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The Use of Fibre Optic Sensing Technology with Intraluminal Impedance Catheter for Functional Gastrointestinal Motility Disorders

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Abstract Summary (35 words)

We present a composite impedance fibre optic manometry catheter for monitoring functional gastrointestinal disorders (FGID). The catheter uses a dual lumen silicone extrusion to separate each technology and has been validated in ex-vivo animal models.

Keywords; Fibre Optic Sensors. Fibre Bragg Gratings, High Resolution Manometry Catheter, Intraluminl Impedance Catheter, Gastroenterology, Motility.

I. INTRODUCTION

Functional Gastrointestinal Disorders (FGID) are associated with abnormal motor patterns of the gastrointestinal (GI) tract. FGIDs include dysphagia (difficulty in swallowing), irritable bowel syndrome, diarrhoea and constipation and can be associated with abdominal pain and bloating. At any given time around one third of the population in Australia report symptoms associated with FGID [1]. Treatment options for FIGDs are variable and their efficacy is dependent upon understanding the cause of the associated symptoms.

When abnormal motor patterns (gut contractions) are suspected there are a number of different tools that can be used to help in the diagnosis or to understand what motor abnormalities are associated with the symptoms [2]. One of these tools, used primarily in the diagnosis of swallowing disorders is impedance/manometry which provides greater diagnostic capability than manometry alone [3]. This tool combines two components: i) manometry which consists of an array of sensors that record the intraluminal pressure and contact force associated with gut contractions; and ii) impedance which records resistance to alternating currents measured between electrode pairs. Impedance within the gut can be used to record the transit of content since the electrical resistance changes as content moves across the electrode pairs. In addition, when the electrical characteristics of the luminal content are controlled, impedance can also provide a measure of the cross sectional area of the lumen.

The current commercial impedance manometry catheters contain electrical or solid state pressure sensors. The large number of wires required to monitor both impedance and pressure increases the catheter diameter, reduces overall flexibility and limits the impedance sensor spacing to 2 cm intervals. Therefore an impedance value can only be attributed to every second pressure sensor (pressure sensors are spaced at 1cm intervals).

Previously our group has developed a fibre-optic manometry catheter based upon Fibre Bragg Gratings (FBG) [4]. These manometry catheters have proven to be a viable clinical tool for recording gut contractions over long sections of the GI tract [5]. Each fibre within these catheters can contain up to 36 sensors spaced at 10 mm intervals and as each catheter can have 4 separate fibres we can manufacture manometry catheters with up to 144 sensors while still maintaining a high degree of flexibility and an external diameter of less than 3 mm.

The device reported here combines impedance technology with a smaller variant of our FBG sensors [6], [7] that allows the inclusion of 17 impedance sensors spaced at 10 mm intervals in a catheter with a diameter of 2.8 mm. This paper reports the recording capabilities of this catheter in excised sections of guinea pig and rabbit colon.

II. METHODS

A. Catheter Design

The fibre optic pressure sensors were formed from a pair of helically wound Draw Tower Grating arrays each with FBG elements space 10 mm apart and with Bragg wavelengths spaced at 2 nm intervals over the range 1510 nm to 1590 nm. The winding was controlled so that the FBGs in each fibre at each sensing location were oriented one above the other and either side of the FBG was bonded to a rigid substrate using thermally cured epoxy (EPO-TEK 353 ND, Epoxy Technology, Billerica, MA, USA), so that the applied pressure increased the strain in the lower FBG and decreased it the upper FBG, as shown in Figure 1. This removes the characteristic temperature sensitivity

commonly seen with FBG sensors because the applied force results in a differential change in wavelength whereas a change in temperature causes a common mode change [7].

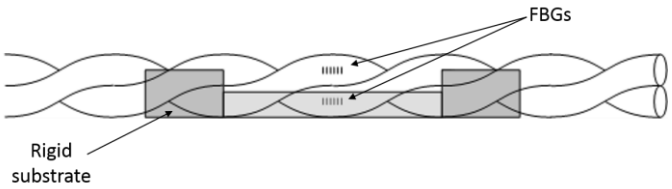

Figure 1. Pressure sensor formed by a pair of fibres containing FBGs arrays bonded into the stainless steel substrate. The FBGs are allocated in the middle of the window and one above the other.

The catheter (Figure 2) was assembled in a dual lumen silicone extrusion of 2.8 mm outer diameter, 2.4 mm inner diameter and containing two semi-circular lumen. The fibre optic sensing array contains 35 pressure sensing regions spaced at 10 mm intervals. The fibre optic sensing array is contained in the upper lumen of the extrusion and the other lumen contains the wires to connect the electrodes with the data acquisition system. The 17 impedance electrodes were also spaced at 10 mm intervals and were coincident with the central 17 pressure sensing elements.

To form the electrodes the wires are pulled through the outer skin of the second lumen and wrapped around the catheter. The wires are then bonded in place with conductive epoxy (EPO-TEK H20E, Epoxy Technology, Billerica, MA, USA).

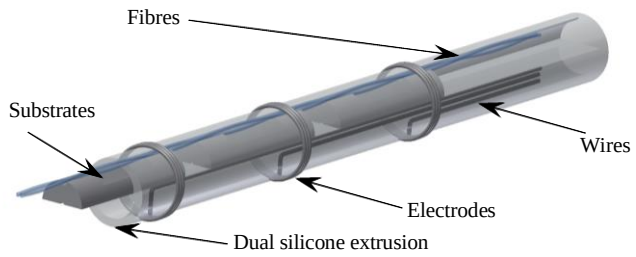

Figure 2. Schematic of a section of the impedance manometry catheter showing the location of optical fibre sensors, electrical wires, electrodes and dual lumen extrusion.

B. Equipment

Three different data sets were used in the experiments; impedance, pressure, and diameter of the segments. This allowed us to directly correlate contractile activity measured using the optical pressure sensors with the luminal cross section measured using impedance. The luminal diameter was confirmed using direct video imaging of the preparation.

A digital video camera (Canon Legria HF S20. Ota, Tokyo, Japan), positioned above the preparation was used to record video images to create spatiotemporal maps of changes in diameter, referred to as 'Dmaps'[8].

Intraluminal impedance was recorded by Bioview impedance manometry system (Sandhill Scientific, Denver, CO, USA), connected to the electrodes to record the impedance of the two consecutive pair of electrodes along the catheter.

A spectral interrogator unit (FBGS FBG-scan 804; FBGS International, Geel, Belgium), connected to the fibres was used to record the pressure profile along all the 35 sensors simultaneously to create spatiotemporal maps of changes in pressure, referred to as 'Pmaps' [9].

C. Procedures

The impedance manometry catheter was tested in excised sections of the proximal and distal colon of two rabbits and the proximal colon of one guinea-pig. Sections of gut were removed from the laboratory animals by methods approved by the Animal Welfare Committee of Flinders University. The removed sections of colon were placed into a beaker containing oxygenated Krebs solution (in mM: NaCl, 118; KCl, 4.7; NaH2PO4, 1.0; NaHCO3, 25; MgCl2, 1.2; D- Glucose, 11; CaCl2, 2.5) and bubbled with 95% O2/ 5% CO2. The faecal pellets were gently flushed out of the colonic segments with Krebs solution.

The excised section of gut was then placed into an organ bath containing the same Krebs solution warmed to 35°C. The Krebs solution keeps the gut alive for many hours allowing both spontaneous and stimulated muscular activity to occur.

In the organ bath the anal end of the proximal colon was attached to a T-shaped plastic connector and the oral end of the proximal colon was attached to another T-shaped plastic (Figure 3). The catheter was passed through T-shaped connector at the oral end and the vertical arm of the oral T-piece was connected to an infusion pump. Warm (35°C) Krebs solution was infused through the infusion pump at different rates (10 rpm to 15 rpm) in order to stimulate contractile activity.

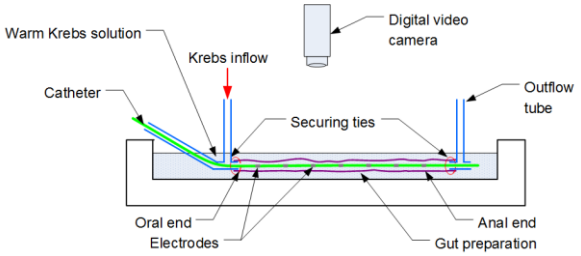

Figure 3. Experimental set-up used to carry out the experiments with the impedance manometry catheter.

D. Construction of diameter maps (Dmaps) and pressure maps (Pmaps)

The videos were re-sampled down to ten frames per second in Quicktime (Apple, Cupertino, California, USA). Each video was then converted into spatiotemporal maps of changes in diameter (Dmaps) using custom-written software in Matlab (MathWorks, Natick, MA, USA) [9]. Based upon earlier work from our laboratory [8], the diameter at each point along the length of the colon was calculated for each frame and converted into grayscale pixels. Regions of minimal diameter (contraction) were represented on maps as white pixels, whereas maximal diameter (distension) was represented by black pixels. Dmaps presented here represent the entire section of colon removed from the animal, with only those regions

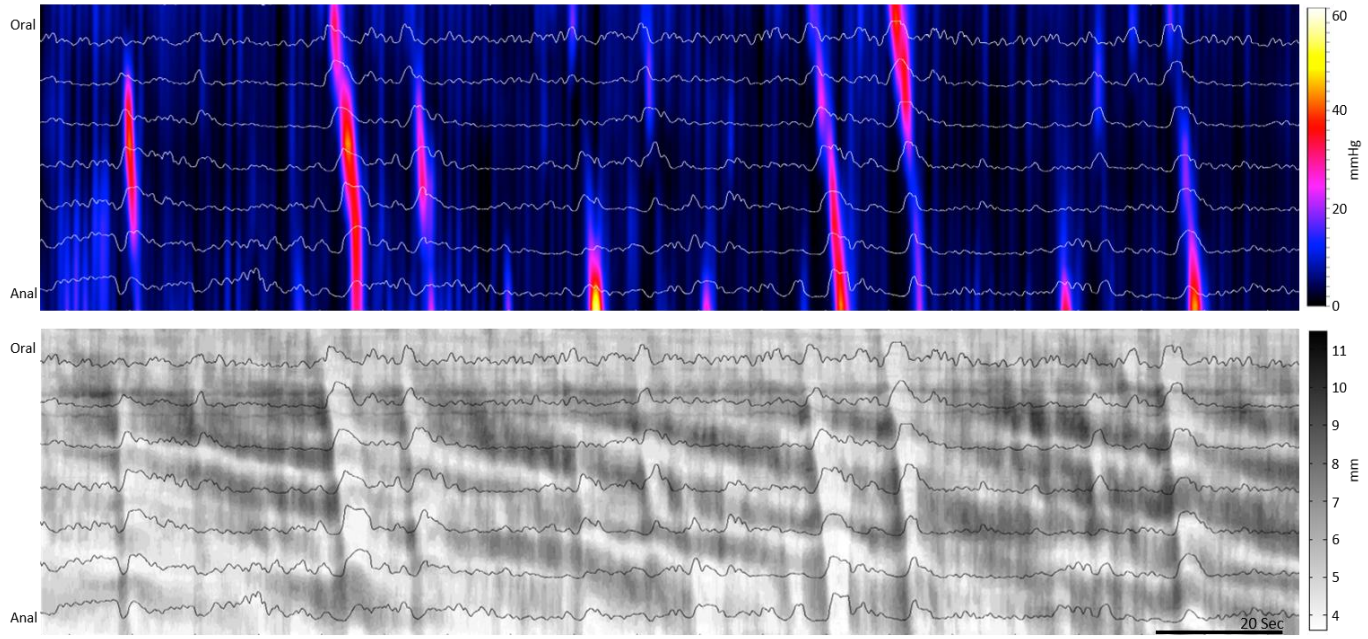

Figure 4. Pressure, impedance and changes in diameter representation of a section of 10 cm guinea pig proximal colon from oral to anal in y axis and time in x axis: a) Pmap with impedance signals, colours represent changes in pressure ranging from 0 to 60 mmHg b) Dmap with impedance signals, greyscale represents diameters ranging from 4 to 11 mm. Impedance is shown in arbitrary units in both instances.

overlying the cannulas at oral and anal ends removed from the analysis.

The recorded manometric and impedance traces were viewed and analysed using software (PlotHRM) developed by one of the authors (LW). The software was written in Matlab (The MathWorks, MA, USA) and Java (Sun Microsystems, CA, USA). The line traces of pressure were converted to spatiotemporal pressure maps (Pmaps) using this software.

III. Results

Data collected from the experiment were processed and plotted in both Pmap and Dmap formats with the impedance signals shown as line plots in Figures 4 a & b. Pmap shown in Figure 4a, the colours represent changes in pressure ranging from 0 to 60 mmHg. Dmap shown in Figure 4b the greyscale represents diameters ranging from 4 to 11 mm. The impedance measurements are only qualitative and are displayed in arbitrary units since the electrical conductivity of the Krebs solution was not quantified during these experiments.

IV. Discussions

The present study is the first impedance fibre optic manometry catheter fabricated to study muscular contractions and the associated movement of luminal content. The small form factor of the fibre optic pressure sensors allowed us to reduce the size required for the manometry sensors and also removed the temperature dependence commonly associated with FBGs. The small pressure sensors also resulted in a highly flexible composite catheter with a diameter of < 3 mm which is significantly smaller than commercially available impedance manometry catheters. The dual lumen nature of the catheter allows the pressure and impedance functions to be assembled separately so that there is no interference between each measurement.

The impedance manometry catheter data has been validated against data obtained from direct video imaging. Comparing pressure, impedance and video data shows that an increase in luminal diameter due to the passage of a fluid bolus is closely followed by a contraction and an increase in pressure.

In our results, we can see these relations clearly. Observing at Dmap and Pmaps representations, dark regions in Dmap mean large diameter due to content and muscles relaxation as it is shown in Pmap to have low pressure. After a relaxation (increase in diameter) a muscular contraction generates a decrease in luminal diameter and increase in intra-luminal pressure. This is also related with impedance as it is inversely proportional to change in diameter when the conductivity of the content is constant.

V. Conclusions

An impedance manometry catheter using fibre optic sensors has been developed. The use of the FBGs as the pressure sensors has allowed us to form large numbers of pressure sensors in a limited space. This provides more real estate to run the electrical wires needed for the impedance electrodes without affecting the overall diameter or flexibility of the catheter.

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