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Case Report

Robotics and Natural Orifice Surgery–a Marriage Made in Heaven?

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Abstract

The geneses of natural orifice and endoluminal platforms have been seen by many as the next step in the evolution of surgery as it moves towards the goal of non-invasive incision-free operative procedures. Robotic surgery has also revolutionized certain surgical disciplines by catalyzing the adoption of advanced laparoscopic procedures (e.g. laparoscopic prostatectomy), reducing associated surgical learning curves and shortening post-operative length of stays. This paper will review the development of endoluminal, natural orifice and robotic surgery and attempt to identify areas of synergy between the two technological platforms and shed a light on combination of these techniques to create a platform that is superior in terms of visibility, maneuverability and clinical application.

Keywords: Natural orifice endoscopic surgery; Natural orifice transluminal endoscopic surgery; Robotics; Endoscopic gastrointestinal surgery; Endoscopic surgical procedures; Endoluminal repairs

Introduction

Over the last two decades, more and more surgical procedures have transitioned from an open to a laparoscopic approach. As incisions have become smaller, operations requiring several day hospital stays have become ambulatory procedures, and post-operative recovery periods have shortened. The geneses of natural orifice and endoluminal platforms have been seen by many as the next step in the evolution of surgery as it moves towards the goal of non-invasive incision-free operative procedures. Robotic surgery has also revolutionized certain surgical disciplines by catalyzing the adoption of advanced laparoscopic procedures (e.g. laparoscopic prostatectomy), reducing associated surgical learning curves and shortening post-operative length of stays. This paper will review the development of endoluminal, natural orifice and robotic surgery and attempt to identify areas of synergy between the two technological platforms.

Endoluminal surgery

Endoluminal gastrointestinal surgery encompasses those procedures performed using flexible endoscopy that occurs entirely in the lumen of the gastrointestinal GI tract. The ability to perform incisionless surgery, coupled with the avoidance of post-operative complications such as wound infections and incisional hernias make endoluminal surgery an attractive technical approach, especially if it can be shown to be as effective as a trans-abdominal approach (be it open or laparoscopic). Potential limitations of endoluminal surgery include those related to the maneuverability of the flexible scope and the reduced triangulation and degrees of freedom, especially with longer working distances. A further major limitation of endoluminal surgery is that the variety of procedures that can be done from within the lumen of the GI tract is restricted to those where entry into the abdominal cavity is not needed. This has therefore meant that the predominance of endoluminal procedures performed to date have been intra-gastric procedures for bariatric and anti-reflux indications.

The creation of endoluminal stitching and stapling devices has opened up new vistas of opportunity for advanced endoscopists, allowing them to perform new invasive upper GI procedures. Treatment of Gastro-Esophageal Reflux Disease (GERD) was one of the early targets of endoluminal surgery. The Bard EndoCinch (C.R. Bard Inc., Murray Hill, NJ), an endoluminal device designed to employ suction to approximate tissues prior to endoluminalstitching, was the first device to be developed in an animal model and later tested in clinical trials [1]. These trials demonstrated that endoscopic treatment of GERD is feasible, although the long term results with EndoCinch have been shown to be inferior to the gold-standard of surgical fundoplication [2,3].

Following those results, other endoluminal anti-reflux devices such as the EsophyX™ device (Endogastric Solutions, Redmond, WA) were developed, building upon the lessons learnt from the early technical difficulties seen with EndoCinch. Two separate two-year trials of Transoral Incisionless Fundoplication (TIF) performed with EsophyX™ have shown TIF to be effective in both eliminating heartburn in 65% [4] and 93% [5] of the patients studied and eliminating the need of daily PPI use in 82% and 71% of the study subjects. Level 1 evidence to support TIF is still lacking and more data on the long term durability of this endoscopic fundoplication are needed. TIF is, however, a promising modality of treatment of moderate GERD. It is based on the core surgical principles underlying traditional fundoplication: it reduces the GE junction back into the abdominal cavity, lengthens the intra-abdominal esophagus, recreates the angle of His and creates an anti-reflux one way flap valve. A possible limitation to the application of the endoscopic approach is the presence of a large hiatal hernia, which is common in patients with GERD: currently, a hiatal hernia of greater than 2cm diameter precludes the performance of TIF alone to treat GERD.

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The endoscopic treatment of GERD paved the way for another major application of endoluminal technology, that of bariatric surgery. Endoluminal platforms have been applied to both primary weight loss procedures and revisional operations. Currently the Food and Drug Administration FDA has only approved endoluminal technology for revisional operations. Labeled indications have so far included general descriptions of tissue apposition such as "soft tissue approximation in minimally invasive gastroenterology procedures, e.g., fistula closure, perforation/leak closure and repair of dilated gastric tissue" (the FDA labeled indication for the USGI Medical Incisionless Operating Platform (IOP) platform) and have deliberately avoided inclusion of "weight loss" as an indicated use.

The majority of these procedures (both primary and secondary) is restrictive and aims to decrease the volume of the stomach in various ways such as stapling or suturing. Primary endoluminal bariatric operations are still considered investigational in the USA by the FDA. They are, however, currently performed in Europe outside of clinical trial settings. The first primary endoluminal bariatric procedure to be studied was trans-oral gastroplasty or the TOGA procedure. TOGA used a stapling device to create a gastric sleeve. In a single arm prospective trial [6], TOGA was shown to be safe and effective, reducing excess weight by 44.8% at 1 year. Longer term data, however, failed to show sustained efficacy due to a high rate of failure of the gastroplasty staple line. Ultimately, the inability of Satiety (Palo Alto, CA: the manufacturer of the device used in the TOGA procedure) to persuade the FDA to approve its device within a 1-2 year time frame caused the company to cease operations (for financial reasons) in January, 2011.

Perhaps more promising is the POSE (Primary Obesity Surgery Endoluminal) weight loss procedure which employs the USGI Medical (San Clemente, CA) Incisionless Operating Platform (IOP) platform: using the IOP and a 4mm pediatric upper endoscope placed through the IOP to visualize the gastric lumen, the POSE is constructed by collapsing down the gastric fundus and narrowing the pre-pyloric channel of the stomach using expandable tissue anchors to create plications of tissue along the fundus and greater curvature of the stomach. These anchors are constructed of polyester suture and durable polyester baskets that expand and hold tissue together. Each POSE procedure requires the placement of approximately 12 tissue plications. The proposed mechanism of action is a combination of reduction in gastric capacity, delayed gastric emptying (leading to enhanced satiety) and reduced ghrelin production by the collapsed fundus (leading to loss of appetite). There are no published data for POSE yet, but anecdotal results suggest significant weight loss with 37% Excess Weight Lost (EWL) at six months (T. Lavin *et al*., unpublished data). Conclusive evidence derived from a sufficient number of patients undergoing POSE has yet to be obtained to show sufficiently durable efficacy by which to recommend the procedure as an effective surgical treatment for severe obesity.

Weight gain after bariatric surgery is common: approximately 20% of patients undergoing roux-en-y gastric bypass regain a significant amount of weight after the initial "honeymoon period" of 2 years after surgery. This may be attributed to the dilatation of the gastric pouch, or dilatation of the gastrojejunal anastomosis, or both. Restorative obesity surgery endoluminally or the ROSE procedure (again employing the USGI Medical IOP system) is a technique designed to reduce the volume of a dilated pouch or the diameter of a dilated stoma. In a prospective single arm study of 116 patients, the ROSE procedure was technically successful in 97% of the cases leading to an average of 32% EWL at 6 months [7]. The procedure was typically able to reduce pouch length by 44% and stomal diameter by 50% [7].

The StomaphyX™ device (Endogastric Solutions Inc, Redmond, WA) uses suction to approximate the tissues of a gastric bypass pouch and then plicates the tissues using 6mm H-shaped polypropylene pledgets. In a study of 64 gastric bypass patients by Leitman et al [8], technical success was achieved in 100% of cases with no reported morbidity and an average weight loss of 17.1lbs (7.6 kg) at a mean follow up of 5.8 months. Mikami et al [9] reported similar results with 22.5lbs (10.0kg) weight loss at 1 year follow up. Both studies suggest that endoluminal gastric pouch reduction with the StomaphyX™ is technically feasible, safe and effective. In a few anecdotal case reports, the StomaphyX™ device has also been used successfully in the management of gastric leaks immediately after gastric bypass surgery [10]. Unfortunately, long term results with StomaphyX™ typically showed poor sustained weight loss beyond 6-9 months after the procedure and the device is now no longer manufactured by Endogastric Solutions.

The Bard EndoCinch suturing system was evaluated by Thompson's group at Harvard as a method of revision of dilated gastrojejunal anastomoses in a randomized sham controlled clinical trial [11]. The study's primary outcome was % absolute weight loss achieved at 6 months in 77 patients. The results were 4.2±5.4% kg weight reduction in 50 patients in the experimental group and 1.9±5.2% kg weight loss in 27 patients in the sham group. Again lack of durability of effect has caused the procedure to fall out of favor.

The Apollo Overstitch device (Apollo Endosurgery, Austin, TX) is a new and exciting endoluminal platform. It is a generally applicable endoluminal suturing device which fits over the end of a 10mm therapeutic gastroscope: it can be used to place running or interrupted sutures (absorbable or permanent) under direct endoscopic vision in the esophagus, stomach and colon. In two pilot studies of 22 [12] and 8 [13] patients undergoing gastric pouch revision using the Apollo Overstitch device, average EWL of 21% (equivalent to 60% loss of regained weight: RWL) at 3 months follow up was reported with 100% technical success. Large scale multi-centered prospective trials examining the Apollo Overstitch device to perform both primary and revisional bariatric surgery are currently underway.

Notes

Natural Orifice Transluminal Endoscopic Surgery (NOTES) goes beyond endoluminal surgery in that it is not only confined to the lumen of the GI or genitourinary GU tract but allows incisionless access to the peritoneal cavity to perform a wider selection of procedures on intra-abdominal organs. Similar to endoluminal surgery, NOTES offers the advantages of less post-operative pain, shorter hospital stays, no wound infections, and no incisional hernias when compared to conventional techniques. Disadvantages of NOTES include concerns regarding the safety of trans-visceral access and closure, and the availability of customized instruments that have been

specifically designed to provide the necessary maneuverability, vision and tissue handling required for this approach. These limitations were recognized several years ago, leading to the development of hybrid techniques such as Mini-laparoscopy Assisted Natural Orifice Surgery (MANOS) and Laparoscopy Assisted Natural Orifice Surgery (LANOS).

Transgastric peritoneoscopy was first performed in 2000 [14]. Three years later, Rao and Reddy performed a transgastric appendectomy: this was subsequently reported at the 2006 SAGES meeting [15]. NOTES cholecystectomy has been described in several studies: the transvaginal route has been preferred over the transgastric route because it affords superior exposure in the upper abdomen. Marescaux *et al* published the first report of transvaginal cholecystectomy in a 30 year old female with symptomatic cholelithiasis [16]. Using a 2mm umbilical port for insufflations of CO_2 and retraction and a double channel gastroscope, the gallbladder was removed without significant post-operative pain or complication. A case series of 4 successful transvaginal cholecystectomies using 2 endoscopes was published by Sousa in 2009 [17], representing the first case series of pure NOTES cholecystectomy. In that series, the mean operative time was 210 minutes, the patients were discharged on the first post-operative day and there were no complications at 30 day follow up. A modification of Sousa's technique was used by Bessler *et al* in 2010 in which they used a 15mm trocar via a separate colpotomy for retraction rather than introducing a second endoscope, thereby also achieving a pure NOTES operation [18].

It is obvious that these groups struggled with the available equipment, and that the suboptimal traction, exposure, and tissue handling offered to them by this equipment prompted them to improvise with the use of these addition endoscopes and/or trocars.

Other investigators felt that the addition of laparoscopic trocars creating a hybrid approach would address all these issues. Two groups (one from Italy and one from Brazil) reported transvaginal cholecystectomies using an additional laparoscopic trochar [19,20]. Linke *et al* reported a series of 102 patients with symptomatic cholelithiasis and cholecystitis, using a hybrid approach to perform transvaginal cholecystectomy: he described only 2 conversions to laparoscopy and 2 major complications (one post-operative stroke and one incisional hernia through the umbilical port) [21]. Similarly, two other case series of 43 and 25 patients respectively reported hybrid cholecystectomy with short hospital stays, minimal post-operative pain, and few complications [22,23].

A variety of pure and hybrid NOTES procedures such as hybrid transanal total mesorectal excision of the rectum [24], transvaginal sigmoidectomy and hemicolectomy [25,26], and transvaginal appendectomy [27] has been reported with successful outcome. In the field of urology, transvaginal nephrectomy [28], transvesical peritoneoscopy [29] have also been described. Other reported procedures include transgastric diagnostic peritoneoscopy [30] and transvaginal splenectomy [31].

Robotic surgery

The global surgical robot market is currently worth around $1 billion with approximately 1800 robots installed to-date – it is anticipated that this could grow to $5 billion by 2015, with potential placement of 6,000 systems worldwide. Robotic surgery was first described 25 years ago in the field of neurosurgery with the introduction of the PUMA 560 system [32]. The PROBOT system was then developed for transurethral prostate resection [32] followed by the ROBODOC for total hip replacement [32]. The next generation of robotic technology arose out of collaboration between Stanford University, the US Department of Defense and NASA. This collaboration was initially designed to provide for robotic telesurgery on the battlefield, whereby surgical robots operated on patients in battlefield hospitals with surgeons controlling the robotic arms from distant locations well behind the lines.

Early iterations of this robotic telepresence technology were Aesop and Zeus (both manufactured by Computer Motions Inc., Goleta, CA). The Da Vinci surgical system (Intuitive Surgical Inc., Sunny Valley, CA) is currently the only FDA approved robotic system indicated for use in laparoscopic surgery. It was approved in 2000 for urologic and 2005 for gynecologic procedures. Titan Medical Inc., a Canadian start-up, is now developing two new products to compete with Da Vinci. The Amadeus Composer is designed for procedures in small or medium surgical spaces. The Amadeus Maestro is a four-armed system designed for operations in larger spaces. Titan aims to get its composer ready for pre-clinical tests in 2012, clinical trials in 2013 and FDA clearance in 2014.

The first surgical robot with robotic telepresence technology was created for cardiac surgery. Robotic telepresence technology has, however, been most widely introduced into the fields of urology and gynecology. Application has been more limited in the disciplines of general surgery, otolaryngology and cardiothoracic surgery. Robotic surgery offers several advantages over the more traditional laparoscopic approach. These include 3-D visualization, reduction in operator tremor and an enhanced range of motion mimicking the anatomy of the human wrist. Wristed robotic instruments, along with the articulation of robotic arms, provide a surgeon with seven degrees of freedom. In contrast, conventional laparoscopic instrumentation only offers five degrees of freedom. The robotic instruments reproduce the hand movements of open surgery, eliminating the counter intuitive fulcrum effect seen in laparoscopy, whereby surgeons must move their hands in a direction opposite to that of the intended target [32]. There is also a scaling down of hand movements with robotic surgery, allowing the robot to perform delicate and precise procedures, such as those employing intra-corporeal suturing [32].

Disadvantages of robotic surgery include the cost of the platform itself (along with the necessary disposable instruments and the annual service contract), the large and cumbersome footprint of the robot and the fixed location of the operating room table after the robot has been docked.

Robotic surgery has revolutionized laparoscopic surgery in many disciplines: nowadays robotic surgery has become the standard approach in prostatectomy and hysterectomy in which visibility and maneuverability are augmented with robotics allowing for superior dissection and lower blood loss. The use of robotics has enabled surgeons to learn complex laparoscopic operations with shorter learning curves. In the field of urology, robotic surgery accelerated the adoption of laparoscopic radical prostatectomy, an operation requiring a significant amount of intra-corporeal suturing. The use

of the robot increased adoption of this procedure from 1% of all prostatectomies performed in the USA in 2001 to more than 50% by 2009 [32]. The conversion from open to laparoscopic prostate resection leads to shorter length of stay, lower rates of blood loss and transfusion, fewer respiratory complications and fewer urethral strictures, without compromising cancer cure rates [32].

Similar results were seen in the adoption of robotic technology in radical cystectomy. The use of robotics to convert from open to laparoscopic radical cystectomy has been shown to reduce intra-operative blood loss and length of stay and lower post-operative complication rates. Operative time, lymph node yield and rate of positive margins were the same in the two groups [32]. These results were achieved after a learning curve of only 20 cases.

Robotic surgery has also been avidly taken up by gynecologists performing hysterectomy. A large study in 2003 showed that only 11.8% of hysterectomies were performed laparoscopically, despite data proving benefits over the open approach [33]. This low level of uptake by gynecologists was most likely due to the steep learning curve for the conventional laparoscopic operation. By 2012, this number had only increased to 30%, again reflecting the tendency of gynecologists to shy away from a technically difficult operation.

The introduction of robotic technology into gynecologic surgery has accelerated the conversion of hysterectomy from an open to a minimally invasive approach. In a recent U.S. study, investigators used a national database to compare the effectiveness of laparoscopic and robotic hysterectomy for endometrial cancer. Of 2464 women who underwent either procedure between 2008 and 2010 at >500 hospitals, 42% had laparoscopic hysterectomies and 58% had robotic procedures. Use of robotics increased from 46% in October 2008 to 61% in March 2010. Overall complication rates were similar at 10% and 8%, respectively, for conventional laparoscopic and robotic approaches [34]. The learning curve for robotic hysterectomy was found to be only around 20 cases, significantly shorter than that for the traditional laparoscopic operation.

One major disadvantage of robotic surgery is the significant financial outlay required by hospitals in order to establish robotic programs: the initial purchase of equipment can cost between $1m to $2m and annual service contracts can run from $150,000 to 400,000 [32]. Additionally, robotic surgery requires the use of $2,200 of disposable equipment for every ten cases (e.g. shears, needle holders, graspers, forceps etc.) [32]. The University of North Carolina study of robotic cystectomy showed an overall cost differential of an extra $1640 per surgery when comparing robotic surgery to open surgery [32]. Hospitals cannot look to recover these extra costs by reducing operative and/or anesthesia time when converting from open to robotic laparoscopic surgery. This leaves only a reduction in length of stay as a source of economy associated with robotic surgery to offset these added capital and operating expenses. Reduction in average post-operative Length of Stay (LOS) becomes an important economic parameter in the business operations of a hospital when it is constrained in the number of in-patient surgical procedures it can perform by the number of available in-patient beds. Reducing LOS with robotic surgery can release hospital beds and allow the hospital to perform a greater number of other in-patient operations, thereby increasing hospital revenue.

The use of robotics in interventional GI endoscopy has shown promise over the last few years. Several systems have been designed to explore the possible synergy between robotics and endoscopy in both animal models and in early clinical trials. The ViaCath system (EndoVia Medical Norwood, MA) consists of a console with an endoscope and 2 flexible instruments that can be used to hold, divide and coagulate tissues, providing 7 degrees of freedom [35]. Another commercially available device is the Transport EndoSurgical Operating Platform (USGI Medical) with its "Shapelock" locking technology [36]. This technology (which employs 4 operating channels and a 4mm endoscope) allows the platform to be fixed while allowing freedom of movement at its tip.

The MASTER (Master and Slave Transluminal Endoscopic Robot) is a robotic system designed by investigators from the University of Singapore to be used with flexible endoscopy. It has been demonstrated successfully in animal models for both Endoscopic Submucosal Resection (ESR) of small gastric lesions as well as transgastric (NOTES) resection of liver lesions [37-40]. It requires an endoscopist to operate the scope and a surgeon/gastroenterologist to operate the robot via a master-slave design similar to the Da Vinci robot. The main feature of this system is that the two effector arms of the robot (a grasper and cautery) are driven by mechanical tendons and sheaths allowing the robot 9 degrees of freedom. The system also uses computer software to control or amplify the surgeons' movements. Phee *et al* used the MASTER system to successfully perform 5 endoscopic submucosal dissections and 2 transgastric wedge liver dissections in an *in vivo* porcine model with operative times as short as 8.5 minutes [39,40]. It was found that the MASTER exhibited good grasping and cutting efficiency in this model. The lesion resection time could be significantly reduced with more practice between the endoscopist and the robot operator. The authors concluded that the success of the MASTER system was related to its maneuverability and dexterity: the system appeared to eliminate many of the constraints faced in NOTES. The MASTER system has now been used to perform ESR in 5 patients with small submucosal gastric lesions with short operative time and no post-operative morbidity (L Ho, unpublished data).

Another application of robotics in NOTES is the use of miniature *in vivo* robots. These mini robots are inserted into the peritoneal cavity through the lumen of either the GI or GU tract and then controlled remotely. One of the early reported models is the endoluminal mobile robot. Its design consists of two helical shaped wheels that allow movement in 4 directions, and a tail that prevents the apparatus from falling [41]. Coupled with a flexible endoscope, it has been deployed through the stomach in a porcine model and has been controlled remotely to explore the abdominal cavity.

The Magnetic Anchoring and Guidance System (MAGS) employ a different approach. Using a rigid access through a colpotomy, the effector instruments (e.g. cautery and retractors) are deployed into the abdomen and fixed using magnetic coupling to an external magnet [42]. Two successful transvaginal cholecystectomies have been reported in a porcine model of MAGS using a gastroscope for imaging guidance.

A hybrid, cooperative model using *in vivo* miniature robots along with the Da Vinci robot has also been used to perform a

Cholecystectomy in a porcine model [43]. A lighting, imaging and retracting robot facilitated the dissection performed using the standard robot. This approach not only improved the efficiency of the robot, but also reduced the number of incisions required.

Another magnetically anchored microrobot has been reported to successfully perform a NOTES Cholecystectomy in a pig [44]. The robot is designed as a central piece containing a camera and two rotational arms to which the effector instruments are attached, typically a retractor and cautery. The robot can be deployed through the stomach and fixed to the abdominal wall using a magnet, and can be controlled by a console consisting of two joysticks with three

degrees of freedom each and a video screen. After encountering some early technical difficulties, the authors concluded that robotic NOTES Cholecystectomy is feasible using this approach.

Endoluminal surgery/NOTES and robotics–a marriage made in heaven?

It is generally accepted that surgical procedures are becoming increasingly less invasive, thereby enhancing patient acceptance, reducing post-operative length of stay and minimizing the risk of post-operative complications. Surgeons have envisioned endoluminal and NOTES platforms as the next logical steps in this evolution of GI surgery. Technical challenges and the lack of long term data showing durable efficacy have hitherto limited the acceptance of endoluminal surgery and NOTES outside the clinical trial setting. Robotic surgery, by mimicking certain aspects of open surgery (e.g. use of tactile feedback, increasing degrees of freedom, reduction of hand tremor) may augment endoluminal surgery by increasing the ease and speed with which endoluminal or NOTES procedures can be performed (e.g. endoluminal submucosal gastric resections, transgastric hepatic resections) as well as by increasing the complexity of these endoluminal or NOTES procedures. The addition of a wide range of effectors (e.g. surgical staplers) onto the end of an endoscope using the interchangeable arms of a robot (e.g. the MASTER device) can enable surgeons and gastroenterologists to perform complex operations such as endoluminal gastroplasties for obesity and acid reflux, gastric resections for tumors and colonic resections for tumors, all previously only contemplated as transperitoneal operations.

The oft demonstrated fact that surgical robots can reproduce the hand movements of open surgery and eliminate the counter intuitive fulcrum effect seen in laparoscopy has converted reluctant open surgeons wary of minimally invasive surgery into competent laparoscopists. This effect has increased surgeon acceptance of certain advanced laparoscopic procedures (e.g. radical prostatectomy), thereby facilitating patient acceptance of these less invasive and less morbid procedures. The marriage of robotics and endoluminal/NOTES technology should have a similar effect: surgeons unaccustomed to performing advanced invasive endoscopy may adopt robotic endoscopy if it can mimic open surgery with the use of (for example) the Amadeus Composer, a system designed for procedures in small or medium surgical spaces. This conversion process could accelerate the paradigm shift of open to laparoscopic to incision-free surgery in surgical disciplines such as thoracic surgery, upper GI/bariatric surgery, colorectal surgery, urology and gynecology.

Target markets for endoluminal robotic surgery could include the treatment of early gastric cancer. Over 900,000 people every year are diagnosed with gastric cancer throughout the world every year. 25,000 new cases of gastric cancer are diagnosed annually in the USA. In Japan, it is the most commonly diagnosed cancer (an estimated 110,000 new cases per year) and the second leading cause of cancer death (54,000 deaths annually) after lung cancer. Up to 50% of cases in Japan are diagnosed at an early stage – this explains why cure rates in Japan are around 50% (several times higher than cure rates in the USA). Endoscopic submucosal resection of early gastric cancer can be performed safely and effectively and has already been demonstrated using the MASTER robotic system in approximately 5 patients. Markets such as Japan and South Korea could therefore yield tens of thousands of possible early gastric tumor cases every year for such robotic systems. If such cases can be performed endoscopically rather than laparoscopically, then Length of Stay (LOS) (mean LOS typically 8 days after laparoscopic gastrectomy) and cost of hospitalization (approximately $18,500/case and $17,300/case for laparoscopic and open distal gastrectomy in Japan respectively) could both be drastically reduced [45].

Such opportunity may be more limited in the USA, where gastric carcinoma typically presents at a much later stage. Endoluminal robotic surgery could, however, have higher market penetration in the USA for benign upper GI pathology: robotic endoscopic gastroplasty could be developed for both severe obesity and for acid reflux. Currently around 300,000 bariatric procedures are performed every year in the USA. Additionally, 30,000 fundoplications are performed annually in the USA for severe GERD. Even at a conservative rate of 5% conversion to endoscopic robotic cases, this could potentially represent an extra 16,500 cases a year for the appropriate robotic system. Another potential indication for robotic endosurgery could be endoluminal resection of large colonic polyps with closure of the resultant full thickness colonic wall defect. Last year, gastroenterologists José-Ramón Armengol Miró and Sergey Kanstevoy were the first in the world to successfully perform a full-thickness resection of a colonic polyp without the assistance of laparoscopic tools using the Apollo over Stitch endoscopic suturing system [46]. Miró and Kanstevoy removed the polyp and then used a colonoscope and the Over Stitch system to deploy two continuous sutures to close the large 3x6 cm transmural defect. The repair was deemed airtight and allowed distension of the colon to its normal diameter after suturing was complete. The CDC estimated that 1.4 million colonoscopic polypectomies were performed in the USA in 2006 [47]. Even if only a small fraction of these cases involved the removal of large polyps, robotic endoscopic full thickness resection and wall closure for large polyps could significantly add to the total number of robotic procedures performed every year here in the USA and overseas.

Final Word

The potential clinical benefit of a fusion of endoluminal/NOTES surgery and robotics to allow physicians to perform more complex operations with lower risk indeed suggests that this combination could be a marriage made in heaven. Given today's economic stringencies, however, it will require some effort on the part of robotic manufacturers to reduce the purchase and servicing costs to ensure the long-term marital bliss of this union of exciting new surgical

technologies. The next few years will reveal whether NOTES and robotics will truly represent the future of endoscopy and surgery.

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