T. Ranzani, S. Russo, C. J. Walsh, R. J. Wood. "A soft suction-based end effector for endoluminal tissue manipulation", in Proc. of the 6th Hamlyn Symposium on Medical Robotics, London, UK, June 2016

A soft suction-based end effector for endoluminal tissue manipulation

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INTRODUCTION

The trend towards reducing the invasiveness of surgical procedures has pushed research towards the development of smaller and smarter instrumentation, able to access remote body locations by passing through natural orifices or more convenient access points [1]. Although a variety of flexible instruments have been proposed in literature, the endoscope remains the gold standard for diagnostic and therapeutics procedures in the gastrointestinal (GI) tract. Performing therapeutic procedures, such as removal of early stage cancer, through an endoscope introduces several challenges with current instrumentation in terms of instrument stability and the capability to provide accurate and repeatable dexterous motions at the surgical site [2]. Techniques such as endoscopic submucosal dissection (ESD) have been proposed [3], but they require substantial learning curves. Different strategies have been proposed for augmenting the therapeutic capabilities of endoscopes by introducing manipulation aids or add-ons to the endoscope [4]-[6]. Embedding additional functionalities into a system that can be fixed at the tip of the endoscope represent a promising approach for improving current manipulation capabilities without disrupting the current procedure workflow. However, the design and fabrication of tools at these scales introduces several technical challenges, potentially limiting functionality. Recently, we have proposed a soft pop-up hybrid fabrication method as a promising approach for developing mm-scale mechanisms for minimally invasive surgery (MIS), and in particular in [7] we demonstrate a three degree of freedom (DoFs) arm actuated through embedded soft fluidic micro actuators that can be connected to the tip of an endoscope for manipulating endoluminal tissue (Fig. 1).

In this paper, we address the design of an end effector for manipulation of endoluminal tissue. Millimeter-scale end effectors that provide safe and effective manipulation presents a challenge for design and manufacturing. Previous work has primarily focused on jaw-like cable-actuated [8] or SMA-based grippers [9]. We propose a soft suction-based gripper that can be integrated at the tip of an arm as represented in Fig.1. The use of vacuum grippers in laparoscopy has been successfully investigated in [10][11], showing reduced skill-dependent damage to the tissues. In addition,

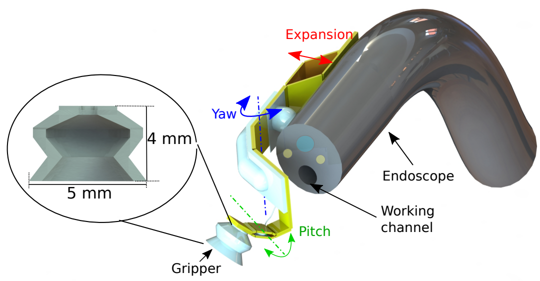

Fig. 1 CAD rendering of the soft pop-up arm proposed in [7] with an integrated suction based soft gripper.

Fig. 2. Left, fabricated prototypes of suction based soft grippers, right, zoomed view of the gripper.

suction has been successfully adopted as safe and painless locomotion strategy in the GI tract [12].

MATERIALS AND METHODS

The soft grippers are fabricated by molding Dragonskin 20 (DS20) and Ecoflex 0030 (Eco0030), (Smooth-On, PA, USA), using 3D printed molds. Four grippers are fabricated for each material (Fig. 2); the relevant dimensions are reported in the inset of Fig.1. A variation on the design includes a 200 μm membrane fabricated by spin coating Ecoflex 0030 on a wafer at 800 rpm for 30 s. The membrane is then bonded on the tip of the gripper to prevent clogging during suction.

The grippers are tested both *in vitro* and *ex vivo*. The *in vitro* characterization involved fixing the gripper on the moving tool of an Instron materials testing machine as shown in Fig.3a. Applying continuous vacuum pressure (-0.9 MPa) results in adhesion to the bottom plate. The maximum force before detachment is measured. In the *ex-vivo* test, pig stomach is selected as a specimen. The same protocol as for the *in vitro* tests is adopted. The gripper is fixed in the same way and the pig stomach is positioned on the bottom plate (Fig. 3b). A final test consisted of exploiting the gripper to tension the tissue specimen and use a scalpel to cut it (Fig. 4).

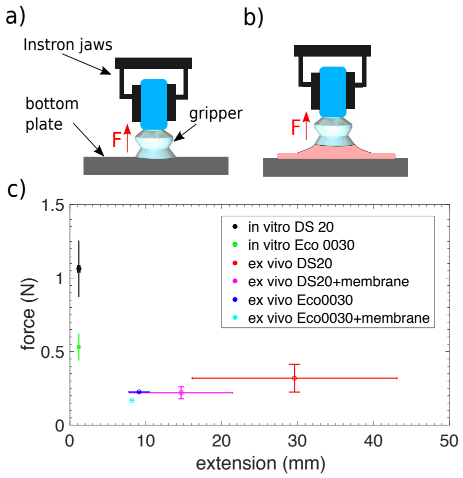

Fig. 3 Suction-based soft gripper characterization. Diagram of the setup used for *in vitro* a) and *ex vivo* b) tests. c) Results from the *in vitro* and *ex vivo* tests on pig stomach in terms of maximum tissue extension versus force required. Scale bars represents one standard deviation (for both maximum force and maximum extension) computed on three prototypes for each material, tested three times each.

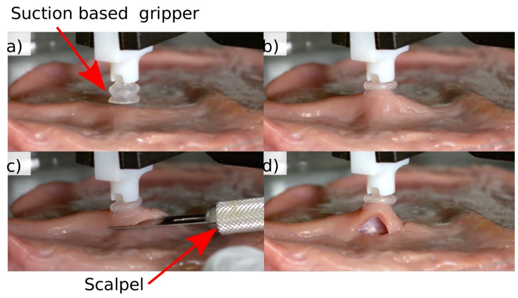

Fig. 4 Demo of the soft suction-based gripper: a) approaching the tissue, b) retraction, c) holding during cutting with a scalpel, d) additional tissue retraction.

RESULTS

Results from the i*n vitro* and *ex vivo* tests are reported in Fig. 3c. The plot shows the maximum extension versus the maximum force needed for three grippers for each material, grasping at three different locations on the tissue analogue. In the *in vitro* tests, the DS20 gripper is able to generate forces ranging from 0.9 to 1.26 N while the Eco0030 provided roughly half this force. In the *ex vivo* tests, the DS20 gripper is able to retract the tissue between 16 to 44 mm above the surface. The integration of the membrane leads to lower performance but still guarantees tissue tensioning and exposure for cutting (between 8 and 22 mm). The Eco0030 gripper resulted in lower retraction both with and without membrane. A demonstration of tissue cutting with a scalpel after pretensioning with a DS20 gripper is shown in Fig. 4.

DISCUSSION

We introduced a soft suction-based gripper for endoluminal manipulation. We tested two different materials, one softer (Eco0030) and one stiffer (DS20), the first one provided low forces and thus lower tissue exposure making it less suitable for effective tissue manipulation. The DS20 showed promising performance, providing newton range forces in *in vitro* conditions and tissue retraction up to 40 mm in *ex vivo*. We also investigate the effect of integrating a membrane on the grippers to prevent clogging during operation. The membrane reduces the performances of the gripper, although in the case of the DS20 gripper, it still provides a retraction of more than 10 mm. In order to better assess the functionality of the proposed gripper we performed a demonstration showing that the tensioning provided is sufficient to enable cutting of the specimen using a scalpel that would reasonably need more force with respect to commonly used electrocautery devices. Since the gripper uses suction, it easily grasps the tissue as soon as it is in contact with it. In addition, due to its soft nature, it passively follows changes in orientation during manipulation without requiring distal DoFs. Future work will focus on integrating the gripper on the arm presented in [7].

ACKNOWLEDGMENT

The authors would like to acknowledge the Wyss Institute for Biologically-Inspired Engineering for their support of this work. The authors would also like to acknowledge DARPA (grant FA8650-15-C-7548).

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