# Initial Feasibility Studies on Wireless Insufflation of the GI Tract

Jenna L. Toennies*, Gastone Ciuti[+], Byron Smith*, Pietro Valdastri[+],
Arianna Menciassi[+], and Robert J. Webster III*
*Medical & Electromechanical Design Laboratory, Vanderbilt University, Nashville, TN, USA
[+]Center of Research In Microengineering, Scuola Superiore Sant'Anna, Pisa, Italy

Commercial capsule endoscopes such as the PillCam (Given Imaging, Inc.) and competing devices are rapidly becoming the gold standard for diagnosis in the small intestine and are beginning to extend their reach into the esophagus and colon [1]. The success of passive commercial capsules has lead researchers to begin exploring ways to robotically enhance their diagnostic and interventional capabilities [2]. One difficulty with some of these mechanisms (as well as with visualization) is the lack of tissue distention via insufflation, which is an integral part of traditional endoscopy. Furthermore, a fundamental obstacle to clinical application of all but the simplest of robotic capsules is the lack of a sufficiently energy-dense power source. Valdastri et al. [3] determined that a large battery (10mm in diameter by 30mm long) was needed to power their legged capsule for a sufficiently long functional life (see Figure 1).

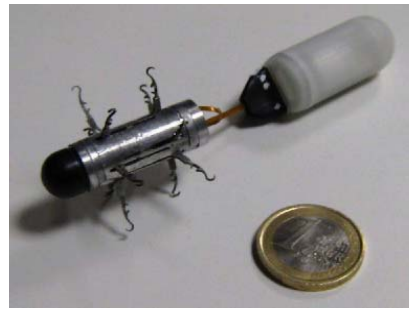

**Figure 1.** A 12-legged capsule developed by Valdastri et al. [3] which requires a separate battery pack for power supply due to space limitations onboard the capsule.

We propose fluid power (pneumatic pressure generated via liquid carried onboard the capsule) as a means of addressing both these issues. Previously applied in rocketry and prosthetics, fluid power can provide an order of magnitude higher actuation potential (an energetic figure of merit) than conventional batteries [4]. We foresee fluid power being used in the future to power miniature pneumatic actuators in robotic capsules. As an initial application of fluid power in capsule robots, we investigate wireless insufflation. Note that in comparison to many future robotic capsule applications, insufflation is simultaneously easier (simpler internal capsule mechanisms) and harder (more gas required). Furthermore, insufflation may be particularly useful for magnetically actuated capsules, which can be impeded by the deflated lumen of the gastrointestinal (GI) tract (see e.g. [5]). We hypothesize that insufflation can also improve visualization for all capsules in both the large and small intestines. We expect it to be particularly useful in the large intestine, where the larger lumen makes viewing the entire surface impossible.

To investigate this, a first prototype insufflation capsule was constructed to explore the feasibility of creating a fluid-powered capsule robot using off-the-shelf components [6] (See Figure 2). With a similar prototype, the feasibility of inflating a balloon attached to the front of a capsule has been demonstrated. This was accomplished using biocompatible Perfluorpentane (approximately 0.2mL), which is liquid at room temperature and gaseous at body temperature.

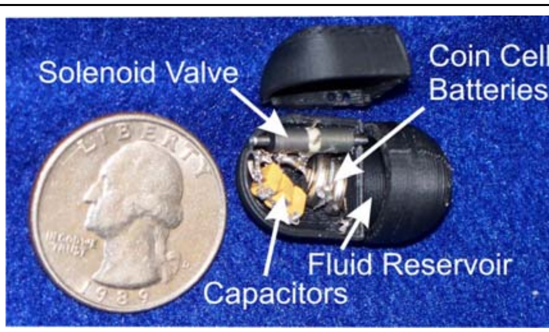


**Figure 2.** Internal components of the insufflation system: two 3V batteries charge 3 capacitors that fire the solenoid valve. In our initial proof-of-concept study we have packaged all components in a 26 mm long by 11 mm diameter capsule.

In our current work, we investigate how much fluid a capsule would have to carry to enhance visualization of the colon, if the gas were simply vented to the ambient environment. To assess this, we conducted the following experiment. We began with deflated porcine large intestine, with dimensions representative of an average adult colon (150cm long, 6cm in diameter) [7]. This was arranged in a human anatomical model in a configuration approximating the curved path of the human colon, and was sealed at both ends, with an endoscope inserted in one end. Nine colored markers serving as identifiable fiducials were evenly spaced and attached around the intestinal surface (see Figure 3(e)).

Using an insufflator for laparoscopy (Surgiflator-40, World of Medicine), the intestine was then incrementally inflated through a channel in the endoscope, with an inline flow sensor (AWM3300V, Honeywell) used to record volume. Images were captured using the endoscope camera at each volume increment. Results are shown in Figure 3. Using the Ideal Gas Law, we determined the fluid volume a capsule would need to carry to generate the inflation increments above, using a variety of candidate fluids, including Perfluoropentane, Chloromethane, and Hydrogen Peroxide. At just 50mL of inflation, visualization was improved (Figure 3b). At 100mL approximately 50% of the markers were visible, at which point the required initial fluid volumes that a capsule would have to carry were less than 0.713mL for all candidate fluids considered (commercial capsules have a volume of 2.47mL). Even the upper threshold of 450mL of gas, where all markers were visible, does not require more initial fluid than a capsule can hold for most candidate fluids (all but Perfluoropentane). Further experiments with Hydrogen Peroxide are ongoing, to validate theoretical calculations on gas production (see Figure 4).

We conclude that insufflation can be accomplished in a capsule constructed from over-the-shelf components, with a volume of fluid feasible for carrying onboard a swallowable capsule. Future work includes optimization of the capsule components and body, the integration of the wireless communication electronics and wireless circuit boards for controlling the solenoid valve, and the combination of insufflation with magnetic guidance.

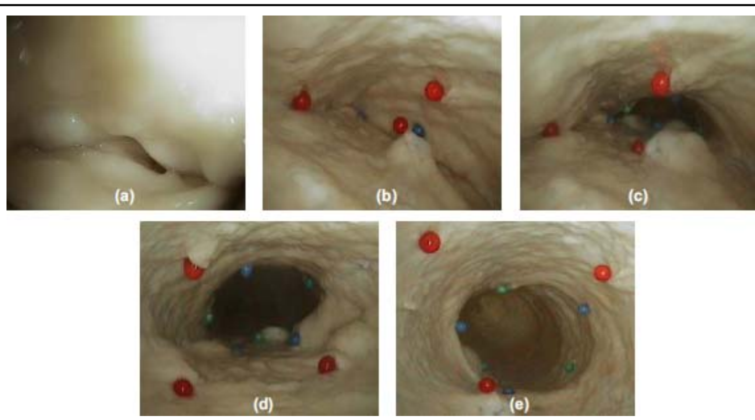


**Figure 3**: (a) The intestine in its deflated state, showing 0 of the 9 markers in the field of view with no insufflation. (b) With just 50mL of insufflation, 4 of the 9 markers become visible. (c) At 200mL, all 9 markers first come into the field of view. (d) The threshold above which all 9 markers were always visible was 450mL. (e) The maximum insufflation applied was 1500mL.

**Figure 4.** Hydrogen Peroxide reacting with a silver mesh.

[1] Moglia, A., Menciassi, A., Schurr, M., and Dario, P., 2007, “Wireless capsule endoscopy: from diagnostic devices to multipurpose robotic systems," Biomedical Microdevices, 9, pp. 235-243.

[2] Toennies, J. L., Tortora, G., Simi, M., Valdastri, P., and Webster III, R. J., 2010, “Swallowable medical devices for diagnosis and surgery: The state of the art," Journal of Mechanical Engineering Science, (In Press).

[3] Valdastri, P., Webster III, R. J., Quaglia, C., Quirini, M., Menciassi, A., and Dario, P., 2009, “A new mechanism for mesoscale legged locomotion in compliant tubular environments," IEEE Transactions on Robotics, 25(5), pp. 1047-1057.

[4] Goldfarb, M., Barth, E., Gongola, M., and Wehrmeyer, J., 2003, “Design and energetic characterization of a liquid-propellant-powered actuator for self-powered robots," IEEE/ASME Transactions on Mechatronics, 8, pp. 254-262.

[5] Ciuti, G., Valdastri, P., Menciassi, A., and Dario, P., 2010, “Robotic magnetic steering and locomotion of capsule endoscope for diagnostic and surgical endoluminal procedures," Robotica, 28, pp.199-207.

[6] J. L. Toennies and R. J. Webster III., 2009, “A Wireless Insufflation System for Capsular Endoscopes,” ASME Journal of Medical Devices, 3(2), pp. 027514.

[7] Encyclopedia Britannica Online. “Human Digestive System," 2009. http://www.britannica.com/.