Development of a Reflectance Photoplethysmographic Sensor used for the Assessment of Perfusion of Free Jejunum Flaps: a case report

Tina Zaman, P.A. Kyriacou
School of Engineering and Mathematical Sciences
City University London
London, UK
Tina.Zaman.1@city.ac.uk, p.kyriacou@city.ac.uk

A. Belhaj[1], R. M. Langford[1], H. D. L. Patel[2]
[1]Pain and Anaesthesia Research Centre, [2]Department of Plastics and Reconstructive Surgery
Barts and the London NHS Trust, UK
London, UK

Abstract— **Free jejunum flaps have been widely used as a reconstruction option after total laryngopharyngectomy. Monitoring of flap perfusion assists in early detection of flap failure, increasing the possibility of flap salvage.**

Considering the free jejunum flap is a hidden flap there is still no single reliable, non invasive perfusion monitoring technique to assist in recognizing flap failure. We have developed a dual-wavelength photoplethysmographic (PPG) sensor and processing system to investigate the ability of the system in detecting flap perfusion. This is a case report of evaluation of the new prototype reflectance PPG sensor on one patient undergoing total laryngopharyngectomy and reconstruction with a free jejunum flap. PPG signals were successfully obtained intra-operatively which suggest that photoplethysmography may be a suitable method for assessing free jejunum flap perfusion.

***Index Terms*—Photoplethysmography, Jejunum, Free Flap, Perfusion.**

I. Introduction

The jejunal free flap is a standard technique commonly used in reconstructive surgery of the head and neck [1]. In patients diagnosed with early carcinomas of the upper aero-digestive tract, laryngopharyngectomy is often performed; this procedure involves the complete removal of the larynx with partial or complete removal of the pharynx. The pharynx is then reconstructed using a flap from part of the intestine, the jejunum, which provides a way to preserve the patient's ability to swallow [2]. Free jejunal flaps are used as they can provide cover for large circumferential defects, secrete mucus, have intrinsic peristalsis, tolerate radiotherapy well and they do not cause strictures, these are important factors which are advantageous in selecting this flap for use in the upper pharynx and esophagus [3].

Free flap is the detachment of tissue from a specific section of the body with its blood supply which is transferred to a recipient site [4]. The most serious complication of free flap is anastomotic thrombosis which occurs post-operatively, resulting in graft necrosis [5]. The mortality rate of jejunal flap when used for reconstruction of the esophageal defect is between 2.4% and 5% which usually occurs within the first 3 postoperative days [6]. In intestinal flaps the tolerance for low levels of oxygen in blood is 2 hours, after which the tissue becomes necrotic [4].

Therefore the success of such procedure strongly depends on the maintenance of adequate perfusion in the flap. It is imperative to detect any indication of ischemia early as revision of microvascular anastomosis and restoring blood flow might salvage the flap to avoid further surgery and harvesting additional jejunum flap from the abdomen [5, 7]. Postoperative monitoring of the flap is necessary to identify vascular compromise as delayed diagnosis may result in flap failure.

Numerous techniques and monitoring devices have been used for assessing perfusion of jejunal flaps post operatively. Katsaros *et al* described one of the most popular methods of observing the viability of the flap post operatively by dividing the jejunum into two segments, one of which to be used for reconstructive purposes and the other segment used for monitoring; both of these parts are left on the same mesenteric blood supply [8]. The exteriorised section will be used for monitoring the flaps color, temperature, peristalsis and bleeding during the postoperative period. Similar methods of this monitoring technique with possible variation to its surgical procedure are "watch window" or sentinel [5-6, 9].

Laser Doppler flowmetry and microdialysis have also been used in monitoring the jejunum flap by securing the probe directly on the flap intra-operatively and leaving the probe in place for post operative monitoring [10-11].

However, there are disadvantages to these techniques such as; the requirement for technical skill or subjective interpretation from the medical staff, intermittent monitoring and invasive nature of the monitoring device. Therefore, there is still a need for a less invasive, accurate, easy to use, reproducible and inexpensive monitoring device.

In an attempt to overcome the limitations of the current techniques for assessing jejunum flap perfusion, this paper describes the design, development and preliminary *in vivo* assessment of an optical sensor and processing system utilizing the principle of reflectance photoplethysmography.

The concept of using photoplethysmography in monitoring free flaps has previously been discussed in an initial pilot study [7] as well as its use in monitoring the bloody oxygen saturation in the esophagus [12].

Photoplethysmographic signals are acquired from the interaction of light emitted from LEDs at specific wavelengths and their absorption by oxy-haemoglobin and deoxy-haemoglobin through the tissue and detection of the reflected or transmitted light using a photodetector. The amount of light detected is dependent on the volume of blood in the arteries and arterioles which change due to the pulsation of blood. The PPG signal acquired is divided into two components, the ac and dc signals. The ac is the pulsatile component of the signal which usually represents the change in arterial blood volume. The dc component of the signal is the signal detected from the non-pulsatile components which the light has been reflected or transmitted by, such as tissue, bone and venous blood [13].

Pulse oximetry utilizes PPG measurements to determine the oxygen saturation of arterial blood (SpO_2). By using two wavelengths of 660nm (red) and 940nm (infrared) and measuring the light absorption of blood, it is possible to estimate the blood oxygen saturation [14]. From the amplitude of the ac component and the constant voltage of the dc component of the PPG signal at these two wavelengths, the R/IR ratio is calculated and the resulting value is compared to a “look-up” table which is based on calibration curves derived from healthy subjects at various SpO_2 levels [14]. Equation (1) is used to derive the R value.

$$R\ (\text{ratio}) = (ac_{660}/dc_{660})/(ac_{940}/dc_{940}) \qquad (1)$$

The calculated R value is then used to compute the arterial oxygen saturation using (2).

$$SpO_2 = 110\text{-}25R \qquad (2)$$

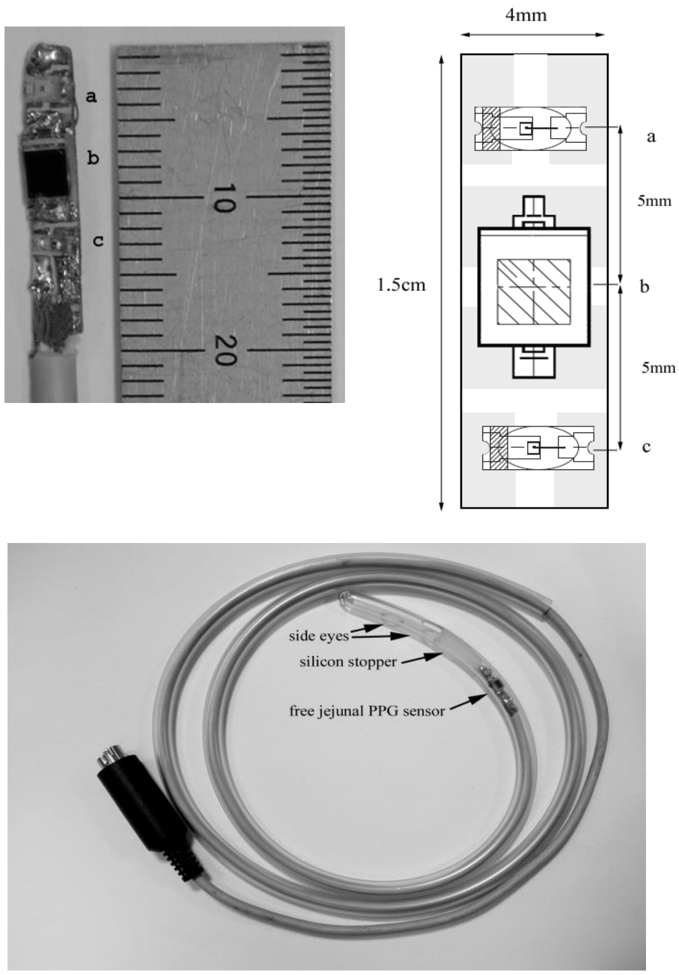
II. Methods

A. Photoplethysmographic Sensor

A new reflectance, dual-wavelength photoplethysmographic sensor was developed which consisted of one infrared (IR) and one red (R) ceramic chip surface mount LED (peak emission wavelengths at 940 nm and 660 nm respectively) and a photodiode (single photodiode with an active area of 7.5 mm^2 with spectral range sensitivity between 400-1100 nm). Fig.1 shows the photograph and the diagram of the developed sensor.

The distance between the LEDs and the photodiode was 5 mm as such distance has been proven to provide good quality PPGs in reflectance pulse oximetry [15]. The shape of the sensor was rectangular and designed to be adequately narrow in width in order to be accommodated into the jejunal flap which is 2.5 cm in internal diameter during and after the operation. Also, the PPG sensor was designed to fit into a conventional transparent sterile nasogastric tube 20 CH (each French units = 0.33 mm) (see Fig 1 iii).

(i) (ii)



(iii)

Fig. 1. Reflectance photoplethysmographic free jejunal flap sensor; (i) shows a photograph of the jejunal PPG sensor; (ii) shows a diagram of the free jejunal flap PPG sensor; a: IR surface mount LED; b: PIN photodiode in miniature flat plastic package; c: Red surface mount LED; (iii) is a photograph of the PPG sensor inside the nasogastric tube with silicon stopper in place to prevent liquid damage to sensor.

B. Processing System

A battery powered processing system has been designed and developed to drive the optical components of the jejunal photoplethysmographic sensor and also to detect and pre-process the red and infrared ac and dc PPG signals. A block diagram of the processing system is shown in Fig.2.

A programmable microcontroller (AVR ATtiny2313) was used to generate multiplexing clock signals at 100Hz which were used to switch both red and infrared LEDs on and off in such a way that at no time both LEDs were on. The driver current of both LEDs was set to 70 mA. The light emitted by the LEDs interacts with the vascular tissue under observation and the backscattered energy was then detected using a photodiode which converted this energy to current.

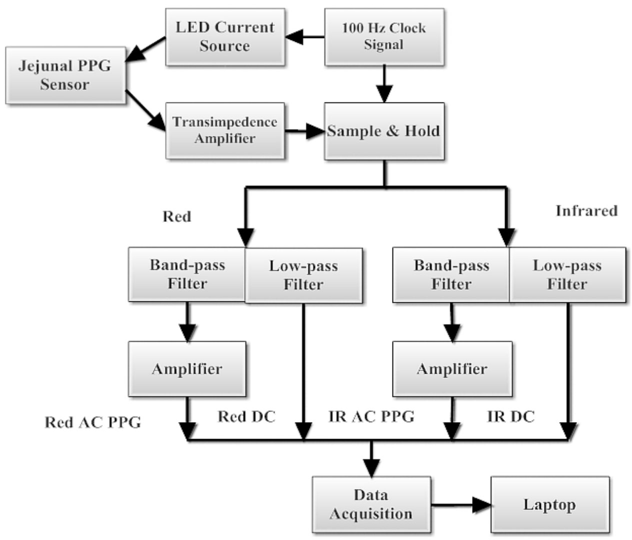


Fig. 2. Block Diagram of the processing system.

A transimpedance amplifier was then used to convert the current to voltage. This signal contained both red and infrared PPG signals and therefore a sample and hold circuit was used in order to demultiplex the signals to their individual wavelengths using the clock signals generated by the microcontroller. The separated red and IR signals were then filtered using a Butterworth second order band-pass filter with a cut off frequency of 0.5 Hz and 19 Hz in order to extract the ac PPG signal and a low-pass filter with a cut off frequency of 1.5 Hz in order to extract the dc component of the obtained PPG signals. The ac PPG signals at both wavelengths were then amplified before digitization. All ac and dc PPG signals at both wavelengths were then digitized using a 12-bit data acquisition card (DAQCardTM-6024E) by National Instruments. A Virtual Instrument (VI) was implemented using LabView in order to acquire, display, analyze and store the PPG signals in text format for further offline data analysis.

C. Preliminary Investigation of Free Flap Sensor

Local research ethics committee approval and patient consent were acquired prior to the study. The clinical trials were carried out at The Royal London Hospital, UK.

A pilot study on a free jejunum flap surgical case was carried out to test the functionality of the PPG sensor and its capability in detecting PPG signals at both wavelengths in the jejunum flap.

Following isolation of the jejunal, the flap was then transferred to the neck when the recipient vessels were isolated. The venous and arterial anastomosis were then performed by the surgical team. Prior to removal of the arterial clamp an initial measurement was acquired by placing the PPG sensor inside the distal end of the jejunal flap and kept it in place during the process of clamp removal in order to capture the reperfusion and the flow of blood through the jejunal flap. The second PPG measurement also took place in the operating room after the flap was re-perfused in its final position (in the recipient site). Fig.3 shows a photograph taken intra-operatively after the upper and lower anastomosis of the jejunum and esophagus were performed and prior to closing the surgical site with a chest drain in place.

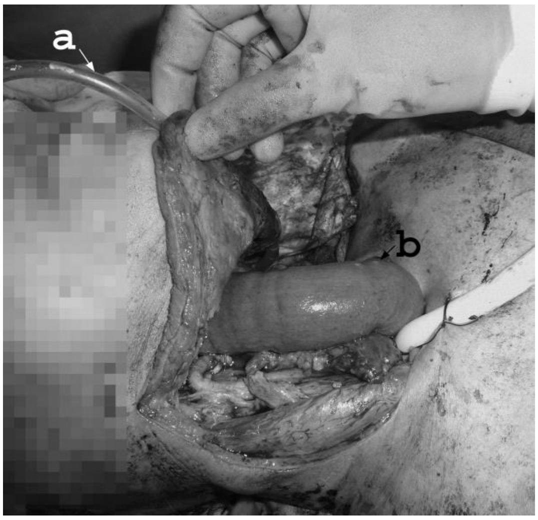


Fig. 3. Jejunal flap sutured in recipient site; a: jejunal PPG sensor in nasogastric tube fed through the nasal cavity; b: the jejunal flap with PPG sensor.

III. Results

Photoplethysmographic signals of good quality and at both wavelengths were successfully recorded intra-operatively.

A. Intra-operative Measurement

Following anastomoses of the vessels of the free flap to the recipient site, arterial and venous clamps were removed thus resulting in blood flow through the free flap. Fig. 4 depicts the PPG signals before and after the release of the arterial clamp.

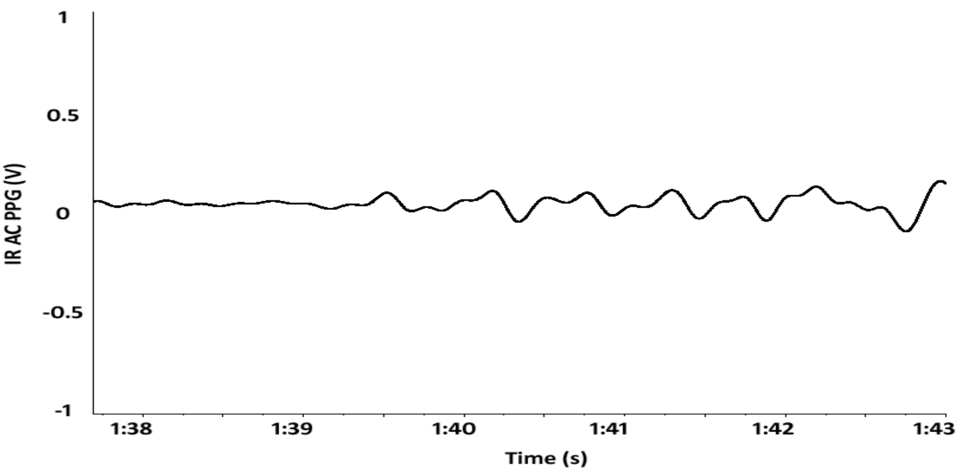


Fig. 4. Free flap IR ac PPGs (arterial after the venous and arterial clamps were removed.

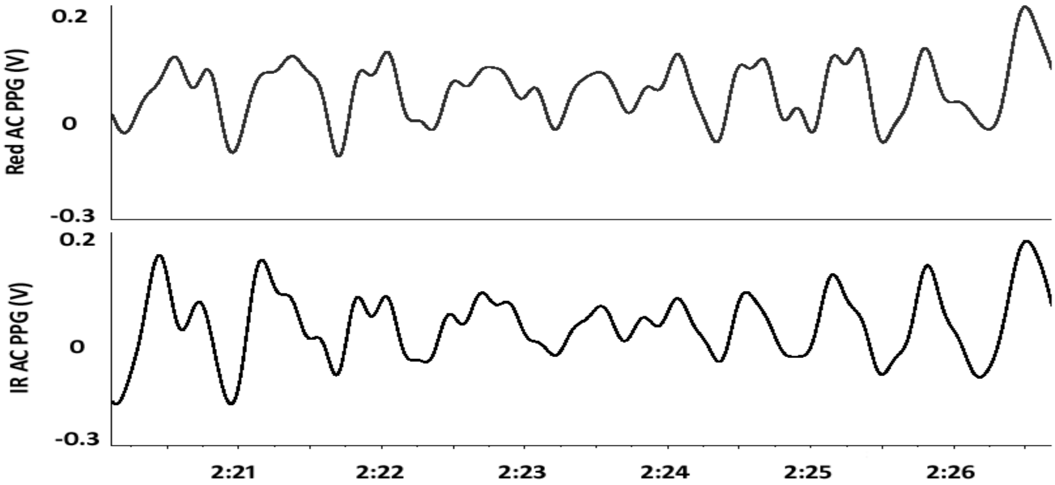


Fig. 5. Jejunal flap red and IR ac PPG signals two minutes post clamp removal.

In the first section of Fig. 4, a low amplitude noise can be seen (no PPG was observed). As the clamps were removed at approximately 01:38 seconds (see Fig.4), a noticeable PPG signal was observed which suggests the successful reperfusion of the flap.

Fig. 5 shows a seven second period of red and IR ac PPGs two minutes post flap reperfusion.

B. Pulse Oximetry in Free Jejunal Flap

Good quality PPG signals were obtained following clamp removal and during post reperfusion of the flap.

Blood oxygen saturation values estimated (using (1) and (2)) from the jejunal sensor were in broad agreement with the commercial finger pulse oximeter used during this study.

IV. CONCLUSION

A dual-wavelength photoplethysmographic free jejunal flap perfusion sensor and processing system has been successfully designed and developed. The system was used in a pilot study for intra-operative measurements. Good quality photoplethysmographic signals, which act as an indicator of good perfusion were acquired from the jejunal free flap during the operation. Preliminary SpO_2 values from the jejunal sensor were calculated and were in broad agreement with the commercial finger pulse oximeter. This is the first time that a dual-wavelength (red and infrared) PPG system has been used for monitoring perfusion in free jejunal flaps as well as providing the advantage of estimating blood oxygen saturation in these flaps.

In conclusion, this work details the design and development of a free jejunal flap photoplethysmographic sensor, and presents preliminary clinical measurements. The results of this pilot study suggest that such technology has the potential to be used for the assessment of jejunal flap perfusion. This device also has the potential for use in post-operative monitoring of the free jejunal flap. Clinical trials are currently underway in order to evaluate the technology further and investigate flap perfusion post operatively.

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