Hyperspectral Reflectance and Fluorescence Probe for Endoscopic Imaging

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I. Introduction

The current standard of care dictates that lesions discovered during inspection of the gastrointestinal (GI) and respiratory tracts are removed, due to the fact that confirmation of tissue pathology is only possible through histological examination of excised tissue (biopsy). However, many lesions are subsequently confirmed as benign (40%, in the case of colonic polyps [1]), and therefore could have been left *in situ*, had the clinician been able to make an objective, quantitative assessment *in vivo*. This would avoid potential risks and discomfort to the patient during tissue removal, as well as reducing lab costs for the hospital. Furthermore, the risk of sampling error when choosing a biopsy site, which has been reported in diagnosis of Barrett's oesophagus [2], can result in false negatives. Quantitative tissue assessment could help avoid this by guiding the clinician's choice of where to biopsy.

Commonly-used commercial imaging modalities, such as narrowband imaging (NBI), have shown potential in identifying Barrett's oesophagus and classifying colonic polyps by increasing the contrast between blood vessels and background tissue. However these techniques still require the clinician to make a subjective assessment, the accuracy of which is highly dependent on their experience and training. Reported improvements are often variable and not statistically significantly better than white light assessment alone [3]. Biophotonic methods employing quantitative spectral analysis of the tissue have recently shown promise in extracting pathology-specific information from optical measures of structure and function [2, 4, 5]. Additionally, endogenous fluorophores related to metabolism have demonstrated signal changes specific to neoplastic and non-neoplastic tissue [6].

In this paper an endoscopic hyperspectral imaging (HSI) probe is described that can measure tissue diffuse reflectance and autofluorescence. The system, compatible with standard flexible endoscopes, is described, and demonstrations of its usability on test targets and intraoperatively are presented.

II. Materials and Methods

The probe is a custom assembly (FiberTech Optica, Inc., Canada) incorporating a 30,000-element fibre image guide (FIG; Fujikura Ltd., Japan). A tip-mounted GRIN lens (Grintech GmbH, Germany) forms an image onto the distal face of the FIG, while illumination is provided by 21 multimode optical fibres surrounding the lens [7]. The illumination fibres are divided into three arms, carrying light from a xenon lamp (Karl STORZ GmbH, Germany), 375 nm laser (Roithner LaserTechnik GmbH, Germany), and 405 nm laser (Thorlabs Ltd., UK). Pushbroom HSI is implemented by imaging the FIG's proximal face onto the slit of a spectrograph (ImSpector, Spectral Imaging Ltd., Finland) using a 10× objective and 100 mm focal length lens. An sCMOS camera (optiMOS; QImaging, Inc., Canada) detects the dispersed spectrum. The complete set-up in shown in Fig. 1.

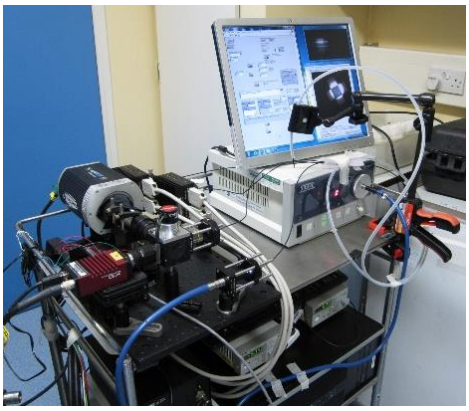

Fig. 1. Multimodal hyperspectral imaging endoscope.

Scanning was accomplished with a 1D galvo-scanning mirror (Thorlabs Ltd., UK). Positioning the mirror parallel to the probe's optical axis allowed light to pass straight through to an RGB camera (Prosilica; Allied Vision Technologies, USA) for video-rate white-light navigation.

The system was characterised using a USAF target for resolution and Macbeth colour chart for spectral validation. The probe was used in a pilot *in vivo* experiment in an open porcine abdominal surgery to image the serosal surface of the bowel. In diffuse reflectance mode the xyλ hypercube was used to calculate tissue oxygen saturation (StO_2), total haemoglobin (*THb*) and to reconstruct colour (RGB) data [8]. Autofluorescence emission spectra under 375 and 405 nm excitation were then acquired sequentially.

III. Results

Images of a USAF target show that, at a working distance of 10 mm, the Group 1, Element 4 lines are resolvable, while at 20 mm the Group 1 Element 4 lines parallel to the y-axis are indistinguishable. Spectral validation results from five different Macbeth colour panels are shown in Fig. 2 along with RGB images reconstructed from the spectra. The recorded spectra show good agreement with the gold standard device (spectra measured using a separate spectrometer [USB 4000HR, Ocean Optics, Inc., USA]), and the reconstructed RGB images also show good qualitative similarity to the ground truth. The largest errors were observed at wavelengths below 450 nm and above 650 nm.

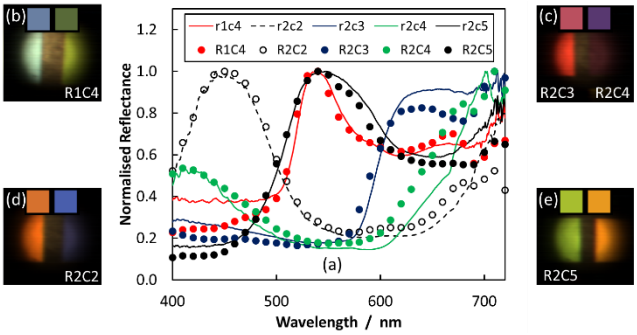

Fig. 2. Spectral validation. (a) Reflectance spectra of selected Macbeth panels measured using the HSI system (dots, 10 nm resolution) and stand-alone spectrometer (solid lines). (b-e) Corresponding reconstructed RGB images of panels alongside ground truth manufacturer images. *Modified from [7].*

In vivo imaging results from porcine large bowel are shown in Fig. 3 and demonstrate that, despite breathing-related motion, vascular features seen in the navigation camera can also be found in the HSI data. Sub-mm diameter vessels are visible on the surface using 50 lines to reconstruct the image.

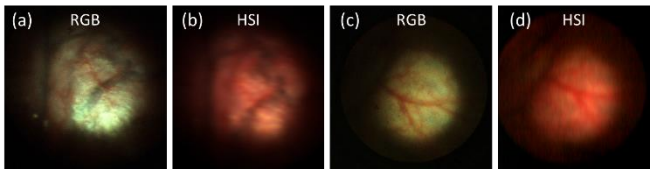

Fig. 3. Serosal surface of large bowel imaged using (a, c) the RGB navigation camera and from (b, d) 50 HSI scan lines.

An absorbance spectrum of a region of small bowel is shown in Fig. 4. The 500-620 nm range was used to carry out least-squares regression, subject to assumptions [8], resulting in the fit indicated by the solid red line. The regression output was used to calculate *THb* and StO_2 for each pixel location.

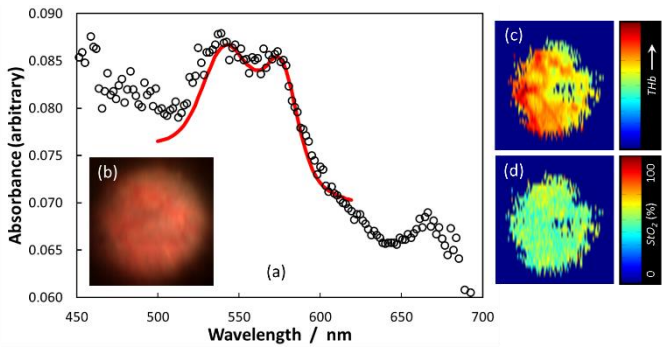

Fig. 4. (a) Tissue absorbance spectrum showing oxyhaemoglobin double-peak and regression model fit (red line). Processed HSI images showing (b) reconstructed RGB and maps of (c) *THb* and (d) StO_2.

Autofluorescence emission results are shown in Fig. 5. The spectrum is characteristically broad, and peaks over the green and red regions of the visible spectrum. A total fluorescence image was formed by integrating the detected signal at wavelengths greater than the excitation light. The image in Fig. 5 (b) shows generally homogeneous emission from the tissue, with a dark line corresponding to the location of a blood vessel.

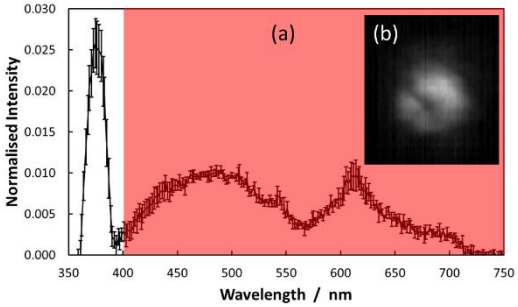

Fig. 5. (a) Average autofluorescence spectrum from small bowel tissue. The large peak is the 375 nm excitation light. (b) Fluorescence emission image using signal integrated from wavelengths greater than 400 nm.

IV. Conclusions

An endoscopic HSI probe has been developed that can measure diffuse reflectance and autofluorescence from tissue. The probe, compatible with clinical endoscope biopsy ports, can resolve sub-mm vascular features from 50 pushbroom-scanned lines. Spectral detection accuracy has been verified using a Macbeth colour chart and high resolution spectrometer. *In vivo* results show that the system can detect the haemoglobin absorption signal in bowel serosa, and calculate *THb* and StO_2. In autofluorescence mode the imager detected broad emission spectra consistent with NADH and collagen. Dark lines in the integrated autofluorescence images were likely due to reabsorption by haemoglobin in blood vessels. These results demonstrate the potential utility of this device in future clinical experiments as high resolution spectral data were recorded and spatial information preserved, despite tissue motion.

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