Multispectral Imaging using a Fast Filter Wheel System during Vascular Surgery

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INTRODUCTION

Visualisation of oxygenation of the *vasa vasorum* as a means of assessing oxygen transport from the lumen to the vessel walls may be a valuable tool for the study of haemodynamics at anastomotic junctions [1]. This information could then be used for prediction of neointimal hyperplasia (NIH), a thickening of vessel walls, which itself is a cause of anastomotic failure [2]. Currently, in the case of fistula failure for example, NIH is not specifically detected in individual patients but has been identified in studies as a cause of stenosis [3]. Intraoperative measurement of vessel wall oxygenation would allow further investigation of the correlation between oxygenation and clinical outcomes.

Recent work by our group has shown the applicability of multispectral imaging in the measurement of perfusion changes intra-operatively for robotic surgery applications in the bowel [4], and for organ viability monitoring following anastomoses of transplanted organs [5]. These spectral imaging systems used liquid crystal tuneable filters (LCTFs) with convenient electronic switching capabilities to extract high spectral resolution information. However, LCTFs have transmission values of less than 50%, which must be compensated for with long integration times [4].

In this paper, a laparoscopic adaptation of a fast filter wheel multispectral imaging (MSI) system is demonstrated using the recently-developed SpectroCam platform (Ocean Optics, Inc., USA). This allows high-throughput imaging at multiple spectral bands at 30 Hz. Initial *in vivo* results obtained using the system in a porcine subject show changes in oxyhaemoglobin at the anastomosis site during arterio-venous fistula creation.

MATERIALS AND METHODS

The laparoscopic system described in this paper is built on the SpectroCam platform (Fig. 1), which is a fast filter wheel multispectral imaging device capable of accommodating up to eight separate filters. The spectral properties of the current configuration are shown in Fig. 1 (a). Acquisition of five multispectral stacks, of eight high-resolution (1392×1040 pixels) images each, can be accomplished in 0.27 s. A 30° laparoscope (KARL STORZ GmbH & Co. KG, Germany) was attached to the system using a custom-made F-mount adapter. This also housed a 50 mm focal length imaging lens that fixed the working distance at approximately 3 cm.

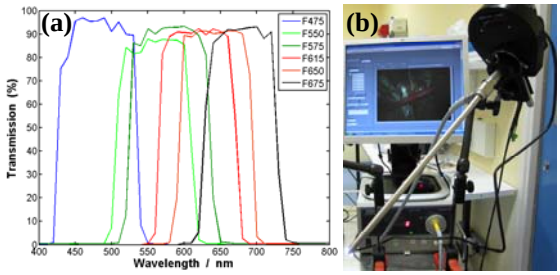

Fig. 1 (a) Transmission characteristics of filters used, covering the visible range. (b) Photograph of MSI system with laparoscope and xenon white light source attached.

The system was used to monitor perfusion at the anastomosis site during the creation of an arterio-venous fistula in a 75 kg Yorkshire pig (conducted under a Home Office licence). The carotid artery and jugular vein were exposed through a 12 cm incision in the neck and then joined in an end-to-side anastomosis. In order to complete this, the artery was clamped upstream of the anastomosis site, flushed with saline and clamped again downstream. The jugular was clamped and divided in preparation. Static MSI images of the artery in its native state, and after clamping and flushing were acquired. A time series was then acquired as the clamps were released to monitor the perfusion change in the vein.

Perfusion and oxygenation changes were assessed by measuring the absorbance of light at each filter waveband. Reflected light was compared to the reflected light intensity from a reference standard at each waveband to calculate the experimental absorbance, A (Eq. 1).

$$A = -\ln\left(I/I_R\right) \quad \textbf{(1)}$$

where I is the measured intensity at a particular waveband and I_R is the corresponding intensity detected from a reflectance standard. Assuming that absorption

by haemoglobin is the dominant mechanism of light attenuation and that scattering losses are flat across the wavelength range of interest then a simple model [6] can be used to predict *A*, as shown in Eq. 2.

$$A = [HbO_2]\varepsilon_{HbO_2} + [Hb]\varepsilon_{Hb} + \alpha \qquad \textbf{(2)}$$

where [HbO_2] and [Hb] are fractional concentrations of oxy- and deoxy-haemoglobin respectively, ε is the known extinction coefficient of haemoglobin (convolved with the spectrum of each filter in Fig. 1) and α is a constant term accounting for scattering losses. Experimentally measured absorbance spectra from each pixel location in the MSI stack were then fit by the three parameter model in Eq. 2 to calculate [HbO_2] and [Hb] at each point in the field-of-view.

RESULTS

Figure 2 shows the dissected porcine aorta prior to anastomosis isolated with a sterile plastic sling. The colour image shown in Fig. 2 (a) was assembled from three of the wavebands centred on 475, 575 and 650 nm. In the oxyhaemoglobin colour map (Fig. 2 (b)), the fine network of the *vasa vasorum* is visible in the central portion of the image. Superficial droplets of blood resulting from the dissection obscure the extreme ends.

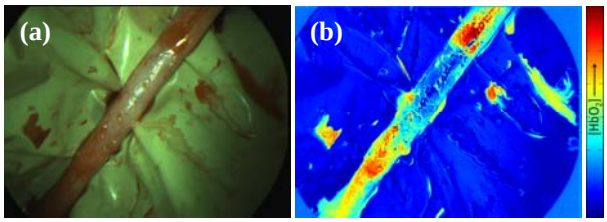

Fig. 2 MSI of the porcine aorta. (a) Colour RGB. (b) Map of oxyhaemoglobin concentration.

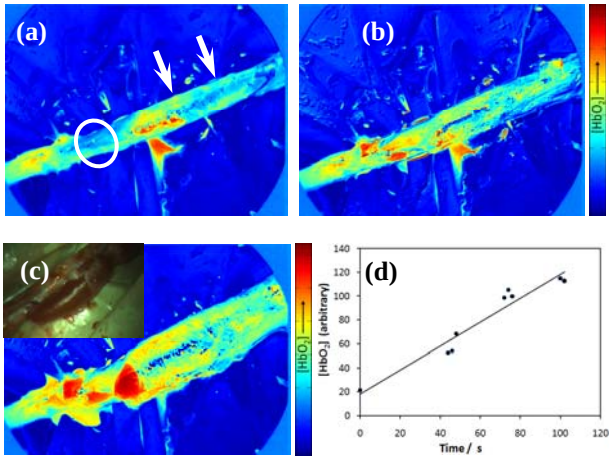

Fig. 3 Arterio-venous anastomosis. The jugular vein is lying directly on top of the aorta (white arrows) and the location of the sutures is indicated (white circle). The change in oxyhaemoglobin concentration over time following the release of the upstream aortic clamp is shown at (a) t = 0 s (b) t = 72 s (c) t = 114 s. Inset: side view of the anastomosis. (d) [HbO_2] time course for region of interest indicated in (a).

Following the clamping and flushing procedure described earlier, the jugular vein was joined to the aorta in an end-to-side anastomosis. Figure 3 (a) shows the site immediately prior to the release of the clamps with the vein lying directly on top of the artery.

The high-speed acquisition of the MIS system allows capture of the haemodynamics as highly oxygenated arterial blood begins to flow into the vein. The increase in oxyhaemoglobin is visible in Fig. 3 (d) along with the characteristic dilatation of the vein due to the increased arterial pressure.

DISCUSSION

A new laparoscopic implementation of a multispectral imaging system has been presented. The fast filter wheel allows rapid detection of multispectral image stacks, minimising the influence of motion artefact. This was seen in the *in vivo* data in the capture of the venous dilatation. The transmission filters used have high light transmission (almost 100%), exceeding alternative systems such as LCTFs and resulting in reduced noise.

The results described here combine absorption by blood in the lumen of the vessel as well as the *vasa vasorum*. Future work will concentrate on further analysis of the origin of the absorption signal in depth and the separation of these contributors. This will allow a greater understanding of the mechanism of oxygen transport across the vessel walls. Possible applications include monitoring and predicting the success of arterio-venous fistulae and optimisation of anastomosis procedures.

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