A New Fibre Optic Pulse Oximeter Probe for Monitoring Splanchnic Organ Arterial Blood Oxygen Saturation

M. Hickey[1], N. Samuels[2], N. Randive[2], R. Langford[2] and P.A. Kyriacou[1]

[1] School of Engineering and Mathematical Sciences, City University London, London, UK
[2] Anaesthetic Laboratory and Department, St Bartholomew's Hospital, London UK

Abstract— **a new continuous method of monitoring splanchnic organ oxygen saturation (SpO_2) would make the early detection of inadequate tissue oxygenation feasible, reducing the risk of hypoperfusion, severe ischaemia, and, ultimately, death. In an attempt to provide such a device, a new fiber optic based reflectance pulse oximeter probe and processing system were developed followed by an *in vivo* evaluation of the technology on seventeen patients undergoing elective laparotomy. Photoplethysmographic (PPG) signals of good quality were obtained from the small bowel, large bowel, liver and stomach. Simultaneous peripheral PPG signals from the finger were also obtained for comparison purposes. Analysis of the amplitudes of all acquired PPG signals indicated much larger amplitudes for those signals obtained from splanchnic organs than those obtained from the periphery. Estimated SpO_2 values for splanchnic organs showed good agreement with those obtained from the peripheral fibre optic probe and those obtained from a commercial device. These preliminary results suggest that a miniaturized 'indwelling' fibre optic sensor may be a suitable method for pre-operative and post-operative evaluation of splanchnic organ SpO_2 and their health.**

Keywords— **Fibre optics, pulse oximetry, photoplethysmography, perfusion, splanchnic organs.**

I. Introduction

If an organ or tissue is not sufficiently perfused with oxygenated blood, cell death and tissue necrosis can ensue. Failure of one organ due to malperfusion may lead indirectly to the dysfunction of distance organs through the release of various toxins into the portal blood stream [1]. This could result in the onset of multiple organ failure, which is a common cause of morbidity following major surgery [2]. Previous studies have indicated that the gastrointestinal tract may be the canary of the body, making early detection of malperfusion feasible [3]. Therefore, a continuous method for monitoring perfusion of the splanchnic area would be invaluable in the early detection of inadequate tissue oxygenation [4].

Current methods for assessing splanchnic perfusion have not been widely accepted for use in the clinical care environment. Techniques such as polarographic oxygen electrodes and positron emission tomography remain research tools [2], while laser Doppler, Doppler ultrasound [5], and intravenous fluorescein [2] methods are complex, expensive, do not measure oxygenation directly, and are not suitable for routine monitoring. Gastric tonometry, although one of the few techniques currently used in clinical practice for estimating intestinal hypoxia, has not been widely accepted due to the intermittent, heavily operator dependent and time consuming nature of the device [6].

Pulse oximetry has also been used experimentally in both animals and humans [7, 8] where it was found to be a rapid, reproducible, as well as a highly sensitive and specific technique for detecting small bowel ischaemia. The use of commercial pulse oximeters for estimating splanchnic perfusion in humans has been found to be impractical (bulky probes, cannot be sterilized, etc) [4]. More recently a custom made reflectance pulse oximeter has shown for the first time that good quality photoplethysmographic (PPG) signals can be detected from various human abdominal organs (bowel, kidney, liver) during open laparotomy [4]. However, this probe is not suitable for prolonged continuous monitoring in the abdomen.

In an attempt to overcome the limitations of the current techniques for measuring splanchnic perfusion, a new prototype fibre-optic probe was developed for investigating PPG signals from various splanchnic organs and for the estimation of arterial blood oxygen saturation (SpO_2) of splanchnic organs during open laparotomy. An electrically isolated instrumentation system and a virtual instrument were also developed for driving the optical components of the sensor, and pre-processing and displaying the acquired PPG signals on the screen of a laptop computer. The developed system was evaluated *in vivo* on seventeen patients undergoing surgery.

II. Methods

A. Fibre Optic Pulse Oximeter Probes

A reflectance fibre optic splanchnic pulse oximeter probe was designed using 600 μm core silica glass step index fibres, infrared (850nm) and red (650nm) emitters, a $1mm^2$ active area photodiode [9]. In order to facilitate the evaluation of the fibre optic probe during open laparotomy, it was decided to configure the probe as a handheld device.

Fig.1(a) shows the finished splanchnic probe. For comparison purposes an identical reflectance fibre optic probe was also developed to enable the monitoring of PPG signals from a periphery site (finger or toe) (Fig.1(b)).

Fig. 1 (a) the developed splanchnic fibre optic probe and (b) the identical peripheral probe

B. Isolated Instrumentation System and Virtual Instrument

An electrically isolated instrumentation system was designed and developed to drive the optical components of the fibre optic probes and also to detect and pre-process the red and infrared ac and dc PPG signals. A virtual instrument (VI) implemented in *LabVIEW* (National Instruments, USA) was also developed. The VI is used for driving various hardware sections of the instrumentation system and for the acquisition, displaying, analysis and storing of all acquired PPG signals. Detailed technical details of the processing system are described by Hickey and Kyriacou [9].

C. Preliminary Investigation of Fibre-Optic Probe during Open Laparotomy

Ethics Committee approval was obtained to study patients undergoing elective laparotomy. Photoplethysmographic measurements were made in seventeen patients (four male and sixteen female, mean age (±SD): 54 ± 9.7). To enable the use of the fibre-optic PPG sensor in the sterile surgical site, the sensor was placed in a sterile medical ultrasound cover which was transparent to the light being emitted. At an appropriate time during the surgery, the surgeon placed the splanchnic PPG sensor on the surface of each accessible abdominal organ. For comparison purposes the identical fibre optic PPG peripheral sensor was also placed on the finger or toe. Signals were monitored and acquired for approximately two minutes on each site. Blood oxygen saturation from a commercial pulse oximeter (GE Healthcare) was also simultaneously monitored and recorded.

III. RESULTS

Good quality PPG signals with large amplitudes and high signal to noise ratio (80dB) were recorded in all attempts from the small bowel (n = 17), large bowel (n = 14), liver (n=5) and stomach (n=5). Figures 2 to 5 depict typical ac red (R) and infrared (IR) PPG traces from the splanchnic organs and the corresponding peripheral signals.

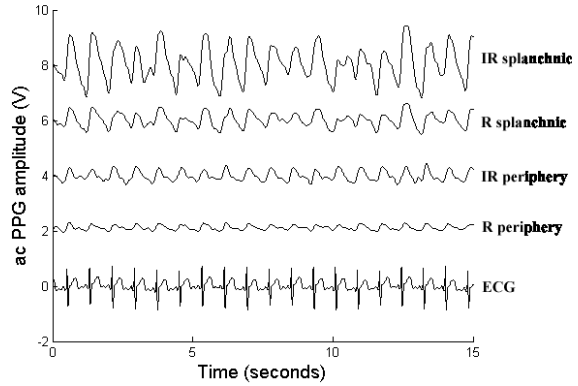

Fig. 2 ac red (R) and infrared (IR) PPG signals from the small bowel and periphery with simultaneous ECG

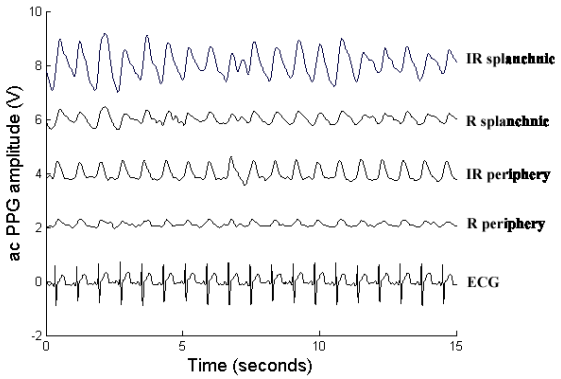

Fig. 3 ac red (R) and infrared (IR) PPG from the large bowel and periphery with simultaneous ECG

The low frequency artifact present on the splanchnic PPG traces was due to the mechanical ventilator and movement of the handheld sensor.

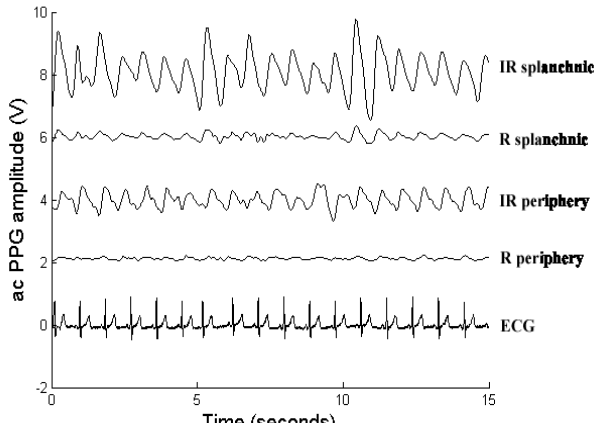

Fig. 4 ac red (R) and infrared (IR) PPG signals from the liver and periphery with simultaneous ECG

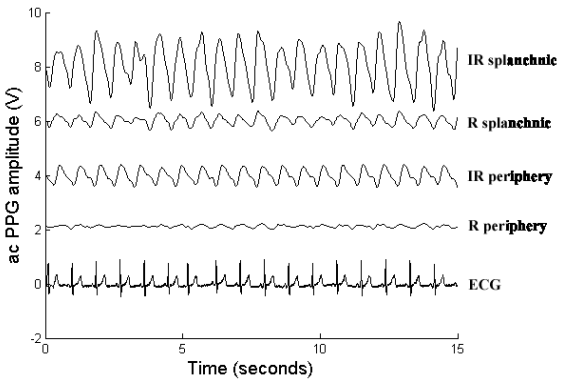

Fig. 5 ac red (R) and infrared (IR) PPG signals from the stomach and periphery with simultaneous ECG

In order to provide an indication of how PPG amplitudes differ between sites, the mean splanchnic ac and dc PPG amplitudes for each site were calculated. The mean peripheral ac and dc amplitudes were also calculated (Fig. 6 and 7).

Although this is an uncalibrated system, preliminary mean SpO_2 values were calculated for the small bowel, large bowel, liver, stomach and periphery (Fig. 8). The mean SpO_2 values from the commercial pulse oximeter are also included for comparison purposes.

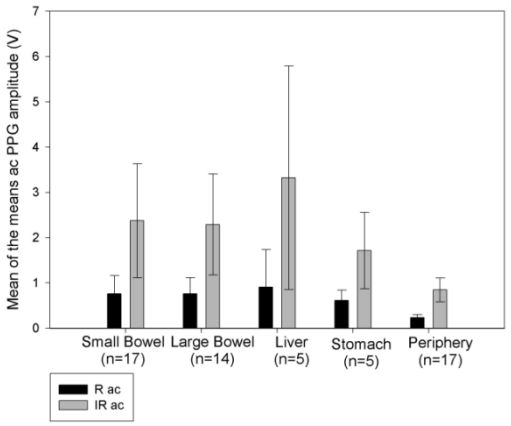

Fig. 6 Mean (±SD) ac PPG amplitudes for the small bowel (n = 17), large bowel (n = 14), liver (n = 5), stomach (n = 5) and the periphery (n = 17)

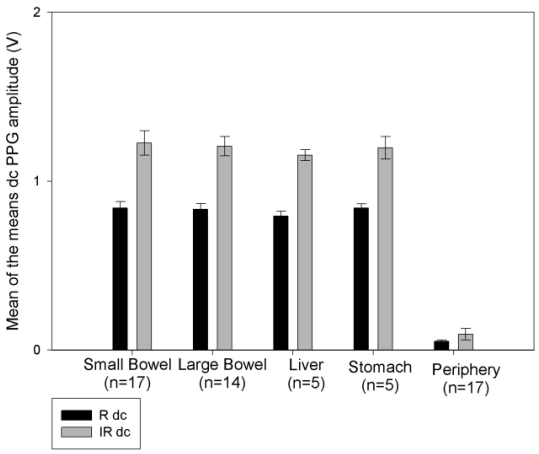

Fig. 7 Mean (±SD) dc PPG amplitudes for the small bowel (n = 17), large bowel (n = 14), liver (n = 5), stomach (n = 5) and the periphery (n = 17)

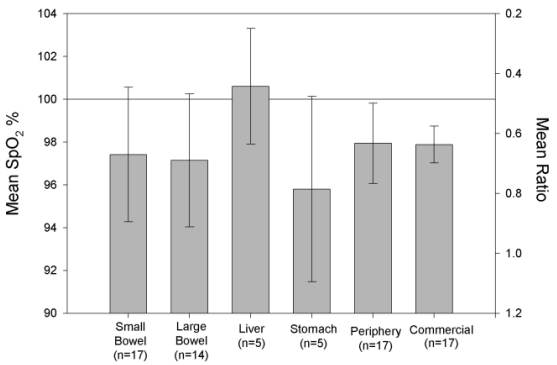

Fig. 8 Mean SpO_2 (±SD) values for small bowel, large bowel, liver, stomach, and periphery. The mean SpO_2 (± SD) value from the commercial device (GE Healthcare) is also indicated for comparison

IV. CONCLUSIONS

A new fibre optic pulse oximeter probe, an instrumentation system and a virtual instrument were successfully developed and evaluated on seventeen patients during surgery. Good quality PPG signals were recorded on all attempts from various splanchnic organs. By observing Fig.6 and Fig.7 it can be seen that there is a significant difference between the mean ac and dc PPG amplitudes obtained from the splanchnic sites when compared with those obtained from the periphery. These differences might be due to differences in tissue type and vasculature amongst the sites investigated. It is possible that the arteries and therefore the blood supply are closer to the surface of the tissue in splanchnic organs when compared to a peripheral site such as the finger. In such occasions the light travelling through the splanchnic tissue will possibly encounter more pulsatile arterial blood along its path, than light travelling in the finger. Therefore, this may explain the larger red and infrared ac PPG signals obtained from the various splanchnic organs in comparison with those obtained from the finger.

Furthermore, due to the thick epidermis layer present in the peripheral tissue, light travelling in the finger may undergo more absorption due to non-pulsatile tissue than light travelling in the splanchnic region. Again, this may explain the smaller red and infrared dc PPG amplitudes obtained from the finger.

Despite the differences in the amplitude of the splanchnic PPGs, the mean SpO_2 values from all splanchnic sites together with the peripheral SpO_2 values estimated from the peripheral fibre optic pulse oximeter and the SpO_2 values obtained from the commercial pulse oximeter showed a broad agreement as depicted in Fig 8.

This preliminary evaluation has provided sufficient confidence that the PPG signals acquired from splanchnic organs using a new fibre optic pulse oximeter probe are of sufficient quality to be used in the determination of splanchnic arterial blood oxygen saturation.

ACKNOWLEDGMENT

The authors would like to thank the EPSRC (UK) for funding this work.

REFERENCES

[1] Rittoo D, Gosling P, Bonnici C et al. (2002) Splanchnic oxygenation in patients undergoing abdominal aortic aneurysm repair and volume expansion with eloHAES. Cardiovascular Surgery 10: 128-133

[2] Jury of the Consensus. (1996) Tissue Hypoxia: How to detect, how to correct, how to prevent? Intensive Care Med 22:1250-57

[3] Dantzker DR. (1993) The gastrointestinal tract. The canary of the body?, JAMA, 270:1247-8

[4] Crerar-Gilbert AJ, Kyriacou PA, Jones DP, Langford RM. (2002) Assessment of photoplethysmographic signals for the determination of splanchnic oxygen saturation in humans. Anaesthesia 57: 442-45

[5] Lynn Dyess D, Bruner BW, Donnell CA, Ferrara JJ, Powell RW. (1991) Intraoperative Evaluation of Intestinal Ischemia: A Comparison of Methods. Southern Medical Journal 84: 966-970

[6] Kinnala PJ, Kuttila KT, Gronroos JM, Havia TV, Nevalainen TJ, Niinikoski JHA. (2002) Splanchnic and Pancreatic Tissue Perfusion in Experimental Acute Pancreatitis. Scandinavian of Gastroenterology 7:845-849

[7] DeNobile J, Guzzetta P, Patterson K. (1990) Pulse Oximetry as a means of assessing bowel viability. Journal of Surgical Research 48:21-3

[8] Ouriel K, Fiore WM, Geary JE. (1988) Detection of occult colonic ischemia during aortic procedures: use of an intraoperative photoplethysmographic technique. J. Vasc. Surg. 7: 5-9

[9] Hickey M, Kyriacou PA (2007) Development of a New Splanchnic Perfusion Sensor. Conf. Proc. IEEE. Eng Med. Bil. Soc, 2952-5

Use macro [author address] to enter the address of the corresponding author:

Author: Dr Panayiotis A Kyriacou
Institute: City University London
Street: Northampton Square
City: London
Country: United Kingdom
Email: P.Kyriacou@city.ac.uk