Instruments and Techniques

A Novel Robotic Endoscopic Device Used for Operative Hysteroscopy

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ABSTRACT

To trial the use of a novel endoscopic robot that functions using concentric tube robots, enabling 2-handed surgery in small spaces, in a bioengineering laboratory. This was a feasibility study of the endoscopic robot for hysteroscopic applications, including removal of a simulated endometrial polyp. The endoscopic robot was successfully used to resect a simulated endometrial polyp from a porcine uterine tissue model in a fluid environment. The potential advantages of this platform to the surgeon may include improved exposure, finer dissection capability, and use of a 2-handed surgical technique. Further study regarding the safe, efficient, and cost-effective use of the endoscopic robot in gynecology is needed. Journal of Minimally Invasive Gynecology (2020) 27, 1631–1635. © 2020 AAGL. All rights reserved.

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Background

With the exception of the hysteroscopic morcellator, there have been few advancements in hysteroscopic technology in recent years. Indeed, innovations in operative hysteroscopy have been limited by the small size of the uterine cavity and the need to access this space through a device that also serves to provide vision and exchange of distension medium. Thus, surgical interventions have been restricted to linear movements with only 1 instrument at a time. This precludes the use of fundamental surgical principles such as traction and countertraction and application of electrosurgical energy perpendicular to tissue to minimize lateral thermal injury. Although current robotic platforms offer many advantages for gynecologic laparoscopy, these benefits are not able to be translated to hysteroscopic surgery owing to the limitation of uterine cavity size and access. However, adaptation of the principles of robotic endoscopic surgery may enable enhanced surgical techniques and capabilities for the hysteroscopic surgeon.

Materials and Methods

A new robotic system for endoscopic surgery is under development by Virtuoso Surgical, Inc. (Nashville, TN), with the goal of addressing the inability to apply current endoscopic instrumentation to confined spaces, including the bladder and uterus. The core technology of this system is based on concentric tube robot manipulators [1], which enable robotic tools to be miniaturized to a size amenable to deployment through a rigid endoscope (Fig. 1A). Two of these manipulators can be passed through a 9-mm sheath, along with a standard 3-mm rod lens. Each manipulator consists of 2 precurved nitinol tubes, which can telescopically extend and axially rotate with respect to one another to create “tentacle-like” motions at the tip of the endoscope (Fig. 1B). This provides a dexterous 2-armed instrument, with a tool motion that is independent of endoscope angulation, while simultaneously decoupling the movement of the...
endoscope view from the movement of the surgical instruments. This enables the surgeon to precisely resect tissue along complex geometries.

The tubes are held proximal to the endoscope and actuated by brushless direct current motors (one motor for telescopic extension-retraction of the tube and the other for axial rotation). The outer diameter of each manipulator is 1.5 mm, and the lumen of the inner tube is 0.75 mm. The innermost tube provides an open lumen suitable for passing a variety of interventional instruments to the concentric tube manipulator tips. For the set of experiments described below, an electro-surgical tip was used in 1 arm and a blunt probe was used in the other. Other tools that have been successfully prototyped for this system include monopolar electrosurgery tips, bipolar electrosurgery tips, forceps, side gripping/cutting tools, suction/irrigation, baskets, and plain probes.

The surgeon controls the movement of each of the manipulators using custom-designed input devices (Fig. 2). Each input device has 4 degrees of freedom: translation along the tool axis, as well as pan, tilt, and roll rotations. The control of the input device is analogous to controlling a laparoscopic tool with the tip of the input device representing the tip of the concentric tube manipulator.

A graphic of the system set-up (Fig. 3) is shown below. The endoscope is held by a robot-assisted arm that is positioned by the clinician and cannot undergo autonomous movement when the endoscope is engaged with the patient. The system is designed to be portable, allowing it to be easily moved between operating rooms. On the basis of laboratory attempts, the set-up time is estimated to be 15 minutes. Real-world studies will be needed to refine this estimate.

This system has been trialed in early benchtop training models and cadaver studies in other fields such as urology [2] and interventional pulmonology [3], and has promise for applications in neurosurgery and otolaryngology where the operative space is constrained. However, hysteroscopy presents some unique challenges, including the need to operate in a pressurized fluid environment, the need for broad visualization of the entire uterine cavity, and the need to apply significant forces to tissue to remove uterine pathology.
Our experimental protocol in applying this system to hysteroscopy follows. We performed several laboratory trials of the device in realistic animal tissue–based hysteroscopic simulators. Several porcine uterine models were obtained from Gynesim (Nelson, NH) [4] that included simulated pathology such as endometrial polyps, Asherman’s syndrome, and retained intrauterine devices (IUDs). The endoscopic robot was inserted through a 23 Fr rigid hysteroscopic sheath. A fluid inflow/outflow system was created that enabled the porcine models to be filled with saline.

Results

Polypectomy

The instruments used for this included a probe and monopolar electrosurgical tip (Fig. 4). The probe was useful for better exposing and stabilizing the base of the polyp while enabling the electrosurgical tip to resect the base of the polyp. Using surgical principles, applying tension on the polyp while operating improved the electrosurgical resection process. In addition, with very fine movements, the polyp could be repositioned as needed to expose more of the unresected base. This enabled resection of the polyp at the base with little surrounding tissue damage and required minimal time. Please refer to Supplemental Video 1 for a demonstration of this technique. Currently, using electrosurgery to remove a polyp can be accomplished with only 1 “hand.” This usually means taking large “swipes” with an electrosurgical instrument that encompasses a polyp base. The hysteroscopic morcellator or cold scissors offer less thermal tissue damage, but may leave the polyp base. The endoscopic robot may offer some advantages over both methods by enabling very fine application of electrosurgery.

Asherman’s Syndrome

The instruments for this technique included the probe and monopolar electrosurgical tip (Fig. 5). Surgical principles of traction and countertraction were used to more clearly define the appropriate surgical plane. The small monopolar electrosurgical tip was used to separate the layers. The ability to use traction resulted in a very small thermal spread and enabled the surgeon to minimize damage to the endometrium.

Embedded IUD

In this model, a hook was used to manipulate the IUD while the electrosurgical probe desiccated tissue directly over the IUD (Fig. 6). The application of traction of the IUD toward the surgeon enabled better tensioning of the tissue over the IUD and minimized damage to the surrounding tissue. In addition, being able to retract the IUD and overlying target tissue toward the surgeon with one “hand” while operating with the other hand may decrease the risk of uterine perforation.

Fig. 4

Images from the polypectomy experiment. (A and B) Moving the polyp with both manipulators to expose the stalk. (C and D) Cutting the stalk using electrosurgery while holding the polyp in traction. (E and F) Flipping the polyp up to expose the underside of the stalk and completing the resection.
**Fig 5**
Images from the Asherman’s syndrome experiment. (A–C) Exposing the tissue plane. (D) Cutting the adhered tissue using electrosurgery. (E–F) Retracting the cut tissue and continuing to cut along the tissue plane.

![Images from the Asherman’s syndrome experiment](image_url)

**Fig 6**
Endoscopic images from the embedded intrauterine device (IUD) experiment. (A) Cutting to expose the base of the IUD. (B) Grasping the IUD with the hooked tool. (C) Pulling the IUD away from the tissue. (D) Exposing more of the IUD by retracting the tissue and cutting with electrosurgery. (E–F) Removing the IUD.

![Endoscopic images from the embedded intrauterine device (IUD) experiment](image_url)
Conclusions

This is the first description of an endoscopic robotic system with multiple concentric tube manipulators adapted to the challenges of hysteroscopy. The robotic endoscope platform may be able to offer advantages over conventional hysteroscopy that could be useful for some indications. These potential advantages include improved vision by uncoupling of the telescope from hysteroscopic instruments, improved exposure with finer dissection capability, and simultaneous use of 2 independently controlled instruments to enable traction and countertraction. In addition, it may offer ergonomic advantages to surgeons by allowing them to stand and hold the controls at an adjustable height comfortable for them.

The potential limitations of the platform include the need for surgeons and operating room staff to learn the system. The cost of the system will need to be studied and balanced with any potential benefits it may offer. Specific cost projections are not available at this stage of development. However, this system is significantly less complex than other surgical robotic systems that are on the market, and because of this it is expected to cost significantly less.

Although the device is in a prototype stage, and further refinement is needed before clinical applications can move forward, system performance in our simulated models has demonstrated excellent application to a variety of common operative hysteroscopic scenarios. Further study regarding the safe, efficient, and cost-effective use of the endoscopic robot in gynecology is ongoing.

Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.jmig.2020.06.009.

References