



# A current review of robotic colorectal surgery

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**Abstract:** Colorectal surgery has seen significant advancements in minimally invasive surgery (MIS) over the last several decades which has resulted improved perioperative outcomes when compared to traditional open approaches. With development and utilization of robotic technologies, there have been several studies comparing the efficacy and safety of robotics to traditional laparoscopy. Given the current available data, it appears that robotic surgery offers equivalent perioperative results with comparable short term and long-term oncologic outcomes when compared to laparoscopy. These same studies, however, do consistently demonstrate that robotic surgery results in decreased rates of conversion to an operation, but at an increased overall cost to the patient and healthcare system. This review aims to review the history of advances in MIS in colorectal surgery, review the available data in robotic resections and discuss the known limitations to full adoption of robotic surgery.

**Keywords:** Robotics; colorectal surgery; minimally invasive surgery (MIS)

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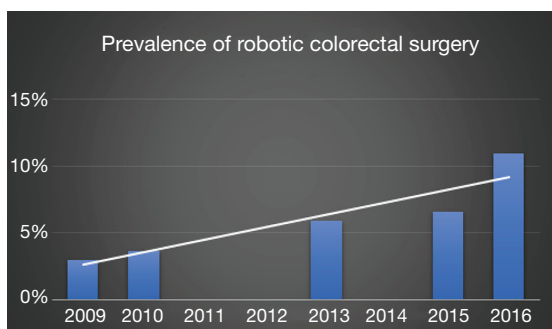
## Minimally invasive colorectal surgery: the framework and history

Over the last 30 years, colorectal surgery has seen significant advancement in minimally invasive surgery (MIS) techniques. The earliest case reports of laparoscopic colon resection were published in in the early 1990's (1-3) and laparoscopic volume has steadily increased over the last 30 years to represent 40–50% of all colorectal resection for both benign and malignant disease (4,5). After Heald's landmark description of the "holy plane" for total mesorectal excision (TME) for rectal cancer (6), early adopters of laparoscopy pioneered the laparoscopic approach to rectal resection (7,8). Since then, several landmark studies have confirmed equivalent, non-inferior or improved short and long term perioperative and oncologic outcomes of laparoscopy when compared to traditional open resection (9-15). Laparoscopic MIS techniques have shown to result in earlier return of bowel function, earlier

initiation of diet, shorter index hospitalization length of stay, decreased postoperative pain, and improved cosmesis (10,16). With advancements in laparoscopic platforms, instruments, technical skill and early training during surgical residency, laparoscopy has become, in many instances, the default surgical approach for many surgeons within the abdominal cavity.

In the dawn of the new millennium, robotic surgery made its first legitimate appearance as a novel technique in minimally invasive abdominal surgery, and in July, 2,000 robotic surgery was FDA-approved for abdominal, general surgery procedures (17). The use of robotics in pelvic surgery, especially in a nerve-sparing manner within the narrow pelvis, was championed early-on by our urologic and gynecologic colleagues (18,19). In 2009 85% of all robotic cases were limited to urologic and gynecologic procedures (20) and by 2012, 75% of all radical prostatectomies were performed robotically (21).

The first robotic colorectal series was published in



**Figure 1** Percentage of U.S. robotic colorectal surgery using combined data from various available national population datasets (31-34).

2002 (22), treating benign colon and sigmoid pathologies. Soon thereafter, various national and international groups began publishing their own data comparing robotic and laparoscopic colorectal surgery (23-25). Not surprisingly, these were non-randomized, retrospective, single institution experiences which did not differentiate benign and malignant pathology with small sample sizes.

In 2006, the first case-series describing robotic, oncologic low anterior resections (LAR) with TME was published (26). The authors reported no significant differences in perioperative clinical outcomes or pathologic assessment within their small sample size when compared to conventional laparoscopic LAR with TME. Despite the paucity of data at the time, the technical advantages of the robotic platform over laparoscopy, especially within in the narrow pelvis, were often cited by proponents of the new instrumentation, including the seven degrees of movement with micro-wristed instruments, magnified 3-D view with lack of hand-tremor, a natural hand-eye target axis and ergonomic comfort (27-29).

From 2010 to 2012 the prevalence of robotics within U.S. hospital systems rose from 20% to 27% according to data compiled from the American Hospital Association (30), with the highest density of robotic platforms centralized in metropolitan, teaching hospitals that provide inpatient, oncologic surgery. There has been a steady annual increase in robotic colorectal surgery to almost 11% of all colorectal resections in 2016 (31) (*Figure 1*).

Concomitantly, marketing and advertising for robotics increased steeply with 86% of 400 randomly selected U.S. hospitals that offered robotic surgery publishing statements of clinical superiority of robotics hospital websites (35). When surveyed on the perceived benefits of robotic surgery

over laparoscopy, patients, administrators and non-surgeon providers demonstrated several assumed conclusions (and misconceptions) as to the benefits (perioperative outcomes, oncologic outcomes, etc.) of robotic surgery which were largely based on an expected correlation to a new and advanced technology (36).

### The MIS learning curve: from laparoscopy to robotics

With robotic colorectal surgery increasing year by year (30,33,37) and with its increasing popularity, new and experienced surgeons alike must face a steep learning curve—the process of becoming proficient, safe and independent—with this relatively novel surgical technique. Facing this robotic learning curve, however, is not an unfamiliar process for the practicing minimally invasive surgeon who also faced a learning curve when developing their laparoscopic skills. Tekkis *et al.* evaluated the learning curve for laparoscopic left-sided and right-sided resections using multidimensional rubric that included operative time, conversion to open surgery, readmission rates and postoperative complications (38). The authors calculated that 55 cases were necessary to gain proficiency for right-sided resections while left-sided resections necessitated 62 cases. Park *et al.* using similar multidimensional methods, found the learning curve for proficient laparoscopic rectal resection is 90 cases (39).

The available knowledge on the robotic learning curve, however, should be approached with an a priori understanding that many first-time robotics users have a foundation in minimally invasive and laparoscopic techniques. Since 2008, General Surgery trainees have been required to demonstrate competence in fundamental laparoscopy by successfully completing the Fundamental of Laparoscopic Surgery (FLS) course and are required to complete 100 basic- and 75 complex-laparoscopic cases as a prerequisite to sit for the American Board of Surgery (ABS) certifying exam (40,41). Additionally, with the aforementioned technical improvements in the robotic platform, such as 3-D visualization, degrees of freedom of wristed instruments, etc. the proposed advantages to robotics should conceivably offer a more rapidly advanced skill-progression to the surgeon with a strong MIS foundation (28). However, even with these ergonomic and technical advantages and advances, there continue to be real limitations to immediate adoption, including a loss of haptic feedback, limited range of motion of the robotic

arms, inability to reposition the surgical bed while docked (although the option/upgrade is available) and continued need for skilled (and trained) bedside assistance that a new user must overcome.

Demographic data on current robotics users has shown that younger surgeons (0–10 years out from training), board certified colorectal surgeons and high-volume surgeons are more likely to be performing robotic surgery (42). With colorectal surgery fellows expressing increased need for more robotic experience within their training curriculum (43), understanding the expected learning curve is an important aspect of developing new training curricula. Jimenez-Rodriguez *et al.* performed a meta-analysis of the currently available, reliable data pertaining to the learning curve of robotic rectal cancer surgery and calculated the mean number of cases required for surgeon to be classified as an expert in robotic to be 39 (44), which is notably less than the aforementioned laparoscopic learning curve numbers (38,39).

### Robotic colorectal surgery: data to date

After just a decade, available data on robotics in colorectal surgery has increased exponentially. We now have multi-institutional, national and international database analyses, systematic reviews (45) and meta analyses evaluating robotic outcomes. Queries of the National Inpatient Sample (NIS) (30,33), National Cancer Database (NCDB) (37), and ACS/NSQIP (34) data sets have demonstrated that robotic surgery results in similar or lower postoperative lengths of stay, equal perioperative morbidity, similar anastomotic leak rates, similar postoperative ileus and a decreased conversion to open surgery in both colonic and rectal resections when compared to laparoscopy. Furthermore, pathologically, there were no reported differences in lymph node (LN) retrieval or positive surgical margins. The most consistently reported limitations of robotics, however, were an increase in operative time and overall cost when compared to laparoscopy—items to be discussed later. These large analyses have demonstrated that robotic colorectal surgery is, at the least, a safe and feasible alternative to laparoscopy.

As previously noted, many of the technical advantages of robotic surgery have been highlighted while working in the pelvis, and, as such, rectal surgery has been thoroughly evaluated as a primary utilization for robotics in colorectal surgery. In 2017 the long awaited Robotic *vs.* Laparoscopic Resection for Rectal Cancer (ROLARR) trial was published (46), an international (10 countries), multicenter (29 sites), randomized controlled trial (RCT) assessing

primary endpoint of conversion to laparotomy for performing part of the TME, and is the largest study of its kind to date. The study was designed to exclude surgeons who were still on their learning curve, and, as such, only experienced surgeons in laparoscopy (mean of at least 90 prior cases) and robotics (mean of at least 50) were included. Secondary endpoints included evaluation of circumferential radial margin, postoperative complications, mortality, bladder and sexual dysfunction, and pathologic assessment of the TME. There were no reported differences in conversion rates or other secondary end points, but robotic surgery did result in longer operative time. These authors concluded that robotic resection does not confer an advantage in rectal cancer, and given the increased cost with near equivalent outcomes, robotic surgery for rectal cancer is not justified.

ROLARR's results were met with mixed responses, especially within the robotics community. Soliman notes in an editorial (47), that the ROLARR trial was underpowered based on results from the CLASICC trial (16) and the study only utilized the da Vinci Si robot. When looking closer, the data show there were clear advantages favoring robotics to prevent conversion in obese patients, patients with low tumors, and males. These are the patients where one would expect the most benefit. He also notes that surgeons with fewer robotic case experience had equivalent outcomes to surgeons with 2–3 times the laparoscopic case experience and that circumferential radial margin (CRM) positive rates in the robotic arm (5.1%) was less than those reported laparoscopically in COLOR II (10%) (14), CLASICC (7%) (16), AlaCaRT (7%) (15) and the Z6501 (12%) (9) trials.

In a 2018 meta-analysis of five randomized controlled trials, including ROLARR, Prete *et al.* assessed robotic versus laparoscopic resection for rectal cancer (48). The authors found no significant differences in TME grade, CRM positivity rates, LN harvest, postoperative leak, mortality, or complication rates. There, again, was a decreased rate of open conversion in the robotics arm, however, a significant increase in operative time in robotic resections across all five trials.

Oncologically speaking, the decreased conversion rates are of great importance for short and long-term outcomes for several reasons. Conversion from a MIS to open resection results in increased postoperative complication rates, overall episodic costs, delays in time to chemotherapy completion which can ultimately affects oncologic outcomes, specifically, decreasing 5-year disease free survival and trends towards higher recurrence rates (34,49–51).

While arguments favoring robotic approaches for pelvic surgery and rectal resection seem to be clear, the utility of robotic surgery on colonic resections, specifically right-sided resections, remain unknown. Ma *et al.*, in 2019, published a systematic review and meta-analysis of 13 trials, mostly retrospective in design, comparing robotic and laparoscopic right-sided resections (52). The pooled data found that robotic resections were associated with significantly longer operative times and higher costs, but a decreased postoperative length of stay, and, again, lower conversion rates. Authors of the only included RCT from 2012 included in this analysis concluded in their study that the robotic right colectomy was feasible when compared to the laparoscopic approach but provided no benefit to the costs of the surgery (53).

There is new data emerging, however, on the utility of robotics on performing a right sided complete mesocolic excision (CME) with central venous ligation as initially described in the open setting by Hohenberger *et al.* (54). A modified CME done robotically has been shown in retrospective series to have equivalent oncologic outcomes with negligible conversion rates when compared to laparoscopy (55-57). Authors highlight that the delicate vascular dissection is improved with the utility of the robot when compared to laparoscopy. Nonetheless, with a higher morbidity and complication rate, it's unclear if any small oncologic survival benefit derived from the resection approach is of value (58), regardless of approach.

### Cost analysis

To date, there is only one mainstream distributor producing commercially available robot platforms within the United States. Da Vinci (Intuitive Surgical Corp, Sunnyvale, Ca) robots have dominated the market and represent the operating platform for all the aforementioned studies. In 2006, Intuitive launched its "S" system and most of the data we have available to us today have been based on studies and experiences on that console and its variations. Compared to newer, advanced models within the da Vinci family, the S and Si systems were limited in their performance capacity. Specifically, the configuration and maneuverability of its operative arms limited access to several abdominal quadrants and often required a hybrid approach with laparoscopy and/or repositioning the robot to achieve adequate dissection and exposure. For left sided colorectal resections, for example, the splenic flexure mobilization and vessel (inferior mesenteric artery) dissection and division

were often performed laparoscopically while the TME was dissected robotically or the robot was repositioned mid procedure to complete these steps (59,60).

In 2014, da Vinci launched the Xi platform, their fourth-generation design. The Xi Touts new advances including smaller arms with wider range of motion with patient clearing joints allowing for multi-quadrant access, longer instruments and easier docking and undocking capacity (28) dies comparing the Xi and Si platforms in colorectal surgery demonstrated shorter console times with equivalent quality and oncologic outcome measures (60,61).

When laparoscopic surgery was first being evaluated for cost effectiveness, supporters of its use note that any additional costs incurred in the operating room were the result of increased OR time or instrumentation costs which were ultimately justified by hospitalization savings with decreased length of stay, readmission rates and complication rates (16,62). As surgeons became more proficient with laparoscopy and had plateaued on their learning curve, the operative times decreased, and laparoscopy became increasingly cost-effective (63).

With perioperative clinical outcome data being thus far equivalent between robotic and -laparoscopic surgery, the question of cost-efficacy with the robotic platform is often cited as a significant limitation and disadvantage (46,53). There are data demonstrating decreased postoperative length of stay following robotic colorectal surgery and other data demonstrating a 2-3 fold decreased conversion rates when compared to laparoscopy which both have direct effects on cost (33,34,42,49).

The "cost" of a robot is a common discussion-point, but understanding the nuances of the robotic "price-tag" is critical when trying to place a value on its use. According to the 2017 Intuitive Surgical Annual Report along with data collected from the American Hospital Association there were approximately 4,400 da Vinci systems worldwide in 2017, with nearly 2,800 of the 5,500 (51%) United States hospitals having a robotic presence (up from 27% in 2012). There were an estimated 644,000 robotic procedures performed in the United States the same year with largest growing market (and second largest standing market behind gynecology) being within the general surgery population which includes colorectal surgery. The average sales price of a da Vinci robot in 2017 was \$1.47 million with an annual service contract ranging from \$80,000 to \$170,000.

Using these data, Feldstein *et al.* (64) note that cost of ownership of a da Vinci robot can be calculated by the summation of the cost of initial equipment acquisition,

variable case cost by service or procedure (supplies, staff time), and the maintenance cost. The authors calculated that the average robot in the United States performs 424 cases annually and estimate that the average fixed cost per use of the robot is \$948. The weighted average variable cost per procedure was \$8,025 [ranging from \$3,325 (cholecystectomy) to \$16,986 (rectal resection)]. Based on their calculations of 14 high-volume robotic hospitals (academic, community and rural) the total cost for a single colon resection was \$11,258 and for a rectal resection was \$17,970. These data have been validated within randomized controlled trials which demonstrated significantly increased costs for robotic *vs.* laparoscopic colonic resection, even after insurance patient payments (52,53).

## Conclusions

There has been remarkable advancement in MIS techniques in colorectal surgery in recent decades. However, in a newly published population analysis of 191,000 patients undergoing colorectal surgery from the Medicare Provider Analysis and Review from 2010 to 2016, nearly half (46%) were still performed open (32). The current body of high-quality data available (database/population analysis, randomized control trials, meta-analysis, and systematic review) confirms that minimally invasive techniques are superior to an open approach but equal to one-another with regards to perioperative outcomes. The primary differentiating variable between laparoscopy and robots, in the hands of seasoned users, at this moment, is cost. As a younger generation of surgeons enter the work-force who are trained to be technically proficient and efficient in minimally invasive approaches, and as technology and the market-share for robotics continues to grow and diversify, costs will improve. As such, the surgeon will be able to use his or her discretion to determine optimal approach.

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## Footnote

*Conflicts of Interest:* MR Albert: Applied Medical: consultant, stock options, education; Stryker Endoscopy: consultant; Conmed Surgical: consultant; Human Extensions: consultant, stock options; Cooper Surgical: consultant, honorarium. JP Wright has no conflicts of interest to declare.

*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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