Bimodal MRI-optics endoluminal probe for early stage colorectal cancer diagnosis: Design and Preliminary in-vivo results.

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Introduction

Flat adenomas are precursors of colorectal cancer and develop mainly underneath the mucosal layer. Their growth leads to angiogenesis which is also hallmark of colorectal cancer[(1)]. Early detection and resection are keys to reducing death and recurrence rate. Due to initial sub-surface development, subtle morphological deformations are tricky and delicate to assess through White Light Endoscopy (WLE). High spatial Resolution Magnetic Resonance Imaging (HR-MRI) might provide an alternative solution to this problem. Optical spectroscopy has tremendous potential in diagnosing biochemical changes through non invasive optical biopsies[(2)]. This ongoing study is aimed at coupling HR-MRI to optical spectroscopy through the design and development of an endoluminal bimodal probe and highlights how these 2 techniques complement each other to offer an innovative and early stage colorectal cancer diagnostic tool.

Material and Method

Following a first macroscopic version of the bimodal probe[(3)] in which a single optical fiber was used for the optical modality, a second version (ø-12 mm, length-50mm), hereby presented and consisting of a dual optical channel coupled to the MR modality, was designed (fig 1a) and built (fig 1b). The overall architecture was conceived around a single-loop MR coil of rectangular geometry developed and caracterised previously[(4)].

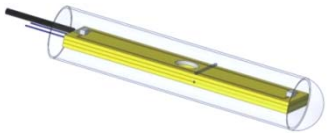

Figure 1a: Bimodal probe designed using Solidworks.

The conductive pathway (rectangular loop) was etched (chemical milling) on a Printed Circuit Board (PCB) of 50mm (L) x 10mm (W) x 0.8mm (H). The Printed Circuit Assembly is composed of a set of case A ATC capacitors (American Technical Ceramic, New York) allowing a 63.7 MHz tuning and a 50 Ω matching. An active decoupling circuit was also included using a PIN diode (Temex DH 80106 PIN diode) driven by the MR system during RF pulse transmission. As for the optical modality 2 pairs of 200 µm core diameter UV-VIS optical fiber, each pair formed by an excitation and emission fiber were used.

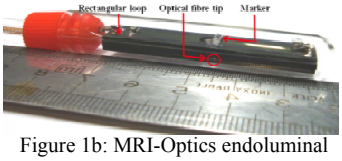

Figure 1b: MRI-Optics endoluminal probe used during our experiments.

The optical fibers were lodged antagonistically on a copper-free PCB on which two 400 µm large grooves with a 9 mm curvature radius had been carved. Bending the optical fibers assured that the ROI was the same for both modalities. Moreover, a 0.8mm diameter tube filled with 1,25g/L NiSO4 water solution was fixed on the PCB at the exact location where the pair of fibers acquired their spectra. This marker was used for precise optical ROI localisation on MR images. Both PCB were then fixed together and housed in a glass sheath (fig 1c). The optical excitation-emission bench consisted of a 405 nm laser for autofluorescence spectroscopy and a halogen white light for diffuse reflectance spectroscopy. A feasibility study was then carried out *in-vivo* on a small animal model, a rabbit. All *in-vivo* experiments strictly abided to a protocol validated by the University Ethic Committee. The probe was inserted 10 cm in the rabbit's colon while the latter was under general anesthesia. An aqua-gel was used to facilitate the probe insertion all while preventing any interference (parasitic fluorescence emission) with the optical measurements. The pre-established imaging protocol was composed of high-resolution 2D Flash sequences with and without Fat Saturation (FS), 2D and 3D True-Fisp, Turbo Spin-Echo (TSE). Imaging parameters were: 60 to 80 mm FOV; 1.5 to 2.5 mm slice thickness; 448 base matrix. For endoluminal coil tracking, a 2D True-Fisp sequence in the coronal plane with real time reconstruction was performed with 1 sec/image acquisition rate. Optical spectroscopy which was performed while MR acquisitions were underway took no more than 2 seconds per spectrum.

Results

Real-time tracking of the endoluminal coil within the colon (fig 2) provided the exact spatial localisation of the probe during acquisition. We followed the marker which appears in hypercontrast on the image (shown by arrows fig 2 & 3) for that. The SNR gain of the endoluminal coil (fig 3a) compared to the SNR of gain of the external 8-channel abdominal coil (fig 3b), measured at 15 mm from the centre of the image was 25/1. The mucosal and sub mucosal complex was clearly distinguishable (fig 3a) from the highly contrasted image and high SNR obtained with the internal coil. Such fine degree of differentiation with the external coil cannot be reasonably attained even with much longer scan durations.

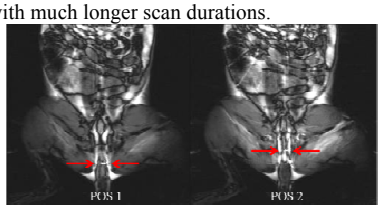

Figure 2: real-time endoluminal coil tracking performed with a 2D True-Fisp sequence with a TR/TE of 6/3ms and a 70° flip angle.

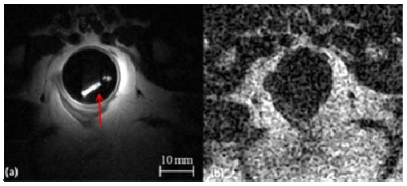

Figure 3: MR image of endoluminal coil (a) compared to external coil (b). T2-weighted TSE sequence with a TR/TE of 3000/94 ms, 70 mm FOV, 2mm slice thickness and a 156 x 222 µm^2 pixel size was used for both acquisitions.

Autofluorescence spectra of the 2 ROI were identical and confirmed the healthiness of the rabbit. Intrinsic fluorophores[(5)] accounting for the peak around 500 nm (fig 4a) are being scrutinised and NADH seems to be the main active fluorophore. Reflectance spectrum acquired (fig 4b) underlines the high mucosal surface vasculature and when fitted with absorptivity data of oxy and deoxy-haemoglobin[(6)] (modified Beer-Lambert's law), highlights the contribution of haemoglobin which absorbs much of the excitation light within the 500-600 nm range. How blood oxygen saturation affects the measurements was also witnessed through dynamic acquisitions.

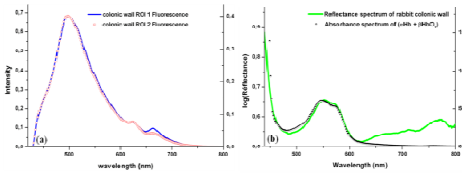

Figure 4: a. Colonic wall autofluorescence. b. Reflectance spectrum fitted with Hb & HbO_2 absorptivity data.

Conclusion

The first part of this ongoing study provided a technical validation of both modalities working simultaneously without interference and also demonstrates the tremendous potential of coupling HR-MRI to optics. A smaller, flexible and guided probe (6mm outer diameter) more suitable for small animal model is already being built to further this study. It will also allow a larger section of the colon to be analysed.

References

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