it was estimated that the sensor was situated in the esophagus at the level of the aorta behind the heart. Figure 2 shows the severity of the injuries on the child and where the bedside SpO₂ sensor was placed.



Fig. 2: First degree burns injuries (40 % covering), periphery inaccessible for SpO₂ monitoring.

Photoplethysmographic signals were acquired and visualized in real time with a continuous reading of estimated SpO₂ for the TES and RFS simultaneously.

Heart rate and SpO₂ information from the bed-side healthcare equipment was noted and marked into the data file using time stamps.

III. RESULTS

The total monitoring time for the sensor in-situ was 57 minutes. Saved data was analyzed offline with MATLAB (The Mathworks, USA) and SpO₂s were calculated using the linear approximation (1);

$$SpO_2 = 110 - 25R \quad (1)$$

where R is the ratio of ratios of the AC and DC amplitudes of the red and infrared PPG signals.

Figure 3 depicts PPG signals at both wavelengths from the esophagus and the temple of the infant. The esophageal signals are of good quality with large amplitudes and good signal to noise ratio.

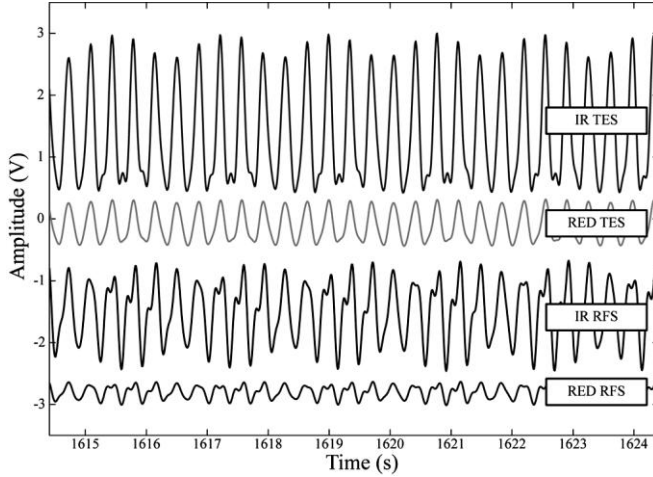


Fig. 3: Ten second sample, PPG signals (RED and IR) from the esophagus (TES) and temple (RFS) sensors

Figure 4 plots the approximation of SpO₂ from the esophagus and temple against the calibrated ear SpO₂ sensor used on the commercial device.

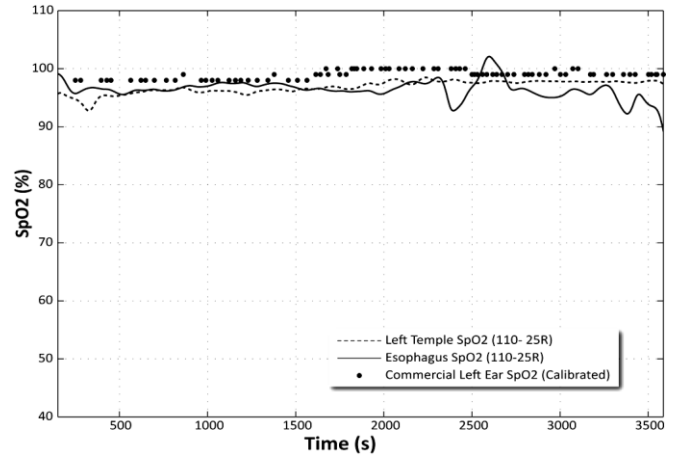


Fig. 4: Simultaneous SpO₂ readings from the temple, esophagus and commercial monitor.

An analysis of the amplitudes of the raw PPG signals was also performed and is shown in table 1.

Amplitudes (V)	IR RFS	RED RFS	IR TES	RED TES
Mean AC ($\pm$ STD)	1.43 (0.33)	0.29 (0.06)	2.53 (0.64)	0.78 (0.26)
Mean DC level ($\pm$ STD)	9.73 (0.21)	3.80 (0.10)	9.85 (0.10)	5.58 (0.07)
Mean Ratio AC/DC	0.15	0.08	0.26	0.14

Table 1: TES and RFS AC and DC analysis.

IV. DISCUSSION AND CONCLUSION

Pulse oximetry is a valuable monitoring technique, however, this may not be the case in major burned patients. Standard sites for pulse oximeter probe application, such as fingers, toes and ear lobes, may be affected by the burn and therefore vital information regarding oxygenation may be unobtainable. In such situations the clinician might have to rely on intermittent arterial blood samples and a blood gas analyzer or a CO-oximeter which is not always ideal.

A pulse oximeter probe attached to the tongue has been used with some success in children with extensive burns [6] however, for 25% of the time in that study the tongue oximeter failed to register saturation values. To overcome these problems we have used a reflectance photoplethysmographic probe in the esophagus which gives continuous oxygen saturation readings. The esophageal probe may give more reliable results, and in this case study preliminary SpO₂ measurements were in

broad agreement with the commercial ear lobe pulse oximeter.

Our study was aimed at evaluating the reliability of esophageal pulse oximetry in major burns children. Good quality esophageal PPG signals with large amplitudes were measured within the esophagus. In summary, the data suggest that esophageal reflectance pulse oximetry may be a reliable and useful alternative method for monitoring continuous oxygen saturation in major burns infants. Further studies in a larger population and a wider range of SpO₂ levels are needed to evaluate further the infant esophagus as a suitable site for measuring SpO₂ in this type of patients.

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