EndoVine: Soft Robotic Endoscope for Colonoscopy

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INTRODUCTION

Colonoscopy is the gold standard examination procedure for screening colorectal cancer (CRC), providing the ability to inspect the lower digestive tract [1]. Standard colonoscopy is carried out with a minimally invasive approach based on a flexible endoscope controlled by the steering knobs. However, for routine screening, the intrusive nature of the intervention, the rigidity of the device and the lack of intuitiveness in steering can make the experience highly unpleasant to the recipient [2]. Patient discomfort and pain are due to tissue stretching and friction as the endoscope is pushed through the colon [1]. Furthermore, the use of rigid instruments introduces risks such as tissue perforation and anaesthesia-related adverse events [2]. Overcoming the design limitations of the flexible endoscope by using soft material can reduce both tissue stretching and friction, making it more tolerable for the patient.

Soft everting robots that show growth from the tip have demonstrated successful application in navigating highly constrained environment without damaging it. Tip-extending soft robots, called vine robots, take flexible film as body material and air pressure as input power to propel forward [3]. Natural orifice intraluminal procedures that operate through constrained bodily lumens such as colon, oesophagus, and trachea, represent suitable scenarios for vine robots. Recent work has investigated soft pressure-driven colonoscope via inflation of tip balloons [4], which may cause harmful local tissue stretching. Another work by Dehghani et al. developed a pneumatically driven colonoscopy robot [5]; however, their prototype does not allow retraction of the tip and does not provide room for instruments. Retraction of vine robots is believed to be a challenging problem due to the buckling of the robots [3].

Therefore, in this abstract, we present an Endoscopic Vine robot (EndoVine) designed for colonoscopy with a novel retraction mechanism. EndoVine comprises a double inverted soft inflatable sleeve that propels the tip using internal pneumatic propulsion. It will be equipped with an internal flexible channel for the camera, light source and working instruments to enable bowel inspection. The soft robotic body has been designed to be disposable, reducing the risk of infection transmission, which is a concern with traditional flexible endoscope [5]. In the following sections, we present the design of EndoVine and demonstrate its feasibility in navigating and retracting the colonic tract in a controlled manner. For the experiments, a simplified colon model was created referring to the CT colonography dataset [6] considering the opinion of the domain expert to conform with the shape and size of the average human colon. The colon model was 3D printed with a rigid polymer.

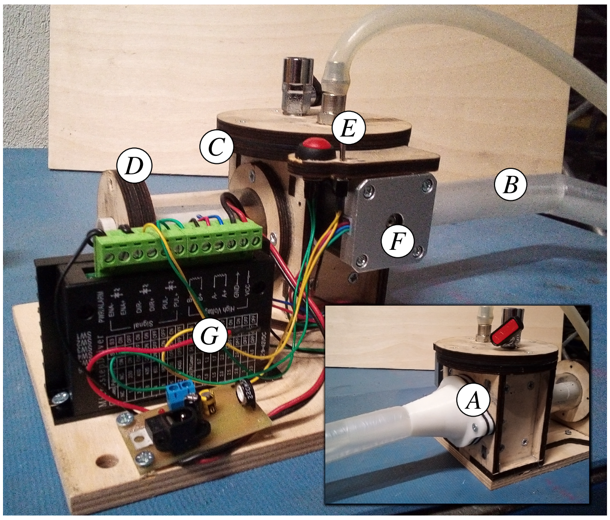

Fig. 1 The prototype of the EndoVine robot used in the experiments. (a) the anatomical interface, (b) the robot sleeve, (c) the airtight chamber, (d) the opening for the instrument insertion, (e) the air pressure connector, (f, g) the motor and its controller.

MATERIALS AND METHODS

EndoVine improves the technology of vine robots [3] making it suitable for colonoscopy with the adoption of a sleeved pressure chamber (Fig. 1). This approach allows for a free instrument channel in the centre of the robot through which the protruding tip carries a soft, bendable tube. The concept is based on the robotic growth inside the cavity to protect the surrounding sensitive tissue when instruments are inserted. By the properties of vine robots, the expansion occurs only at the tooltip, thus leaving the material in contact with the tissue static, reducing the overall friction.

The robot consists of a main pressurised airtight chamber, with the entry for the instrument channel on its

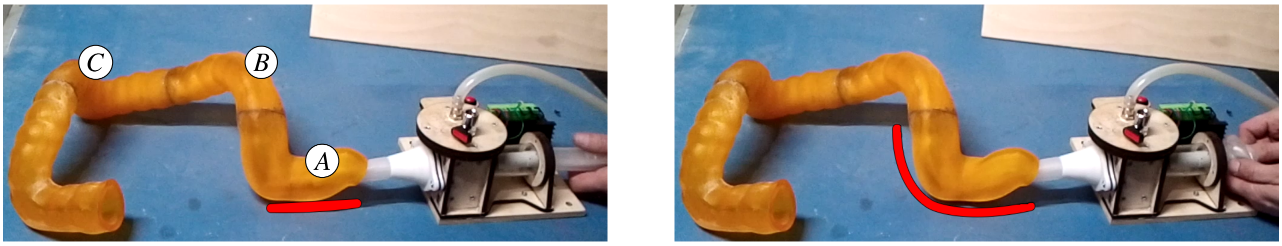

Fig. 2 The experimental setup. The EndoVine travels through the rectum (A) into the sigmoid curve (B). It adapts its shape to overcome the curve to reach the splenic flexure (C).

posterior side. There is an anatomical interface on the anterior side of the chamber from where the robot's sleeve grows. The airtight chamber has an electric stepper motor used to control the tip's eversion speed and provide the retraction of the robot's body. During retraction, the pressure is decreased while the stepper motor wraps the sleeve along a rigid tube at the posterior of the airtight chamber. The electric motor, using a set of rollers internal to the airtight chamber, wraps and unwraps the sleeves along the tube while the instrument channel goes through the back port. This is possible because the pressure of the sleeve keeps the internal instrument channel rigidly coupled to it.
The instrument channel for this preliminary setup is a silicon tube with 10 mm diameter. The soft sleeve is made with natural rubber latex and polymers, complying with ASTM F1671 clinical specifications. It has a diameter of 38 mm when inflated to be compatible with the anatomical dimension of the human colon.

RESULTS

The experiments show a preliminary evaluation of the navigation capabilities of our prototype using the colon model in Fig. 2. The air pressure to inflate the soft sleeve is tuned up to 0.15 bar maximum to reduce the risk of rupture and high forces on the surrounding anatomy. The entire length of the sleeve has been lubricated with Vaseline to reduce friction. The robot, as shown in Fig. 2, can traverse through the sigmoid curve and approach the splenic flexure, which are considered challenging bending curves [5]. To visualise the robot moving through the phantom, please refer to the supplementary video [1], where a rollout of the experiment is shown. The tip stops at approximately 60% of the colon length due to the current maximum length (46 cm) of the sleeve and the internal channel. The total navigation time is ~ 90 s comparable with that of standard endoscopists. Although representative of the general conformation and size of a real adult colon, the rigid colon model used to test the platform does not allow any flexing to accommodate the protruding robot tip.

DISCUSSION

The soft robot endoscope solution for colonoscopy could positively impact in the early detection of CRC by reducing patient discomfort and enhancing social acceptance. The sleeved pressure chamber solution proposed in this abstract introduces an inner flexible channel, which will pave the way towards safe, non-traumatic, intra-operative flexible instruments insertion. The current prototype requires further design and development: in particular, buckling shall be avoided during retraction. This can be done improving the wrapping mechanism in the posterior of the airtight chamber. Active steering mechanism at the tip of the robot will also be implemented to ensure successful navigation across challenging bends of the colonic tract, avoiding undesired pushing and friction on anatomical walls. Moreover, a more accurate selection of sleeve and inner chamber material will be required for the feasibility of a clinical application. We will finally perform more advanced testing of our prototype on more realistic deformable anatomical manikins with a longer sleeve and wider inner channel to improve navigation at most challenging colon bending and minimise the overall intrusiveness of the device.

ACKNOWLEDGEMENTS

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[1]Supplementary Video: `https://youtu.be/ahpHrZtOfmU`