Evaluation of oesophageal reflectance pulse oximetry in major burns patients

S.K. Pal[a,*], P.A. Kyriacou[b], S. Kumaran[c], S. Fadheel[c], R. Emamdee[c], R.M. Langford[d], D.P. Jones[e]

[a]*St. Andrew's Centre for Plastic Surgery and Burns, Broomfield Hospital, Chelmsford, Essex CM17ET, UK*
[b]*Department of Biomedical Engineering, School of Engineering and Mathematical Sciences, City University, London, UK*
[c]*Department of Anaesthesia, St. Andrew's Centre for Plastic Surgery and Burns, Broomfield Hospital, Chelmsford, Essex CM17ET, UK*
[d]*St. Bartholomew's Hospital, London, UK*
[e]*Department of Medical Electronics and Physics, Queen Mary University of London, London, UK*

Abstract

Pulse oximetry is being used in everyday clinical practice in anaesthesia utilising a peripheral probe. However, it may be unreliable in certain clinical situations such as hypothermia, hypovolemia, vasoconstriction and decreased cardiac output. Similar situations occur in burns patients and, more importantly, burns to extremities which limit the sites available for measurement of peripheral oxygen saturation (SpO_2). To overcome these limitations, the oesophagus has been investigated as an alternative measurement site, as perfusion may be preferentially preserved centrally. A miniaturised reflectance oesophageal saturation (SpO_2) probe has been constructed utilising infrared and red photodiodes and a photodetector. Our study was aimed at evaluating the reliability of oesophageal pulse oximetry in major burns patients. Seven adult patients (five males, two females) were studied. They were sedated and ventilated as part of their routine care. Measurable photoplethysmographic (PPG) traces and SpO_2 values were obtained in the oesophagus of all patients at a mean depth of 15.6 ± 1.8 cm (measured from the lips). It was found that the oesophageal pulse oximeter results were in good agreement with oxygen saturation measurements obtained by a CO-oximeter. The mean ($\pm$S.D.) of the differences between the oesophageal oxygen saturation results and those from CO-oximetry was $0.50 \pm 0.69\%$. A Bland and Altman analysis showed that the bias and the limits of agreement between the oesophageal and commercial toe pulse oximeters were 0.4% and -3.6% to 4.6%, respectively. This study suggests that the oesophagus can be used as an alternative site for monitoring arterial blood oxygen saturation by pulse oximetry in burned patients.

Keywords: Photoplethysmography (PPG); Reflectance; Pulse oximetry; Oesophagus; Burns

1. Introduction

Pulse oximetry is widely used in anaesthesia and intensive care monitoring. It is a valuable, non-invasive optical monitoring technique used for continuous measurement of arterial blood oxygen saturation (SpO_2) [1]. In the early 1990s, pulse oximetry became a mandated international standard for monitoring during anaesthesia. 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 [2–5]. When peripheral perfusion is poor, as in states of hypovolaemia, 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.

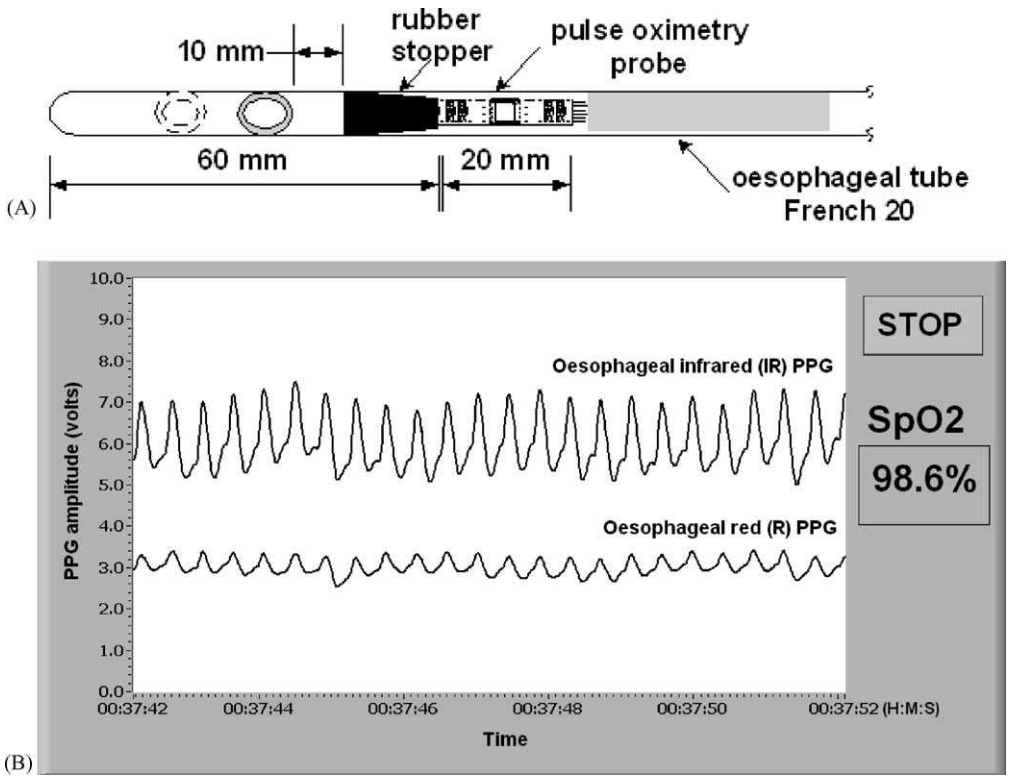

Fig. 1. (A) Schematic diagram of the probe and (B) real time PPG traces.

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 (SpO_2) is estimated. Hence, the technique of pulse oximetry relies on the presence of adequate peripheral arterial pulsations, which are detected as photoplethysmographic (PPG) signals [6].

Studies have shown that measurable PPG signals can be detected in the oesophagus of healthy adult patients during general anaesthesia, and in patients undergoing cardiothoracic surgery [7–11]. The present study was aimed at evaluating the reliability of oesophageal pulse oximetry in major burns patients.

2. Method

2.1. Oesophageal PPG sensor design

A reflectance oesophageal PPG probe has been constructed utilising miniature surface mount infrared and red emitters and a photodetector (Fig. 1A). The probe uses two infrared emitters with peak emission wavelengths at 880 nm and two red emitters with wavelengths at 655 nm. A single silicon photodiode detector was used to detect radiation backscattered by the tissue from the emitters. The distance between each pair of emitters and the photodetector was 5 mm. The PPG probe was designed to fit into a conventional disposable transparent nasogastric tube (20 French gauge) of internal diameter 4.6 mm. There is little clearance between the wall of the nasogastric tube and the probe thereby minimising relative movement.

2.2. Data acquisition and processing system

An electrically isolated, PPG processing system was developed to detect and pre-process simultaneously the red and infrared ac and dc PPG output signals. Oesophageal ac and dc PPG traces (obtained at red and infrared wavelengths) were digitised by a 16-bit data acquisition card (National Instruments Corporation, Austin, TX). The digitised PPG signals were further analysed by a Virtual Instrument implemented in LabVIEW (National Instruments Corporation, Austin, TX). Oesophageal PPG signals were displayed simultaneously on a laptop computer (see Fig. 1B). The design of the Virtual Instrument incorporated algorithms allowing the online estimation of oesophageal SpO_2. A general block diagram of the processing system is shown in Fig. 2.

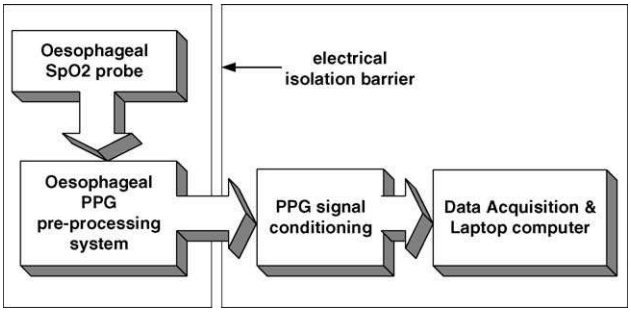

Fig. 2. General block diagram of the oesophageal pulse oximetry processing system.

2.3. Patients and clinical methods

Following Local Research Ethical Committee approval and after obtaining informed, written consent, seven patients with major burns, admitted to burns intensive care, were recruited for the study. The ages of five men and two women ranged between 26 and 52 years. The total body surface area burnt (TBSA) ranged between 28% and 90%. The study was observational and the patient's anaesthetic (intensive care) and surgical management were as per routine. All patients were sedated and ventilated as part of their routine care.

A nasogastric tube containing the reflectance PPG probe was placed in each patient's oesophagus. The PPG signals were recorded at various depths in the oesophagus. The peripheral and core temperatures and vital signs were recorded. A peripheral commercial pulse oximeter (Datex Ohmeda, Nellcor, Helsinki) saturation probe was connected to the toe of each patient. Arterial blood samples (two to seven samples) were taken for estimation of oxygen saturation using a CO-oximeter (800 series Model 865, Bayer Diagnostics, UK) at 20 min intervals or when there was a significant discrepancy between the peripheral and oesophageal oxygen saturation readings. The approximate total measurement time for the patients on average was 1 h. The data were subject to analysis in the following manner.

Linear regression analysis was used to compare the blood oxygen saturation results from the oesophageal pulse oximeter with those from CO-oximetry. It has been suggested that linear regression analysis is appropriate when calibrating an approximate or simple method (like the oesophageal pulse oximeter) with a precise method (such as CO-oximetry) [12]. A Bland and Altman *between-method differences* analysis was performed to calculate the levels of agreement between the oesophageal and commercial probes [12].

3. Results

Measurable PPG traces were obtained from the oesophagus in all patients (see Fig. 1B). The oesophageal PPG signals recorded from all patients were of good quality and large amplitude. The optimal monitoring oesophageal depth ranged from 13 cm to 20 cm, measured from the upper lip (mean ± S.D., 15.6 ± 1.8 cm).

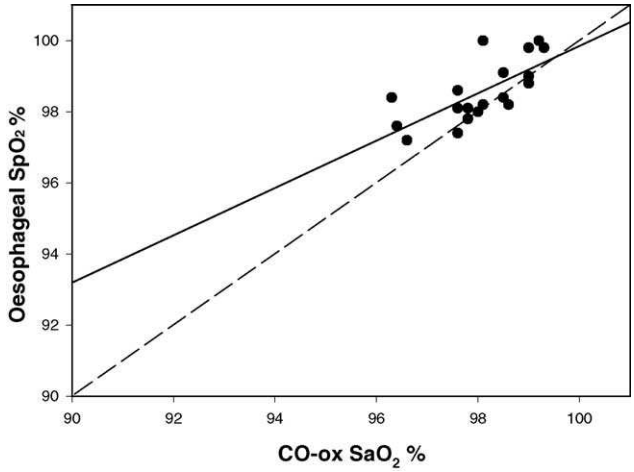

Fig. 3. Plot of SpO_2 measurements obtained from the oesophageal pulse oximeter (OES SpO_2 against SaO_2 from the CO-oximetry (CO-ox SaO_2) for seven patients. The solid line represents the best fit linear regression line: (OES SpO_2) = 33.278 + 0.66 (CO-ox SaO_2); $r^2 = 0.49$; S.E.E. = 0.64; $p < 0.001$. The dashed line represents identity.

A total of 19 pairs of data points, obtained from the CO-oximeter and the oesophageal pulse oximeter, from all seven patients were used for the regression analysis, which gave the estimated slope and intercept of the regression line.

A plot of SpO_2 readings obtained from the reflectance oesophageal pulse oximeter (OES SpO_2) against the SaO_2 values from the CO-oximeter is shown in Fig. 3. The equation of the best fit linear regression line is: (OES SpO_2) = 33.278 + 0.666 (CO-ox SaO_2) (the solid line in Fig. 3); $r^2 = 0.49$; standard error of estimate (S.E.E.) = 0.64; $p < 0.001$. The dashed line represents the line of identity. The mean (±S.D.) of the differences between the oesophageal pulse oximeter SpO_2 values and the corresponding CO-oximeter readings (OES SpO_2–CO-ox SaO_2) is 0.50 ± 0.69%.

Fig. 4 shows a plot of SpO_2 readings obtained from the commercial toe (transmittance) pulse oximeter (CT SpO_2) against the SaO_2 values from the CO-oximeter. The equation of the best fit linear regression line was: (CT SpO_2) = −53.854 + 1.550 (CO-ox SaO_2); $r^2 = 0.61$; S.E.E. = 1.15; $p < 0.001$. The mean and standard deviation of the differences between the commercial toe pulse oximeter and the CO-oximeter readings (CT SpO_2–CO-ox SaO_2) is 0.11 ± 1.23%.

Ninety-two sets of blood oxygen saturation data points from the seven patients were used to compare the oesophageal and the commercial toe pulse oximeters. Since neither can be regarded as a ''gold'' standard, the *between-method differences* analysis as suggested by Bland and Altman [12] was used to compare these two pulse oximeters.

Fig. 5 is a plot of the difference between the commercial toe (CT) and oesophageal (OES) SpO_2 values against their mean. As no obvious relation between the difference and the

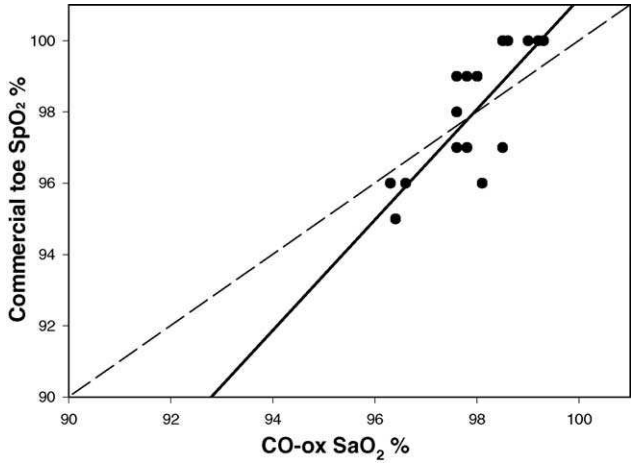

Fig. 4. Plot of SpO_2 measurements obtained from the commercial toe pulse oximeter (CT SpO_2) against SaO_2 from the CO-oximetry (CO-ox SaO_2) for seven patients. The solid line represents the best fit linear regression line: (CT SpO_2) = −53.854 + 1.550 (CO-ox SaO_2); $r^2 = 0.61$; S.E.E. = 1.15; $p < 0.001$. The dashed line represents identity.

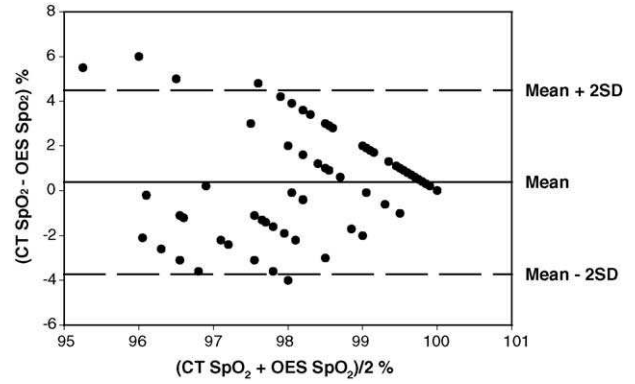

Fig. 5. The difference between blood oxygen saturation values from the commercial toe pulse oximeter (CT SpO_2) and SpO_2 readings obtained from the reflectance oesophageal pulse oximeter (OES SpO_2) plotted against their mean for all seven patients.

mean is revealed in Fig. 5, a calculation of the bias, estimated by the mean difference (d) and the standard deviation of the differences (s) was performed to assess the degree of agreement between the two methods. The bias d (commercial pulse oximeter minus oesophageal pulse oximeter) was 0.4% and s was 2.1%.

The limits of agreement for the SpO_2 data (commercial toe and oesophageal) were, therefore:

$$d - 2s = 0.4 - (2 \times 2.1) = -3.6\%$$

$$d + 2s = 0.4 + (2 \times 2.1) = 4.6\%$$

4. Discussion

Pulse oximetry is a valuable, easy to use, non-invasive optical monitoring technique used for continuous measurement of arterial blood oxygen saturation in anaesthesia and intensive care. 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 this situation, the clinician has to rely on intermittent arterial blood samples and a blood gas analyser 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 [13], 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 oesophagus which gives continuous oxygen saturation readings. The oesophageal probe may give more reliable results, and in these preliminary measurements, consistent readings were obtained in all patients.

It is well known that the accurate assessment of arterial oxygen saturation in patients with carbon monoxide poisoning can currently be performed only by analysis of arterial blood with a laboratory CO-oximetry [14]. All pulse oximeters give inaccurate SpO_2 readings in patients with recent carbon monoxide exposure. However, none of the patients in this study had significant levels of carboxyhaemoglobin (COHb) as confirmed by the CO-oximetry measurements.

Our study was aimed at evaluating the reliability of oesophageal pulse oximetry in major burns patient. Good-quality oesophageal PPG signals with large amplitudes were measured from various depths within the oesophagus. The optimal monitoring oesophageal depth measured from the upper lip, ranged from 13 cm to 20 cm.

It was found that the oesophageal pulse oximeter saturation results were in good agreement with those from the CO-oximeter (see Fig. 3). In a direct comparison between the oesophageal and commercial toe pulse oximeters, using Bland and Altman analysis, the SpO_2 results from the two instruments were in very satisfactory agreement. Although there is some scatter, the bias between them is only 0.4%. The limits of agreement from the analysis were 4.6% to −3.6%.

In summary, the data suggest that oesophageal reflectance pulse oximetry may be a reliable and useful alternative method for monitoring continuous oxygen saturation in major burns patients. Further studies are needed to confirm this result.

Acknowledgements

We gratefully acknowledge the financial support of the University of London Central Research Fund and the R&D Eastern Region.

References

[1] Dorlas JC, Kuipers AH. Pulse oximetry-principle and first experiences during anesthesia. Acta Anaesthesiol Belg 1987;38(2):133–8.

[2] Freund PR, Overand PT, Cooper J, Jacobson L, Bosse S, Walker B, et al. A prospective study of intraoperative pulse oximetry failure. J Clin Monit 1991;7:253–8.

[3] Moller JT, Johannessen NW, Espersen K, Ravlo O, Pedersen BD, Jensen PF, et al. Randomised evaluation of pulse oximetry in 20,802 patients. Anesthesiology 1993;78:436–44.

[4] Reich DL, Timcenko A, Bodian CA, Kraidin J, Hofman J, Deperio M, et al. Predictors of pulse oximetry data failure. Anesthesiology 1996;84:859–64.

[5] Rosenberg J, Pedersen MH. Nasal pulse oximetry overestimates oxygen saturation. Anaesthesia 1990;45:1070–1.

[6] Mendelson Y, Ochs BD. Noninvasive pulse oximetry utilizing skin reflectance photoplethysmography. IEEE Trans Biomed Eng 1988;35:798–805.

[7] Kyriacou PA, Moye AR, Gregg A, Choi DMA, Langford RM, Jones DP. A system for investigating oesophageal photoplethysmographic signals in anaesthetized patients. Med Biol Eng Comput 1999;37(5): 639–43.

[8] Kyriacou PA, Moye AR, Choi DMA, Langford RM, Jones DP. Investigation of the human oesophagus as a new monitoring site for blood oxygen saturation. Physiol Meas 2001;22(1):223–32.

[9] Kyriacou PA, Powell S, Langford RM, Jones DP. Investigation of oesophageal photoplethysmographic signals and blood oxygen saturation measurements in cardiothoracic surgery patients. Physiol Meas 2002;23(3):533–45.

[10] Kyriacou PA, Powell S, Langford RM, Jones DP. Esophageal pulse oximetry utilizing reflectance photoplethysmography. IEEE Trans Biomed Eng 2002;49(11):1360–8.

[11] Kyriacou PA, Powell S, Jones DP, Langford RM. Evaluation of oesophageal pulse oximetry in cardiothoracic surgery patients. Anaesthesia 2003;58(5):422–7.

[12] Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307–10.

[13] Cote CJ, Daniels AL, Connolly M, Szyfelbein SK, Wickens CD. Tongue oximetry in children with extensive thermal injury: comparison with peripheral oximetry. Can J Anaesth 1992;39(May (5 Pt 1)):454–7.

[14] Hampson NB. Pulse oximetry in severe carbon monoxide poisoning. Chest 1998;114(October (4)):1036–41.