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Robotic Colorectal Surgery

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Abstract Surgical innovation is constant, most recently is the introduction of robotic surgery. While the incorporation of minimally invasive surgery in the field of colorectal surgery is generally rapid, robotic surgery is yet to gain momentum in the field. Laparoscopic colorectal surgery is now widely practiced, yet it has its own limitations, specifically in rectal surgery and operating in the pelvis. The advent of robotic surgery comes with hopes to address these limitations at no cost of compromising oncological outcomes. There are abundant reports in the literature on early experiences with the robotic technique with early results demonstrating safety and feasibility of the technique. However, as with any new technology, it comes with its own limitations. Benefits, limitations, outcomes, and future directions of this new technology as it applies to colorectal surgery are discussed.

Keywords Robotic surgery · Colorectal surgery · Robotic colon surgery · Robotic rectal surgery

Introduction

Minimally invasive operative strategies have revolutionized surgical practice. Most surgeons by nature are attracted to less invasive techniques that would yield equal results to antiquated techniques. Robotic surgery is the new kid on the block that medical literature is bustling about. It is valuable to take a look at the history of robotics in surgery prior to discussing its role in colorectal surgery. The first reported robotic procedure was a brain biopsy in 1985 using the Puma Mark II robotic system [1]. In 1987 robotics was used for cholecystectomy. Following that report, robotic technology was utilized in many surgical fields most notable in urology and gynecology. The introduction of the technique in colorectal surgery has been somewhat gradual, which may be secondary to hesitance to abandon well-established principles of open surgery. The use of the da Vinci system for abdominal surgery was approved in 2001 [2]. More than 20 years ago, laparoscopic surgery revolutionized the practice of colorectal surgery. Today, the field experiences yet another revolution as robotic colorectal surgery gains more popularity. The purpose of this article is to review the current literature on robotic colorectal surgery and share our institutional experience.

This article is part of the Topical Collection on *Robotic Surgery*.

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The da Vinci® Surgical System

The da Vinci® Surgical System (Intuitive Surgical Inc., Sunnyvale, CA), first introduced in 1999, is the sole robotic surgical system currently commercially available. It was first approved by the FDA for use in the US in 2001. The initial prototype had three arms; in 2003 the company introduced a newer version with a fourth arm. Since then there has been three generational upgrades: the da Vinci® S in 2006, the da Vinci® Si in 2009, and the latest generation, the da Vinci® Xi, which was introduced in 2014 [3].

- Surgeon's console
- A patient-side robotic cart that has four robotic arms (one for the camera and three for surgical instruments) that are manipulated by the surgeon at the console
- High-definition three-dimensional vision system.

Robotic Colorectal Surgery: An Overview

Operating in the pelvis is a challenge for even the most experienced surgeon, which is one of the many reasons laparoscopic surgery was initially hailed to aid in the challenge. As of date, results in the literature are conflicting with regards to laparoscopic versus open surgery for colorectal cancer. Long-term results of the MRC CLASSIC trial continue to support the use of laparoscopic surgery for both colon and rectal cancer [4]. However, two multicenter prospective randomized trials: ACOSOG Z6051 and the ALaCaRT study failed to prove non-inferiority of the laparoscopic technique for rectal cancer [5, 6]. Whether failure to meet non-inferiority in the ACOSOG Z6051 and ALaCaRT studies will correlate with short- and long-term differences in oncologic outcomes remains to be seen. On the other hand, studies like the COREAN trial and the recently published long-term outcomes of COLOR II do not agree with these results [7]. However, it is important to note that it is really not fair to compare ACOSOG & ALaCaRT to COLOR II given that the researchers in COLOR II trial randomized patients with stage I and II rectal cancer not Stage II and Stage III. Thus, one should be very careful while taking the comparison to surgical practice. Whether these results were anticipated or not is beyond the scope of this article, but the knowledge that almost any new technique comes with its own limitation, is one of the many reasons surgeons started to explore alternative techniques such as three-dimensional laparoscopy or robotics. If one would ignore the split evidence in the scientific literature, there remains to be too many technical limitations to the laparoscopic technique when it comes to the pelvic anatomy. Robotic surgery aims to eliminate those technical difficulties offering better ergonomics with a better visual and a stable camera platform [4]. The tremor filter, three-dimensional vision, and wrist-like movements facilitate the preparation of autonomic nerves in a narrow space such as the pelvis [8••]. It also allows for careful ligation and dissection of the mesenteric vessels (Figs. 1, 2). Outcomes following robotic total mesorectal excision (TME) appear to be comparable to those of laparoscopic surgery. A most recent systematic review of the available literature published in 2014 selected 69 articles, which included 1 randomized controlled trial and concluded that robotic colorectal surgery is both safe

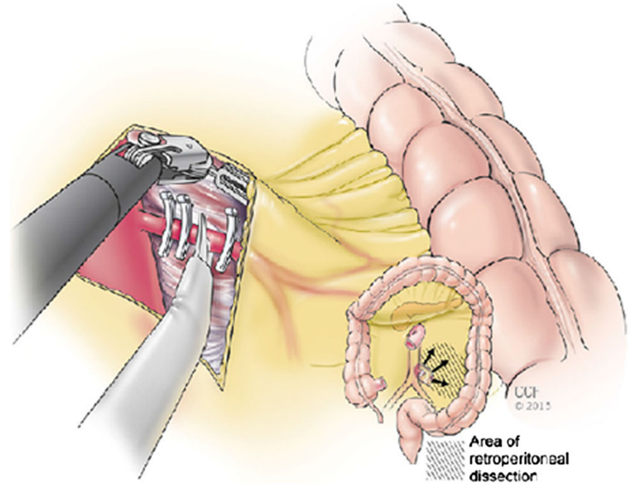

Fig. 1 Robotic ligation of the inferior mesenteric artery

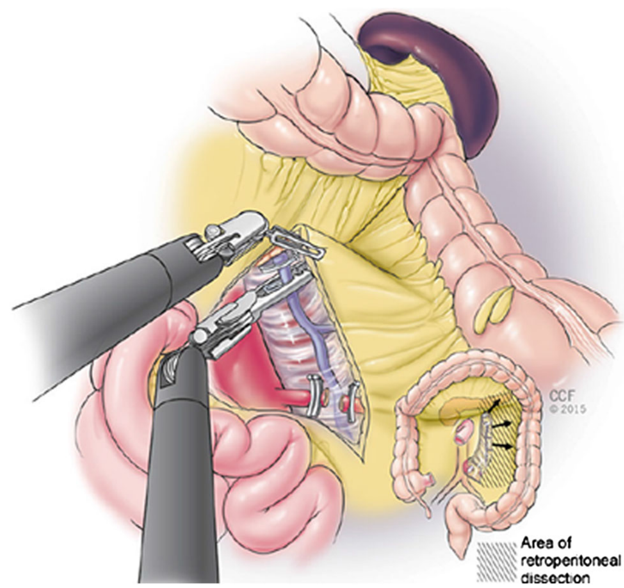

Fig. 2 Robotic ligation of the inferior mesenteric vein

and feasible [9]. It is important to note that most of these data are extrapolated from retrospective studies or prospective non-randomized trials [10].

Surgical Technique

There are two recognized techniques for robotic rectal surgery: the hybrid technique and the total robotic technique.

Hybrid Technique

The hybrid technique is a laparoscopic-assisted robotic technique. This eliminates repeated movements to reposition the robotic system and thus decreases overall operative time. Also, it is easier to mobilize the splenic flexure laparoscopically and then shift to robotic for the pelvic dissection in a (TME). The Si system is designed to work better in the pelvis and requires double docking to take down the splenic flexure. Thus redocking increases operative time and affects the flow of the operation. Further attention is necessary in the positioning of ports, with consideration given to the range of dissection required within the abdomen as well as the potential for external collisions of the robotic arms. Decision making for port locations is gradually and accurately perfected based on individual experience. Port placement for rectal surgery is shown in Fig. 3. Whether totally robotic or hybrid technique will be employed depends on surgeon discretion. While totally robotic rectal procedures have been reported with acceptable safety results, various hybrid procedures likewise offers benefits associated with robotic approach. For the hybrid technique, variations depend on the onset of robotic surgery where it can be either ligating the vessels or followed by laparoscopic splenic flexure mobilization. In all conditions, a minimum distance of "one hand's breadth" is required to avoid external collisions of the robotic arms. Limitations of this technique are that the surgeon has to be well trained in laparoscopic colorectal surgery. However, with the advent of the new da Vinci® Xi a totally robotic TME seems both technically feasible and efficient which will be discussed further in the chapter.

Total Robotic Technique

This technique has the advantage of using the robot for completion of the whole procedure. It is reported that a surgeon who is inexperienced in laparoscopy can still perform a minimally invasive (MIS) colorectal procedure using this technique. However, the authors of this chapter believe that both approaches require good advanced laparoscopic experience. The senior author uses the single-docking approach and flips arm 3 from the right upper quadrant trocar to the left lateral trocar for the pelvic part when using the da Vinci® Si platform. In this approach, the robot does not need to be moved or repositioned except the described arm change. After the colon has been completely mobilized, bowel distal to the pathology is transected with a laparoscopic linear-cutting stapler. Endocutter stapler can be introduced through the right lower quadrant trocar after upsizing to a 12 mm port. This site can ultimately be used as the specimen extraction as well as the stoma location in cases where a diverting ileostomy be needed. Usually, one firing of the stapler is satisfactory to staple and cut across the bowel depending on the level of the transection. This step can also be achieved using the robotic EndoWrist 45 mm stapler. This is a 54-degree wristed articulating robotic stapler and may provide advantage in confined spaces such as deep in the pelvis. After specimen extraction, the extraction site is sealed and peritoneal access regained. In this approach, maintenance of the pneumoperitoneum can be achieved in different ways: our general preference is to use the Alexis bundle wound protectors with "a cap" (Alexis laparoscopic system with Kii Fios First Entry, Applied Medical).

Robotic Colorectal Surgery Outcomes

Anastomotic Leakage Anastomotic leakage is one of the most dreaded complications after colorectal surgery. Kim et al.'s systematic review of available literature reported an anastomotic leakage rate post robotic colorectal surgery of 21.4 % [9]. A review of literature on anastomotic leakage following robotic surgery compared to laparoscopic surgery seems to show no significant difference between both. Baek et al. reported 8.6 % leakage rate for RS compared to 2.9 %, but his findings were not statistically significant [11]. Whether future literature will support or refute the current data remain to be seen, yet it's worth mentioning that the near infrared camera of the robotic platform allows visualizing the vascular structure of the colon after Indocynine green injection. That technology might positively impact rates of leakage rates in the future [12].

Conversion Rates By far the most potential advantage of robotic versus the laparoscopic technique is the lower conversion rate to open. Over the past two decades, laparoscopic technique has been continuously evolving and surgeons' experience has been increasing however the COLOR II trial reported a conversion rate of 17 % [13••]. Furthermore 20 years later, there has been no significant change in the rate of early postoperative complications, except for a decrease in positive surgical margins noted in the past 3 years. While this could be somewhat frustrating, it also gives room to anticipate better results with a newer technique if one would consider that laparoscopic surgery has offered the maximum that it could possibly offer [14].

Oncological Outcomes Several studies in the literature reported 3–5-year overall (OS) and disease-free survival (DFS) rates after RS most on rectal surgery rather than colon (Table 1). Perhaps the largest series published on outcomes following colon resection is by D'annibale et al., where at a median follow-up of 36 months for 50 robotic right hemicolectomies the DFS was 90 % and OS 92 % with cancer-related mortality of 8 %.

Most studies in the literature report no difference between lymph node harvest, and circumferential resection margin positivity (CRM) which concurs with findings from our institution's case-matched study [18•]. One metanalysis

Table 1 Long-term survival outcomes after robotic rectal surgery

Author	*N*	Mean or median follow-up (months)	DFS	OS
Park et al. [15]	106	50.2 (38.4–66.3)	89.6 % (3 years)	93.8 % (3 years)
			80.6 % (5 years)	88.5 % (5 years)
Pai et al. [16]	101	34.9 ± 18.4	79.2 %	90.1 %
Park et al. [17]	133	54.4 ± 17.3	81.9 %	92.8 %

DFS disease-free survival, *OS* overall survival

by Xiong et al. showed a statistically significant lower CRM positivity and conversion rates favoring robotic approach with operative times and local recurrence rates remaining similar [19].

Genitourinary Function After Robotic Colorectal Surgery Robotic rectal surgery offers better optics and visualization of the autonomic nervous plexus in the pelvis, which would consequently help surgeons preserve the nerves and thus preserve genitourinary function postoperatively. Total robotic technique supporters believe that the robotic technique allows for preservation of both pelvis and periaortic nerves, which would translate into less postoperative sexual/bladder dysfunction [20].

Operative Time Most studies report longer operative time with robotic rectal surgery, which concurs with our institutional data where mean operative time was 172 min for RS versus 267 min LS, $P < 0.0001$ [18]. In a systematic review by Mak et al., mean operative time of RS was 281.8 min compared to 242.6 min for LS. Most authors identified the longer time taken with robotic surgery to be due to docking and changing of the robotic arms, a limitation that could perhaps be overcome by the introduction of the da Vinci Xi system [21]. The authors also anticipate that as surgeons and operating room staff gain experience with the robotic technique this would very likely reduce operative time in the future.

Cost

One of the major drawbacks of robotic surgery is the cost. Data from our institute comparing cost of proctectomy between open, laparoscopic, and robotic surgery concluded that robotic surgery costs 30 % more. However, this data included surgeon's learning curve and multiple procedures were bundled in the analysis. A Nationwide Inpatient sample (NIS) study by Juo et al. from John's Hopkins found a statistically significant higher overall hospitalization cost of robotic versus laparoscopic colectomy ($14,847 vs. $11,966) [22]. Yet, Halabi et al. in his review of NIS from 2009 to 2010 demonstrated an increase in robotic rectal surgery cases performed from 1188 cases in 2009 to 2380 cases in 2010 [10, 23]. One would wonder why? Why incur an additive cost on the institution especially with the current era of health reform while there are cheaper, equally effective, and also minimally invasive techniques at hand? Here, we highlight again that the anatomy of the human pelvis is one of the most challenging to a colorectal surgeon and colorectal surgeons grasp upon any validated improved outcome. In a retrospective review of 488 proctectomies for curative intent by our institution, patients were grouped by surgical approach (open, laparoscopic, and robotic). All groups had similar demographics, characteristics, and treatment details [24]. Although, significant outcome differences were found in operative and anesthesia time for the robotic group, one should give credit when credit is due arguing that these patients had a shorter hospital stay and less overall complications compared to open group. In a propensity score-match analysis, Kim et al. concluded that robotic surgery had similar short-term perioperative outcomes compared to laparoscopic surgery and at a higher cost, as one would expect [25]. Results of a cost conscious approach study done by the senior author showed that when we compared restorative proctectomies done open and robotically; after the first 5 robotic cases done by high volume surgeons, the cost by both groups was comparable ($P = 0.02$ for the first 5 cases, then $P = 0.14$). However, owing to the fact that the technique is still in its infancy, literature is lacking on long-term outcomes. We believe that until long-term outcomes prove non-inferior the argument of higher cost cannot be totally validated, at least not on a surgeon's frontier.

Impact of Obesity on Robotic Surgery

It is not uncommon for colorectal surgeons to anticipate hardship when operating on obese patients. In an institutional review that is currently in press, we concluded that in a comparable group of patients (patient demographics, body mass index (34.9 ± 7.2 vs. 35.2 ± 5.0 kg/m^2, $P = 0.71$), co-morbidities, surgical and tumor characteristics), RS was associated with an earlier return to bowel function and shorter hospital stay ($P = 0.02$).

Learning Curve

As with every new technique, there must be a learning curve before surgeons are deemed competent. There is a paucity of evidence on learning curve and robotic colorectal surgery. Learning curve values in the literature range from 15 to 35 cases. In a prospective evaluation of robotic TME, the authors concluded that operative time decreased after 20 cases [26].

The ROLARR Trial: Fall Through the Looking Glass

Any recently published paper in the subject of robotic colorectal surgery, there will be mention of the ROLARR trial. The reason is it is the first pan-world multicenter randomized controlled superiority trial to recruit a considerable number of patients (200 in each group) and evaluate short- (30 days and 6 months) and long-term (3 year) outcomes. Primary outcome of the study is the rate of conversion. The investigators have set 10 surgeries (laparoscopic and robotic) as minimum surgeon experience for recruitment [27••]. Preliminary results of the trial were presented at the American Society of Colorectal Surgeons' meeting in 2015 by Pigazzi on behalf of the ROLARR team. Preliminary data failed to show a statistically significant difference in conversion rates, primary outcome of the study, margin positivity, 30-day complications and mortality (both secondary endpoints) between both arms. Perhaps, one of the most notable findings was an improved benefit of RS in a subanalysis group that included males, obese, and low tumors. These results while widely anticipated are somewhat disheartening. As highlighted above, there was a trend of the literature that showed improved conversion rates and better negative circumferential resection margins and what for a short while seemed to be a promising technique is now yet questioned. However, we would still eagerly anticipate the longer outcomes of the study specially to highlight more on oncological outcomes [27••].

The Cleveland Clinic Experience

Our initial institutional experience published late in 2015 included our first 57 cases using the da Vinci® Si. As of date, we have performed 279 robotic procedures of which 135 were for malignant disease. Since the introduction of the da Vinci® Xi system our institute has performed 51 procedures using the new technology, 42 of which are colorectal procedures. The senior author has previously described his experience using the da Vinci® Si robot system. The da Vinci® Si system is designed to work better in the pelvis and requires double docking to take down the splenic flexure. Thus redocking increases operative time and affects the flow of the operation as this requires repositioning the entire platform. In 2014, Intuitive Surgical marketed a new platform where the da Vinci® Xi system addressed a few limitations of its predecessor. The da Vinci® Xi comes with a light weight camera which facilitates its control and is interchangeable between ports. One of the major advantages, is it allows for a much more superior multi-quadrant surgery.

While it addressed many limitations of the previous platform, the technology is still in its infancy. One of the disadvantages we noted in the Xi system is that the new port placements recommended by Intuitive Surgical there is a trend of the ports coning towards the pelvic dissection as seen in Fig. 4. Deep in the pelvis, the instruments become quiet parallel as opposed to the Si system where all the arms are coming from a wider angle. Therefore the triangulation effect is somewhat compromised. To overcome this limitation, different port placement could be tried.

In a pilot study that included 10 patients in either group, Morelli et al. published a case-matched comparison of short-term outcomes of the da Vinci® Xi and Si surgical systems in robotic TME. The da Vinci® Xi group had a statistically significant shorter overall operative time (257.8 vs. 353.5 min, $P < 0.01$); however there was no difference in mean docking time (19.8 vs. 21.0 min). Also, their study

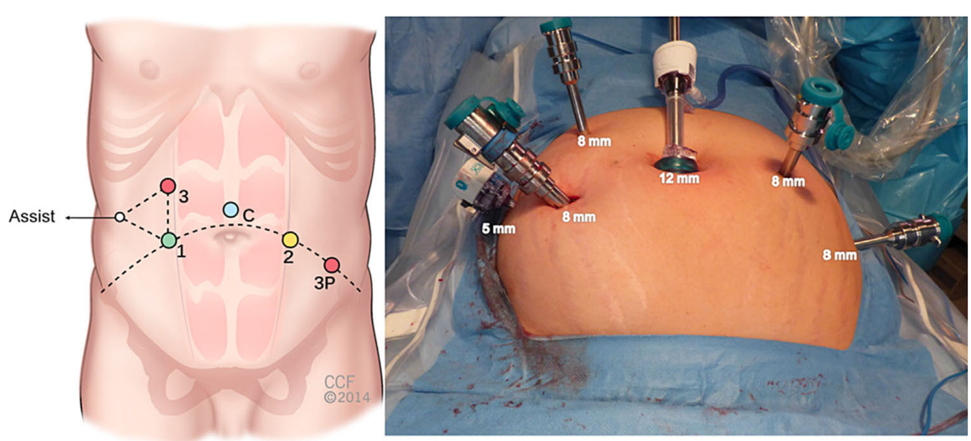

Fig. 3 Port placement da Vinci Si®

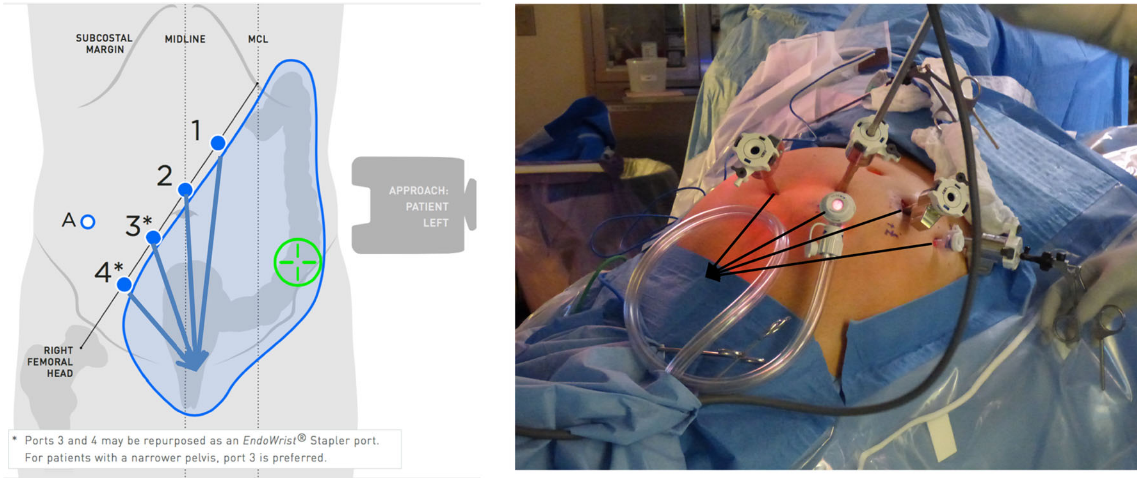

Fig. 4 da Vinci® Xi ports: *left* left-sided approach port placement da Vinci Xi®; *right* robotic APR port placement ©2016 Intuitive Surgical, Inc. used and modified with permission

results showed a significantly shorter hospital length of stay in the da Vinci® Xi group (6.3 days vs. 8.7, $P < 0.01$). There was no significant difference in short-term oncological outcomes namely lymph node harvest (19.0 nodes vs. 17.5), distal margin (17.6 vs. 15.3 mm), and quality of mesorectum (complete in all patients) [28]. While the study is limited by the small number of patients, it will encourage further similar studies from experienced MIS colorectal surgeons that will aid to shed light on the advantages of the new platform.

Future Directions

As the surgical community eagerly awaits long-term results of the ROLARR trial, the authors believe that the debate on the value and cost effectiveness will continue when it comes to robotic surgery. If the literature continue to show non-inferiority it might be difficult to justify in the future the use of a more expensive technique with no added benefit, however, if more data become available on a superior incidence of negative circumferential margins and long-term superior oncological outcomes, it will be the time to give credit to a technique where credit is due, because "the money" is invariably in a technique that results in better oncological outcomes.

Natural Orifice Robotic Surgery

Surgeons strive to avoid large incisions, which serve to benefit both cosmesis and improved postoperative pain. Natural orifice specimen extraction spares a traditional 4–5 cm incision needed for specimen extraction in either laparoscopic or robotic colorectal surgery. Choi et al. published data on 13 patients with robotic-assisted TME for rectal cancer where specimens were extracted either transanally or transvaginally in female patients [29]. Further literature on the topic is anticipated.

Conclusion

Innovation in surgery will continue to evolve, so will scientific evidence of the benefit of such innovations. Robotic colorectal surgery is a promising frontier despite limitations of cost and probable prolonged operative time which could arguably improve with learning curve.

Compliance with Ethics Guidelines

Conflict of Interest Drs. GamalEldin and Gorgun declare no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- •• Of major importance

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