Title
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Journal
Clinics in Colon and Rectal Surgery, 29(03)

ISSN
1531-0043

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Publication Date
2016-09-01

DOI
10.1055/s-0036-1584499

Peer reviewed

Future of Minimally Invasive Colorectal Surgery

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Clin Colon Rectal Surg 2016;29:221–231.

Abstract

Minimally invasive surgery is slowly taking over as the preferred operative approach for colorectal diseases. However, many of the procedures remain technically difficult. This article will give an overview of the state of minimally invasive surgery and the many advances that have been made over the last two decades. Specifically, we discuss the introduction of the robotic platform and some of its benefits and limitations. We also describe some newer techniques related to robotics.

Keywords
- laparoscopy
- robotics
- telesurgical system
- sentinel lymph node

Current State of Minimally Invasive Colorectal Surgery

Colectomy

Minimally invasive surgery has been adapted to a wide variety of colorectal procedures. The first laparoscopic right colectomy was published by Jacobs et al in 1991[1]; shortly after which Fowler performed the first laparoscopic left colectomy. Since these initial reports, several large studies found that the oncologic outcomes of laparoscopic colectomy were equivalent to open surgery and that patients undergoing laparoscopic colectomy tended to have improved short-term outcomes such as decreased blood loss, shorter length of stay, faster return of bowel function, fewer wound complications, and improved postoperative pain.[2–9] Despite the growing body of evidence supporting the use of laparoscopic colectomy for colon cancer, the adoption of the technique was relatively slow with the utilization of laparoscopic colectomy only reaching 41.6% in 2010.[10–12]

Despite its advantages over open surgery, there are some limitations to minimally invasive surgery. Loss of binocular vision, paradoxical motion of the instruments, amplified movements, parallel instrumentation, poor ergonomics,[13,14] increased motion needed to accomplish a given task,[15] and loss of proprioception are all common limitations. To overcome some of these shortfalls, the use of hand-assisted laparoscopy was introduced.[16,17] Although studies have shown similar oncologic outcomes, the short-term outcome benefits of laparoscopy were lost with the hand-assisted technique.[18,19] Furthermore, the incisional hernia rate for hand-assisted laparoscopic surgery has reported to be between 6 and 10.6%,[20,21] although this may be contingent on port site placement.[22]

The da Vinci robotic system (Intuitive Surgical Inc., Sunnyvale, CA) was developed to overcome the limitations of traditional laparoscopic surgery. This system provided several potential advantages over traditional laparoscopic surgery including a stable camera platform, three-dimensional (3D) imaging, improved ergonomics, tremor elimination, ambidextrous capability, motion scaling, and instruments with multiple degrees of freedom. The first two robotic-assisted colectomies described in the literature were performed in 2001 by Weber et al.[23] Several studies have compared the outcomes of laparoscopic versus robotic colectomy[24–33] and overall, robotic-assisted right colectomy had similar perioperative and oncologic outcomes at the expense of longer operation times, and increased surgical costs. Some studies suggest there may be some advantage to robotic right colectomy with regards to decreased estimated blood loss[25,26,30,31] and faster return of bowel function.[30–32] Although no significant benefit of robotic surgery has been seen, some authors feel that a robotic right colectomy is a good procedure for surgeons to tackle the learning curve of robotic surgery before undertaking more complex operations such as a low anterior resection,[24] while others liken the use of robotic surgery for right colectomy to taking a Ferrari to the grocery store to do the weekly shopping.[34]

Left colectomy is a more challenging procedure when compared with right colectomy. There have been several published techniques for robotic left colectomy: hybrid

Issue Theme Hot Topics in Colorectal Surgery; Guest Editor: Gregory D. Kennedy, MD, PhD

DOI http://dx.doi.org/10.1055/s-0036-1584499. ISSN 1531-0043.

(laparoscopic splenic flexure mobilization), single docking (mobilizing the second and third robotic arms for different parts of the surgery), double docking (docking once for splenic flexure mobilization, then redocking for the rest of the procedure), and recently a "single-position flip arm technique" that allows for splenic flexure mobilization and low anterior resection with only one docking position.[35–37] Although good outcome data are not as abundant as for robotic right colectomy, several studies have compared robotic versus laparoscopic left colectomy.[26–30,38] As seen with robotic right colectomy, robotic left colectomy had similar perioperative and oncologic outcomes with increased operative times.

Total Mesorectal Excision

Minimally invasive surgery of the rectum has several potential benefits over open surgery. From a technical standpoint, laparoscopy can provide superior views of the deep pelvis and dissection planes and may facilitate a more precise dissection.[39] Furthermore, a meta-analysis of laparoscopic rectal cancer found shorter lengths of stay and faster return of bowel function when compared with open surgery.[40] In 2013 the American College of Colorectal Surgeons published their revised practice parameters for the management of rectal cancer which supported the use of laparoscopic total mesorectal excision (TME) for the treatment of rectal cancer.[41] This decision was based off the results of several large randomized controlled trials and comparative studies including the Conventional vs. Laparoscopic-Assisted Surgery in Colorectal Cancer (CLASICC), Comparison of Open versus Laparoscopic Surgery for Mid or Low Rectal Cancer after Neoadjuvant Chemoradiotherapy (COREAN), and the COLOR II: Laparoscopic Versus Open Rectal Cancer Removal (COLORII) trials.[8,42–44] Most recently however, the results of the Effect of Laparoscopic-Assisted Resection vs. Open Resection of Stage II or III Rectal Cancer on Pathologic Outcomes (ACOSOG-Z6051), and the Effect of Laparoscopic-Assisted Resection vs. Open Resection on Pathological Outcomes in Rectal Cancer (ALaCaRT) trials were published and were unable to establish non-inferiority of laparoscopic TME and did not support the continued routines use of laparoscopy in the management of rectal cancer.[45,46]

The 3D visualization, superior retraction, articulating instruments, and greater ability for precise dissection are well suited for the narrow deep pelvic anatomy with tight boundaries and close proximity to pelvic nerves and reproductive gave the application of robotic surgery to the treatment of rectal cancer several potential benefits over laparoscopic surgery. The earliest case series of robotic TME (RTME) was published in 2006 by Pigazzi et al,[47] and since then several other studies have demonstrated the efficacy and safety of RTME and compared RTME.[29,35,37,48–61] RTME was associated with lower conversion rates, and reduced rate of erectile dysfunction (ED) than laparoscopic TME in some studies.[49,60,62,63] Furthermore, of those who developed postoperative ED, patients in the robotic groups appeared to have a more rapid improvement of symptoms when assessed at 3 and 6 months. Other perioperative outcomes, and complication rates were similar between the two groups. With regards to oncologic outcomes, two studies found the positive circumferential resection margin rate to be lower in the robotic group,[60,62] and another two studies found no difference in disease free survival between the robotic and laparoscopic TME groups.[52,54] Overall costs were higher with RTME.[50,59,64,65] Despite the current data available, larger randomized studies are needed to better define the short- and long-term outcomes of RTME. A large multinational randomized controlled trial–RObotoic Versus Laparoscopic Resection for Rectal Cancer (ROLARR)– just closed to accrual and its results should help better define the role of robotic surgery in the treatment of rectal cancer.[66]

Rectopexy

There are upwards of 100 different procedures described for the management of rectal prolapse in adults.[67] Procedures are generally classified into one of two types: perineal procedures which tend to be considered safer due to the ability to perform them under local anesthetic but have higher recurrence rates, or transabdominal procedures are more invasive, take longer to perform but have lower recurrence rates and improvements in incontinence.[68] Large randomized controlled trials are lacking, but several comparative-studies and meta-analysis support the use of a minimally invasive approach for the management of rectal prolapse. Compared with traditional laparotomy, laparoscopic rectopexy was associated with longer operative times but shorter hospital length of stay with similar morbidity, recurrence rates, and long-term functional results.[69–72]

The first case series of six patients who underwent robotic suture rectopexy for rectal prolapse was reported in 2004 by Munz et al.[73] Since then several other case series using a variety of techniques have been described.[74–76] Outcomes in these studies were promising with relatively low recurrence rates (range, 0–13%) and good functional outcomes. A recent meta-analysis comparing laparoscopic to robotic ventral mesh rectopexy found that robotic rectopexy had similar functional outcomes and conversion rates but longer operative times with increased costs.[77] The authors also noted that although not statistically significant, there was a trend toward fewer postoperative complications and reduced length of hospital stay with robotic rectopexy.

Transanal Minimally Invasive Surgery

Transanal endoscopic microsurgery (TEM) was introduced in the 1980s by Buess et al as a technique to remove local rectal lesions not amenable to other perianal techniques.[78] This technique, however, had several limitations including cost, complex instrumentation, and a steep learning curve.[79,80] In response to the limitations of TEM, transanal minimally invasive surgery (TAMIS) was developed by Atallah et al.[81] This technique provided a low cost platform with minimal setup time and low equipment costs, in part because of the adaption of traditional laparoscopic instruments. Initial case series have demonstrated the feasibility and efficacy of this technique.[81–87] However, there are limitations to this technique. Due to the use of standard rigid laparoscopic instruments and the restrictive anatomy of the rectum, the working angles can become challenging and often require changing out instruments with the camera port or the application of severe torque that breaks the single-incision laparoscopic surgery (SILS) port seal resulting in loss of CO_2. With its articulating arms, the da Vinci system seems well adept to overcome these limitations and the first description of robotic TAMIS in a cadaveric model was published in 2011 by Atallah et al,[88] since this initial report, several additional authors have published case series on robotic TAMIS.[89–95] The initial results of these studies are promising, however; larger randomized controlled studies will be needed to further define the role of robotic TAMIS.

The field of natural orifice surgery was further advanced when surgeons adapted the TAMIS technique to perform a robotic-assisted transanal-TME (RATS-TME). The feasibility of RATS-TME was first described by Whiteford et al in 2007,[96] and pioneered in 2013 by Atallah et al.[97] In their initial pilot series, three patients underwent successful operations for rectal cancer with adequate oncologic results and no major morbidity or mortality.[98] Since then other case series have been published,[90,94,99] each with successful complete TME. RATS-TME is still a developing procedure but represents the current cutting edge of robotics in colorectal surgery.

Limitations of Current Robotic Platforms and the Need for New Technologies

The da Vinci system is a bulky surgical platform with cumbersome robotic arms. This is an important disadvantage considering that today's operating rooms are crowded with several surgical devices, and the extra space needed likely requires an extra cost. It is also noteworthy that trained and experienced operating room personnel are needed to assure an appropriate positioning of the patient cart, as well as a fast docking of the robotic arms. Many have suggested that miniaturizing the robotic arms and instruments would address the problems associated with their current size, and make the docking procedure easier and smoother.[100]

One of the main concerns associated with the use of the current robotic technology is the high cost. The high price of the da Vinci system makes it unaffordable for many surgical centers around the world and available only in selected hospitals. Whether the price of these systems will fall or rise is just conjecture. Some believe that multidisciplinary use of the robot may amortize the initial investment,[101] on the other hand others believe that improvements in technology will increase the cost of these systems.[102]

Other potential disadvantages are the relatively limited number of compatible instruments and equipment, as well as the inability to adjust the operating table position once the robot has been docked. This can be considered a temporary problem as new technologies have and will further develop to address these deficiencies. Most of the disadvantages of the current robotic system have been identified, and many research teams have worked to find remedies and improvements for the technology. In addition, several prototypes have been developed and some new surgical platforms have been launched.

In the following sections we will provide an overview of the most promising technologies developed to overcome drawbacks and obstacles of the current robotic platform. Although numerous experimental surgical platforms have been developed in recent years, we are going to present only those ones that we believe might have a potential role in overcoming the limitations of current robotic platforms in colorectal surgery.

New Robotic Platforms

A frequent criticism about the da Vinci system is the absence of tactile feedback for the surgeon, which can lead to unexpected damages on tissue and inadvertent injuries. Several prototypes have been developed to address this issue and a couple of surgical platforms have been launched into the market. The Telelap ALF-X system is a novel telesurgical system developed by SOFAR S.p.A (Milan, Italy) (►**Fig. 1**). The system, which obtained European certification for clinical use in 2012, offers some potential advantages over the robotic surgical platforms currently on the market. The system is composed of four individual arms that can utilize conventional laparoscopic instruments, which are manipulated through a detached surgical console. In emergency situations, when a rapid conversion into open access is required, the single robotic arms may be detached from the operating table without the need to disengage the instruments. The surgical console touts improved ergonomics for the surgeon and features such as an innovative zooming system controlled by the surgeon's head movement. Finally, the ALF-X platform provides force feedback through specially designed handles that enable the surgeon to manipulate the instruments with amplified sensed forces and facilitates knot tying without the danger of tearing the suture.[103] The main limitation of this surgical platform is the necessity of a larger operation room to accommodate the individual robotic arms. Furthermore, at the present date, no prospective study has been performed comparing the Telelap ALF-X to other robotic surgical systems.

The University of Pennsylvania (Philadelphia, PA) has developed a product called VerroTouch which is capable of adding haptic capabilities to the current da Vinci surgical system.[104] VerroTouch uses acceleration sensors attached to the patient-side manipulators just below the interchangeable tool mounting point. This location does not interfere with tool or arm motion, and allows measurement of significant vibrations detected during the surgical procedure. The main receiver takes the measured acceleration signals from the sensors and drives them to the corresponding actuators, which are mounted onto the da Vinci master handles on top of the platform wrist joints. Although the system does not transmit low frequencies forces, the replication of vibrations onto the surgical handles provides the surgeon with a haptic feedback potentially useful for surgical task execution.

Surgenious Beta, a surgical platform developed by the University of Verona (Verona, Italy) and Surgica Robotica

Fig. 1 Telelap ALF-X system developed by SOFAR S.p.A. (Copyright TransEnterix, Inc., Milan Italy, 2015.)

S.p.A. (Verona, Italy) consists of individual six degrees-of-freedom robotic arms equipped with tip-force sensors providing haptic feedback to the operator. The platform, which is a technical development of the Robotic-Assisted Micro-Surgery (RAMS) system originally developed by the National Aeronautics and Space Administration, obtained the CE mark in March 2012, and has gotten through both in vivo and in vitro trials. Currently, it waits for further funding before it is made commercially available.[105]

The DLR MIRO is a second-generation modular robotic system developed by the Institute of Robotics and Mechtronics in Germany.[106] The DLR MIRO is a multijointed surgical arm that can be used in groups or as single arm to assist the surgeon directly at the operating table. Each robotic arm guarantees seven degrees-of-freedom with a low weight of 10 kg, and dimensions similar to those of the human arm (►Fig. 2). The flexibility of the platform makes DLR MIRO a versatile system, in contrast to the current platforms, which are mainly specialized and dedicated to a surgical technique or for the treatment of a specific medical disease. The compact, slim and lightweight robot arms feature a versatile core component, which allows the user to add specialized instruments and modify the application workflow to adapt the system to many different surgical, laser, or endoscopic procedures. The communication latency between master and slave platforms poses a major limit to the system and may only be overcome with the automation of certain functions.

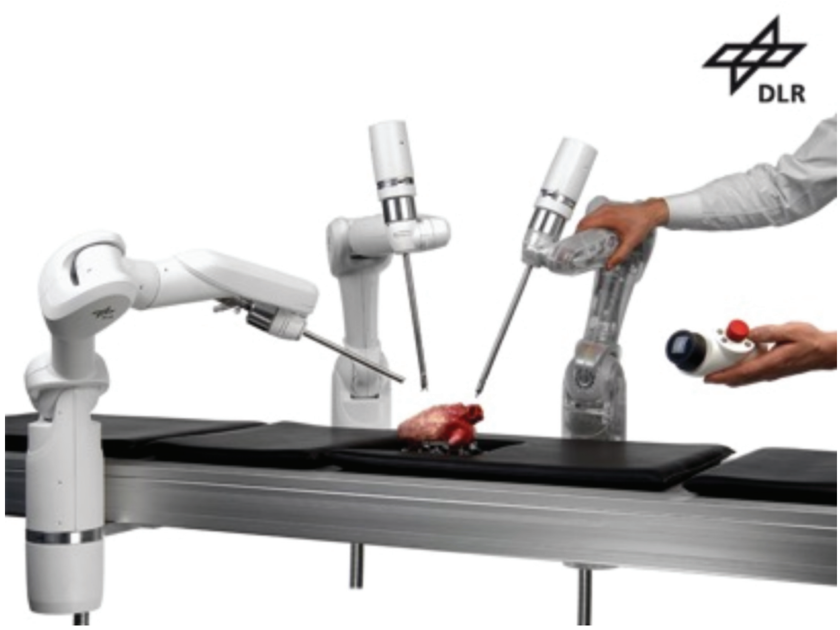

Fig. 2 DLR MIRO surgical robot. (Copyright Institute of Robotics and Mechtronics, Germany, 2016.)

Robotics and Single Access Surgery

Natural orifice transluminal endoscopic surgery (NOTES) and SILS are relatively new minimally invasive surgical techniques aiming to reduce surgical trauma. In NOTES, the abdominal cavity is reached through a viscerotomy via natural orifices (vagina, rectum, and stomach), whereas a single transabdominal incision is utilized in SILS. These techniques present new and specific challenges that robotics could address to simplify and bring the procedures to reality. The current armamentarium to perform NOTES safely is missing an appropriate flexible endoscopic platform that can simultaneously offer stability to provide traction and counteraction to expose tissues, optimal visualization of the operating field, triangulation, and microcontrol of endoscopic instruments, advanced suturing, stapling, and forceful dissection. The main difficulty in SILS, with instruments entering the same incision, is the lack of triangulation giving no other option but to use a chopstick technique. This technique results in a continuous internal and external conflict between operating instruments and the optical system. Robotics could effectively overcome this problem with the ability to cross instruments and simultaneously invert the control panel through software manipulation.[107]

Titan Medical Inc. in Canada is developing the SPORT (single port orifice robotic technology), which is a system for use in minimally invasive surgery (►**Fig. 3**). The SPORT is a single-incision robotic platform that includes a 3D vision system, articulating instruments, and a surgeon console. Similar to the da Vinci surgical system, it offers an interface to the robotic platform for controlling the instruments and providing a 3D endoscopic view of the surgical field. The camera is deployed after being inserted into the patient's body to achieve a working position in surgical triangulation with the operative instruments. The relatively large diameter of the multiarticulating instruments (6 mm) enables good torque force without hampering freedom of movement. The platform is still under development and the device has been tested only in experimental setting so far. In December 2015, the company announced that the first experimental in-human use would be performed in January 2016. Its dexterity and user-friendly console make it a promising device for promoting and expanding SILS surgery.

ARAKNES (array of robots augmenting the kinematics of endoluminal surgery) is an innovative, forward-looking technology has been developed within a framework of a large ongoing European project. Two different miniaturized robotic platforms specifically dedicated for single-incision surgery have been developed so far, SPRINT (single port laparoscopy bimanual robot) and ARAKNES.[108–111] The SPRINT is composed of two remotely controlled robotic arms with six degrees-of-freedom and a stereoscopic camera, which are inserted into the abdominal cavity through a 3-cm introducer. The full intra-abdominal position of robotic units allows for optimal triangulation. The ARAKNES endoluminal platform includes a set of robotic components performing distinct tasks (imaging, manipulation, organ retraction), and each unit can be introduced separately through natural orifices to reach body cavities. Once in place, the units can be anchored to the abdominal wall by magnetic force and offer a stadium view, and enhanced surgical triangulation.

Several snake-like robots are currently under development.[112] The flexible architecture and multiple degrees of freedom render this concept the most suitable one for NOTES and SILS. Anubiscope and Isisscope are two flexible endoscopic platforms developed by Karl Storz (Tuttlingen, Germany) for NOTES and SILS, respectively. These endoscopic platforms are provided with a bivalve tip that opens once in the peritoneal cavity, with flexible instruments passing through working channels and exiting in a triangulated fashion.[113,114] Two ergonomic handles control the instruments, allowing the endoscopic surgeon to operate with both hands and to perform microsurgical sutures and endoluminal surgery.

A telerobotic version of these instruments (STRAS, single-access transluminal robotic assistance for surgeons), which integrates a high-resolution scope, an intuitive haptic interface, and a visual tracking system with which to follow target

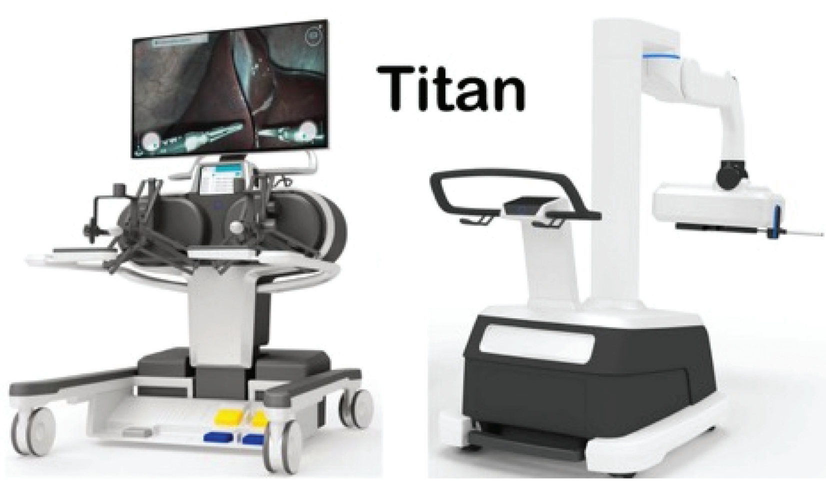

Fig. 3 Titan's SPORT (single port orifice robotic technology) surgical system (Image courtesy Titan Medical, Inc. Canada.)

structures and to compensate for physiological movements, is currently under development.[115] STRAS has been used successfully to perform delicate procedures such as colonic endoscopic submucosal dissections in an experimental model (porcine).

The master and slave transluminal endoscopic robot (MASTER) was developed by Phee et al in Singapore.[116] This robot consists of a telesurgical workstation, a master console, and a flexible slave manipulator. The slave component has two motor-driven end effectors (a grasper and a hook) mounted on the tip of two actuated arms attached to a conventional endoscope.[117] The system has been used to perform in vivo NOTES procedures (cholecystectomy, liver and gastric endoscopic submucosal dissection)[51,118,119] even though the delay in the operation of the master controller is currently a major issue.

Intuitive Surgical has developed a dedicated platform enabling SILS called VeSPA, now marketed under the name Single-site(►Fig. 4). The system comprised a specifically designed silicone access port (Single-site) in which curved cannulas are introduced to house semirigid instruments and is compatible with the existing da Vinci SI system. The platform uses flexible instruments that cross at the point of entry. The crossing is corrected by software in the robotic console to maintain the natural alignment of instruments. High-definition imaging and 3D vision go along with a highly improved ergonomic setup compared with conventional single-incision surgery. The system has been used largely in the clinical setting for cholecystectomies[120,121] and hysterectomies.[122,123] A few case reports have been published so far describing right colectomy,[124–126] and one single case report describes the application of da Vinci in single-incision robotic total colectomy.[127]

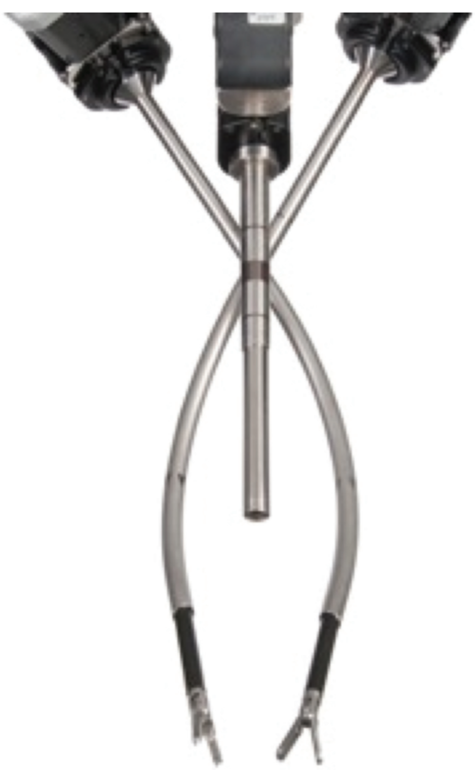

Fig. 4 Intuitive Surgical single-site camera and instruments. (Copyright Intuitive Surgical, Inc. Sunnyvale, CA.)

Finally, a new single-site robotic platform realized by Intuitive Surgical is currently under development. The new robot, called da Vinci SP (single port) is a promising surgical system holding potential to improve the ease and precision of performing single-port surgery (transumbilical, transvaginal, and transoral). Although the robot is not yet market-ready, a phase 1 clinical trial on urological surgery was published in 2004.[128] Both radical prostatectomy and nephrectomy procedures have been performed using the new technology on a total of 19 patients. The application of the new surgical technology was found feasible and safe, with 0% conversion rate and only a slightly higher mean operative time compared with equivalent standard robotic procedures. However, selection patient bias and the lack of a control group pose main limitations in drawing definitive conclusions from this study. Clinical trials on urological surgery are needed to validate these preliminary findings and possibly extend the da Vinci SP's application into colorectal surgery.

Enhancing Current Robotic Platforms

A new form of surgery combining the use of surgery and real-time image guidance has gained popularity in the field of surgical research. Cybernetic surgery is a combination of augmented skills such as augmented reality and computer generated realistic 3D environment with real-image guidance. The main goal is to increase the safety and accuracy of the surgical procedure. Virtual reality (VR) medical software can elaborate a 3D virtual replica of the patient from a computed tomography (CT) or magnetic resonance (MR) image, enabling navigation through the patient's anatomy.[129,130] During the surgical procedure the 3D VR model can be overlapped on real-patient images, providing surgical navigation through virtual organ transparency. In the case of colorectal surgery, one of the current hurdles of the current platform is the use of a static snapshot of anatomical structure which complicates the virtual model due to respiratory movement and deformation of soft tissue during manipulation. To overcome such a problem, the best approach would be to obtain a 3D image of the zone of interest in the operating room, and with a constant uploading of new frames along the surgical procedure. This can be achieved using 4D ultrasonography with CT image or by low-dose CT[131,132] or MRI. Another approach is to provide more flexible virtual modeling to deal with registration challenges, based on organ motion prediction[133] or on deformation prediction.[134,135]

In the field of augmented reality, near-infrared fluorescence has provided an innovative real-time visualization of anatomic structure. Indocyanine green (ICG) is a nontoxic fluorophore with the ability to appear green when excited by light in the near-infrared spectrum[136–138] ICG has been used for more than 40 years for diagnostic tests in ophthalmology, cardiology, and for evaluation of hepatic function.[139] Fluorescence was incorporated into the da Vinci HD system in

2010. The combination of the intrinsic technical advantages of the robot and the additional information that near-infrared fluorescence (NIF) provides will allow an expansion of the applications of robotics in all surgical fields. There are several clinical applications for intraoperative ICG, such as identification of vascular and biliary anatomy,[140] assessment of organ and tissue perfusion,[141] lymph node mapping, and real-time identification of lesions. Although the technique has been applied in different surgical fields[142,143] there is an increasing interest in the role of using NIF to asses blood supply in both colorectal and gastroesophageal surgery. In a multicenter study[144] evaluating patients scheduled for robotic left-sided colon or rectal resections ICG was injected intravenously and the transection location(s) and/or distal rectal stump were reassessed in fluorescent imaging mode. Fluorescence imaging resulted in a change of the proximal transection location in 40% of the patients. The use of fluorescence imaging took an average of 5.1 minutes of the mean overall operative room time of 232 minutes. Of these, 5% patients later developed an anastomotic leak. The authors stated that the use of NIF led them to revise the point of bowel transection since it allowed detection of a hypoperfusion that was otherwise invisible under white light. The real impact of NIF–ICG in decreasing the colonic fistula rates still needs to be determined and future large, prospective trials will be essential in achieving more definite results.

Identification of the sentinel lymph node and lymph node mapping are potentially two of the most interesting applications of NIF. The use of this technique in oncologic surgery may result in recognizing and selectively harvesting only the metastatic lymph nodes, providing more accurate staging of the disease and better oncologic outcomes. NIF has already been used in laparoscopy for the detection of lymph nodes in early gastric and early-stage colorectal cancer.[145] In robotic surgery, the current reports found in literature are regarding lymph node mapping in cervical and endometrial cancer, and pelvic lymphangiography in bladder cancer.[146]

Future Directions

In trying to predict future development directions, human-machine interfaces may be easily considered as one of the main target areas in new surgical platforms. Even though touchless interfaces have been introduced into the market, a more radical approach would be to create a system that provides surgeons the perspective of being within the patient's body. With such a VR system, the surgeon's movements could be tracked and translated to directly control the robotic tools within the patient. This VR could be enhanced with additional information from multiple sources and numerous units could be joined in a collaborative scenario.[147,148] Furthermore, thanks to enhanced VR, different surgical scenarios can be simulated on a high fidelity virtual patient to properly train the surgeon and improve the outcome of real interventions.[149,150]

Looking at the horizon of surgical research and technology, a step beyond the addition on VR would be the addition of cognitive capabilities to the robot, such as the awareness of the current medical situation, and the ability to react in an appropriate way. This capability, commonly referred to as artificial intelligence, will initially address simple tasks, such as preparation, suturing, and basic cutting and puncturing, and then might take over specific parts of procedures, which are difficult to handle, or require repeated similar motions. Miniature robots, VR, wireless technologies, soft robotics, and magnets are among the emerging technologies that may impact the future of surgical practice. Technology is paving the way for a new generation of surgeons, hybrid gastroenterologists–surgeons–radiologists with competences in electronic and computer engineering. However, the introduction of medical robots to the mass market relies on cost reduction. This might either be the shrinking direct costs of the systems or reduced patient care costs at the hospital. Without significant reduction of the costs, any system will only remain available to the richest institutions and most developed countries.

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