# Use of Robotics in Colon and Rectal Surgery

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**Abstract**

The pace of innovation in the field of surgery continues to accelerate. As new technologies are developed in combination with industry and clinicians, specialized patient care improves. In the field of colon and rectal surgery, robotic systems offer clinicians many alternative ways to care for patients. From having the ability to round remotely to improved visualization and dissection in the operating room, robotic assistance can greatly benefit clinical outcomes. Although the field of robotics in surgery is still in its infancy, many groups are actively investigating technologies that will assist clinicians in caring for their patients. As these technologies evolve, surgeons will continue to find new and innovative ways to utilize the systems for improved patient care and comfort.

**Keywords**

- robotics
- colorectal surgery
- robotic-assisted surgery



**Objectives:** On completion of this article, the reader should be able to summarize the current and future state of robotic-assistance in colon and rectal surgery.

## Use of Robotics in Colon and Rectal Surgery: State of the Art

The pace of change in the field of surgery continues to accelerate, and many concepts that were deemed "futuristic" only 10 years ago will now be realized within most of our lifetimes. Obvious limitations encountered with the use of traditional laparoscopic, robotic, and endoluminal instrumentation applied to single-incision laparoscopic surgery (SILS) and natural orifice transluminal endosurgery (NOTES) is driving remarkable innovation across the entire field of surgery. Existing robotic technology and platforms from other industries are being modified or new technologies and platforms developed to address these limitations. In addition to direct surgical applications, robotic technology is being utilized for telemonitoring, telementoring, remote presence clinical applications (daily rounds, conferencing, etc.) and magnetic resonance-guided robotic interventions. Such powerful robotic technology already exists in other industries and is being developed with such rapidity that soon the only limitations to the application of robotics across a wide range of surgical specialties will be the surgeons' bias, skepticism, limits of imagination, and potentially cost.

The use of robotic technology in colon and rectal surgery can be divided into the use of robots in the direct performance of surgical tasks and the employment of robots as communication tools or extension of the physician's clinical and mentoring reach. The state of the art of each of these applications and horizon technologies for each will be discussed.

## Clinical Experience with Robotic-Assisted Colorectal Surgery

The rapid increase in use of the Da Vinci system (Intuitive Surgical, Inc., Menlo Park, CA), particularly in prostatic, gynecologic, cardiac, and increasingly in foregut surgery has demonstrated its utility in allowing surgeons to complete more complex surgical tasks in a minimally invasive manner. What is notable about these areas of surgery is that they occur in a single anatomic region and thus do not require movement and "re-docking" of the robotic system. What is also unique is that the increased degrees of freedom and dexterity the robotic system provides in all these cases offers a surgical advantage over traditional laparoscopic instruments.

In contrast, almost every major colon and rectal procedure requires the surgeon to operate in two or more quadrants of the abdomen. Other demands of colon and rectal surgery, such as the need to manually palpate lesions or surrounding structures in inflammatory disease and the concern for worse

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oncologic outcomes, have inhibited the wide adoption of laparoscopic approaches for colon and rectal problems. Furthermore, existing "traditional" laparoscopic instrumentation and techniques have been refined to such a point that existing "traditional" robotic platforms (currently, primarily the Da Vinci system) offer little advantage in the minds of many laparoscopically proficient colorectal and general surgeons. Finally, as noted by Satava in his 2006 review of this topic, most colon and rectal procedures do not require as high a precision in either the dissection or anastomosis as in, for example, coronary artery bypass surgery or radical prostatectomy.[1]

For the reasons just outlined, general surgeons have been slower to find an operation that fully utilizes the benefits of the robot. Within the subspecialty of colon and rectal surgery, robotic-assistance is used even less. To some degree, this is a side effect of laparoscopy's slow acceptance in the colorectal field for the reasons mentioned in the previous paragraph. However, as more surgeons are trained in advanced laparoscopic techniques, laparoscopic colon and rectal operations are becoming more commonplace outside of specialized centers. With this gradual acceptance of minimally invasive colorectal operations has come a willingness to become trained in and utilize robotic systems.

Although robotic-assisted operations have been utilized for years in other surgical specialties, it was not until 2002 that Weber reported the first two cases of robotic-assisted colectomies.[2] As laparoscopy has continued to gain momentum in recent years, it has naturally evolved into the general adoption and trial of robotic-assisted resections in many centers. Proponents of robotic assistance have argued that rectal surgery is uniquely suited for the robot's strengths; namely, improved visualization in the confined area of the pelvis, articulation of the working arms for improved dissection, and more intuitive instrument manipulation.[3] However, unlike laparoscopy, operating throughout the entire length of the colon is more challenging using the robot. The time and effort of docking and repositioning the robot to the operating field limits its usefulness in long-segment colectomies. Thus, most groups focus on either right or left-sided colectomies and rectal operations. It appears to be the general consensus of robot advocates in colon and rectal surgery that the main benefit of the robot at this time is with rectal resections (and specifically total mesorectal excision (TME)) and performing minimally invasive colon resections in combination with single-incision surgery or natural orifice endoscopic surgery.[4]

Although there have been multiple robotic platforms developed, the da Vinci system® is certainly the most widely used in colorectal surgery. In reviewing the world literature on robotic-assisted colon and rectal surgery, only one large (>10 patients) case series has been reported with a platform other than the da Vinci®.[5] Although no prospective randomized trials have been reported on the use of robotic-assisted versus laparoscopic or traditional open surgery, many groups have reported relatively large case series on their early outcomes with robotic-assisted resection in colon and rectal surgery. ►**Table 1** summarizes the reported robotic-assisted colon and rectal surgery case series with greater than 10 patients.

## Robotic-Assisted Colonic Resections

Early experience in robot-assisted colorectal surgery focused primarily on right- and left-sided resections. The need for limited mobilization and preexisting comfort with laparoscopic right and left colon resections were likely the major factors contributing to early trial. More advanced robotic resections, particularly of low rectal lesions, did not become commonplace until more recently. Most of the case series reported for robotic-assisted colorectal surgery prior to 2007 did not include low rectal resections.[5–8]

### Perioperative Outcomes

The three largest published series of robot-assisted colectomies demonstrated acceptable and comparable perioperative outcomes.[9–11] For example, Deutsch et al compared 79 robotic-assisted colectomies to 92 laparoscopic-assisted colectomies over a 5-year period at his institution. The cohorts were well-matched based on preoperative parameters and their outcomes showed no statistical difference between operative time, blood loss, time to return to bowel function, length of stay, or intra- or postoperative complications.[10]

### Early Oncologic Outcomes

D'Annibale et al reported short-term oncologic outcomes at their institution for 50 consecutive robotic right colectomies for malignancy over an 8-year period. This is the largest series of patients to date evaluating oncologic parameters in robotic colectomies. Median operating time was 223.5 minutes without any conversions to an open operation. Specimen length was 26.7 cm with a median of 18.76 resected lymph nodes. The group developed one case of surgery-related morbidity, a mesenteric twist after an extracorporeal anastomosis (2%). Disease-free survival at 36-month follow-up was 90% and overall survival was 92%. This series demonstrated that early oncologic outcomes are acceptable in robotic-assisted right hemicolectomies.[12] Long-term data are needed to fully assess the value of the robot in cancer operations of the colon.

## Robotic-Assisted Total Mesorectal Excision

As experience with the robot has improved, its role has become more refined in colorectal surgery. Although many groups primarily use this technology for right- and left-sided colectomies, cost and relative comfort of laparoscopic-assisted colectomy techniques limit widespread acceptance. However, in the realm of low rectal lesions and pathology, many groups feel that the benefits of the robot greatly improved resection techniques. The robot's ability for improved visualization in the pelvis and wide degree of instrument articulation allows for improved dissection and preservation of normal anatomy. In the last few years, there has been increased interest in using the robot for total mesorectal excision (TME) in rectal cancers. Multiple groups have published series of cases comparing robotic-assisted TME to laparoscopic TME, open TME, or both. Based on the clustering of robotic-assisted TME research being published recently, popular opinion is that TME may be the colorectal

**Table 1** Summary of large (>10 patients) published series of robotic-assisted colorectal operations

| Author | Year | Robotic system | No. of patients | Operations performed | Country | Pathology |
|---|---|---|---|---|---|---|
| D'Annibale[12] | 2010 | da Vinci® | 50 | RHC | Italy | Malignant |
| Huettner[11] | 2011 | da Vinci® | 102 | RHC, SC | USA | Combined |
| Zimmern[9] | 2010 | da Vinci® | 131 | RHC,AR, TPC,LAR, APR | USA | Combined |
| Patel[47] | 2010 | da Vinci® | 5 | APR | USA | Malignant |
| deSouza[13] | 2011 | da Vinci® | 36 | TME | USA | Malignant |
| Baek[15] | 2010 | da Vinci® | 64 | TME | USA | Malignant |
| Kim[48] | 2012 | da Vinci® | 30 | TME | Korea | Malignant |
| Rawlings[6] | 2006 | da Vinci® | 30 | SC,RHC | USA | Combined |
| Deutsch[10] | 2012 | da Vinci® | 79 | RHC, IC, LHC, AR, LAR | USA | Combined |
| Koh[49] | 2011 | da Vinci® | 21 | AR, LAR, RP | Singapore | Malignant |
| Leong[50] | 2011 | da Vinci® | 29 | ISR | Korea | Malignant |
| Park[14] | 2011 | da Vinci® | 52 | TME | Korea | Malignant |
| Bokhari[51] | 2011 | da Vinci® | 50 | APR, AR, LAR, RP | USA | Combined |
| DeNoto[7] | 2006 | da Vinci® | 11 | SC | USA | Combined |
| Luca[52] | 2009 | da Vinci® | 55 | LC, AR, ISR, APR | Italy | Malignant |
| Anvari[5] | 2004 | Zeus | 10 | RHC, AR, LC, SC | Canada | Combined |
| Patel[53] | 2011 | da Vinci® | 70 | SC, LAR, RP | USA | Combined |
| Giulianotti[8] | 2003 | da Vinci® | 16 | RHC, IC, SC, LAR, APR | Italy | Combined |
| Akmal[54] | 2011 | da Vinci® | 80 | TME | USA | Malignant |
| Choi[55] | 2009 | da Vinci® | 50 | LAR, ISR, APR | Korea | Malignant |
| Spinoglio[56] | 2008 | da Vinci® | 50 | RHC, LC, APR, TC, TAC | Italy | Combined |
| Bianchi[57] | 2010 | da Vinci® | 25 | TME | Italy | Malignant |
| Pigazzi[58] | 2010 | da Vinci® | 143 | LAR, APR, TME | Italy/USA | Malignant |
| Baek[59] | 2010 | da Vinci® | 41 | TME | USA | Malignant |
| Patriti[60] | 2009 | da Vinci® | 29 | AR | Italy | Malignant |
| Hellan[61] | 2007 | da Vinci® | 39 | LAR, ISR, APR | USA | Malignant |
| de Hoog[62] | 2009 | da Vinci® | 20 | RP | Netherlands | Benign |
| Baik[63] | 2009 | da Vinci® | 56 | LAR | Korea | Malignant |

Abbreviations: RHC, right hemicolectomy; SC, sigmoid colectomy; TME, total mesorectal excision; LC, left colectomy; IC, ileocecal resection; AR, anterior resection; LAR, low anterior resection; RP, rectopexy, ISR, intersphincteric resection; TC, transverse colectomy; TAC, total abdominal colectomy.

operation where surgeons benefit the most from robotic-assistance. However, no group has shown clear scientific benefit.

### Perioperative Outcomes

Many groups have looked into short-term and perioperative outcomes in robotic-assisted TME.[13–15] To date, none have conclusively revealed worse outcomes and most show benefit in the robotic operation. In 2011, deSouza and colleagues published a comparison of a hand-assisted "open" technique to a fully robotic TME. Thirty-six patients underwent full robotic TME and were compared with 46 patients who underwent an open technique TME (after laparoscopic mobilization). The two groups were well-matched on preoperative parameters. Operating time was higher in the robotic group by 64 minutes. Blood loss was more in the open group. Overall complication rate, length of stay, and wound infection rate were similar between the groups. There were two anastomotic leaks in the robotic group and one in the open group.[13] Park et al reported in 2011 a comparison between 88 open TME, 123 laparoscopic-assisted TME, and 52 robotic-assisted TME at their institution over the course of 2 years. The groups were again fairly well-matched. The authors concluded that both robotic and laparoscopic TME has equivalent short-term outcomes to open TME with shorter length of stay and time to return of bowel function.[14]

### Short-Term Oncologic Outcomes

Most proponents of robotic-assistance in rectal surgery cite the improved dissection ability and visualization as the benefits of this approach. A fair amount of published literature has looked at whether these benefits will portend a survival benefit, as perhaps the robotic operations allow better technical cancer resections. Because most literature published on robotic TME is from 2010 forward, it is too early to evaluate long-term survival or outcomes. Only one group has studied short-term oncologic outcomes in their patients. In 2010, Baek et al published their data on short-term oncologic outcomes in 64 patients at their institution from 2004–2008. The median number of harvested lymph nodes was 14.5 and the median distal margin length was 3.4 cm. Six patients developed recurrence at 20-month follow-up, two patients had combined distal and local recurrence and four patients had distal recurrence only. The 3-year overall survival rate was 96.2% and the disease-free survival rate was 73.7%.[15] These data support that early oncologic outcomes are similar to standard open TME. Memon et al published a meta-analysis of the available literature on robotic versus laparoscopic proctectomy for rectal cancer in 2012. This analysis revealed that robotic resection had a decreased conversion to an open operation rate, while having no difference in complications, circumferential margin involvement, distal resection margin, lymph node yield, or hospital stay.[16]

## Ongoing and Future Research in Robotic Colorectal Techniques

Currently, an international, multicenter, prospective, randomized, controlled, parallel-group trial comparing robotic-assisted versus laparoscopic surgery for rectal cancer is underway to assess the perioperative outcomes, margin status, recurrence rate, survival, quality of life, and cost effectiveness.[17] This will be the first prospective randomized trial to evaluate robotic rectal surgery to laparoscopic rectal surgery. The group is attempting to enroll 400 patients.

The advent of SILS and NOTES is reinvigorating general and colorectal surgeon interest in novel robotics platforms. Although SILS colorectal surgery techniques are being reported and refined, the limitations of using traditional laparoscopic instruments in these approaches, the learning curve required, and the lack of clear advantages of SILS over traditional laparoscopic approaches (aside from improved cosmetic result) has slowed widespread adoption of SILS in colorectal operations. Similarly, learning curve requirements, instrument limitations, and technical difficultly have kept NOTES procedures largely in the realm of "experimental" surgery or only in highly specialized centers.

General surgeons naturally express reluctance to create an opening in the gastric or colon wall to remove a diseased gallbladder or appendix, and many are uncomfortable or slow to adopt transvaginal approaches due to concerns regarding visualization and instrumentation. However, bowel surgery may be the ideal field for NOTES in that a suture or staple line is likely already being created on the bowel, so creating a transluminal access port does not appear to be adding as much additional risk to the patient. Hence, as novel robotic platforms are created in the form of new endoluminal instruments and in vivo robots, intestinal surgery in fact may be the ideal setting for these devices and approaches.

The da Vinci's® "wristed" instruments are ideal to work in tight working spaces; however, when the arms work in close proximity they frequently collide. This limitation has slowed the use of the robot in SILS and NOTES applications, where it otherwise would improve technical dexterity. Some groups have described techniques, such as "chopstick surgery" to minimize robotic arm collisions.[18] Other groups have begun work on "mini-robots" or "microrobots" that can be deposited in the peritoneal cavity via a single-incision or NOTES access, have individual tasks (e.g., camera or retraction), and are designed to work cooperatively, thus eliminating this concern.[19–21] Novel platforms are in development, such as magnetically positioned and anchored intraabdominal cameras and retractors[22,23] and highly articulated systems ("snake-robots") that have "unlimited but controllable flexibility."[24,25] These platforms may ultimately prove to be ideally suited for transoral or minimally invasive approaches to surgical problems. Tiwari and colleagues provided a thorough review of the state of the art and current development trajectories for robotic NOTES platforms, which include in vivo biopsy robots, mobile in vivo imaging robots, mobile endoluminal robots, cooperative robots, and in vivo dexterous robots.[26] The fact that a detailed discussion of the literature on this topic is beyond the scope of this article is an indication of just how far and how fast the technology is progressing. As robotic instruments and systems become refined, close-proximity procedures (SILS and NOTES) will benefit and become more approachable. These emerging fields will push robotic and technical advancements for better visualization, working ability, and cosmetic outcomes.

## Remote Presence

Remote presence is the ability of an individual to interact with an environment without actually being physically present. Historically, this was limited by communications technology and accomplished via only fixed audio links (i.e., telephones). The first report of a real-time, audiovisual "telemedicine" application was by Grundy and colleagues in 1977.[27] They reported use of a two-way audiovisual link between a community hospital and large university health center, demonstrating that regular consultation in critical care could be provided, was superior to telephonic consultation alone, and could improve care in an intensive care unit. Technology has evolved markedly since then to completely mobile, remote controlled audio-video platforms, which can also integrate directly with a patient's electronic medical records, digital images, and other streams of data. Surgeons now have the ability to remotely steer a mobile, robotic, audio-video platform to a patient's bedside, see and speak directly to them, access electronic data and images, and interact with other medical personnel to render patient care.

Robotic remote presence technology applications can be subdivided into several complimentary and overlapping concepts. Robotic *telerounding* is the use of a robotic platform to perform daily postoperative rounds, a task that has traditionally been done by the physician in person. With current robotic remote-controlled wireless platforms, telerounding can be accomplished from a surgeon's office or home, theoretically allowing the surgeon to speak and interact directly with a patient without being physically present. Robotic *telementoring* is the use of the robotic platform to allow the remote presence of an expert during trainees or junior physicians' performance of a complex clinical task, such as an operation or management of a critically ill patient. The term "telementoring" suggests a structured teaching role, which distinguishes it from robotic *teleconsultation*: the use of a robotic platform to provide nonstructured, on-demand expert remote presence for specific complex clinical scenarios, such as critical care or stroke management.

One of the dominant robotic remote presence platforms currently in utilization for medical purposes is the RemotePresence-7™ (RP-7; In-Touch Health, Santa Barbara, CA). This platform features a roughly human-sized figure with a video screen that can project the operator's face (or other images), remote control of both the robot platform and tilt-pan-zoom imaging camera via a laptop/joystick set up, high-speed broadband (300–600 kbp) Internet, which can allow linking to electronic medical records, and two-way audio/video interaction. The operator may see, hear, verbally interact, and "drive" the robot anywhere he wants, allowing real-time, completely mobile remote presence—as if he was actually there.[28] The robot is simple to operate and requires relatively little training. Published accounts exist of the use of the RP-7 or its predecessors in telerounding, telementoring, and teleconsultation.

## Telerounding

One of the first reports of robotic telerounding on surgical patients was by Ellison and colleagues, who reported the results of a questionnaire administered to 85 patients posturologic surgery. The remote presence robot, a predecessor to the RP-7 (In-Touch Health), was used to augment or replace standard postoperative rounds. Patients in the robotic telerounding arms of the study reported substantially higher satisfaction with regard to physician availability. The majority of patients reported feeling comfortable with the robotic telerounds and felt their care was good or better with such rounds.[29]

Petelin and colleagues from the University of Kansas' Department of Surgery reported on their initial experience with the RP-6 (predecessor to the RP-7), noting relative ease with initial set-up and deployment. Although not formally measured in a survey, the authors also noted high degrees of satisfaction from patients and nursing staff, primarily because of the ease of access to the surgeon during "off hours" (e.g., 7–10 PM). The group reported that robotic telerounds resulted in discharge of patients on average 4 hours earlier than with conventional rounds. The surgeons also reported substantial increase in efficiency of evening and weekend rounds, noting a reduction in total rounding time from 60 minutes (40 minutes round-trip travel from home + 20 minutes rounding time) to 20 minutes (rounds alone via the robot).[30]

Ellison and colleagues then reported a follow-up multicenter randomized assessment of patient outcomes and satisfaction with postoperative robotic telerounding. This three-center study of 270 patients assigned study enrollees to either traditional postoperative rounds or robotic telerounds. Patient satisfaction was equivalently high in both arms of the study, although lengths of stay and morbidity rates were the same in both groups. What should be of considerable importance to surgeons was the finding that patients would prefer to be seen by their own surgeon via the robot rather than one of their surgeon's colleagues in person.[31]

Gandsas and colleagues reported on the use of postoperative robotic telerounds in 92 bariatric surgical patients, again using the RP-7 robot. When compared with a group of 284 patients who had traditional in-person bedside rounds performed, the group of patients treated with robotic telerounds had a significant decrease in length of stay (1.26 days vs. 2.33 days). The authors noted that this early discharge resulted in a savings of $14,378 in room and board costs alone.[32]

Aside from postsurgical rounds, the other area of predominant use of robotic telerounding is in intensive care.[28,33–37] Sucher and colleagues performed a prospective observational survey study on critical care patient and family satisfaction after they integrated regular robotic telerounds via RP-7 with their usual multidisciplinary surgical intensive care unit rounds. They found a majority (84%) of patients found communication with the robot easy and comfortable, and 92% supported continued use of the robot.[35]

In a novel study, Garingo and colleagues compared the evaluation of several neonatal clinical parameters as assessed by an onsite, physically present neonatologist and a neonatologist assessing the same parameters from an offsite location using the RP-7 robot. Excellent or intermediate-to-good agreements were noted for all clinical parameters aside from a few physical exam parameters. Of the physical exam parameters where there was poor agreement between the onsite and offsite neonatologists, the authors noted that there was poor agreement between two neonatologists even when both were onsite. The authors concluded that use of the RP-7 for remote presence was feasible in the neonatal intensive care unit.[38]

McNelis and colleagues were able to demonstrate decreased hospital and intensive care unit length of stay when the RP-7 was employed for after-hours (evening) rounds. Although they noted no difference in mortality from before they began using the RP-7, they did note a decrease in unexpected events and inferred improved patient safety because remote presence via robotic telerounding allowed and experience intensivist to identify problems before they resulted in unexpected events.[39]

## Telementoring and Teleconsultation

Schlachta and colleagues have demonstrated that a structured mentoring and telementoring model can be used to transfer and incorporate laparoscopic colon surgery from a university center to a community setting.[40] The telementoring in their model was conducted via an Internet protocol point-to-point connection, by which the mentor witnessed the laparoscopic colon surgery. The mentor could provide


**Fig. 1** Example of RP-7 robot in community emergency department used for acute stroke teleconsultation staffed by a large university center.

verbal guidance as well as be able to draw on a touch screen with a stylus to create an overlay diagram that the operating surgeon (trainee) could see on his screen.[41]

Sebajang and colleagues took this a step further by providing telementoring and direct telerobotic assistance in laparoscopic colorectal operations via the Zeus TS™ microjoint robotic platform (Computer Motion Inc., Santa Barbara, CA). The surgeons surveyed in the study found the telementoring and telerobotic assistance useful and enabling in all cases.[42]

In a survey comparison of local (onsite) mentoring versus remote mentoring via robotic remote presence (RP-6) in advanced laparoscopic surgical cases performed in an animal model, Sereno and colleagues found onsite mentoring to be statistically superior to robotic telementoring in terms of both interaction with the expert and quality of the mentoring when the onsite mentoring occurred before the remote presence mentoring, but not after. The researchers noted that trainees quickly became comfortable with the robot and although the quality of the robotic telementoring was not as high as onsite mentoring, it was nevertheless still effective. They were also able to complete two cases of intercontinental mentoring without technical problems.[43]

Smith and Skandalakis used robotic telementoring to supervise and proctor medical students through cadaver dissections. The authors noted the advantage of the mobile robotic platform over fixed video feeds.[44] Agarwal and colleagues demonstrated the feasibility of using robotic remote telementoring with the RP-7 to guide surgeons through advanced laparoscopic and endoscopic urologic cases from a location 5 miles from the operating room. The authors completed five such cases without any technical problems with the robot or communications.[45]

Telepresence is being used for rapid, remote assessment of stroke patients in emergency room settings,[46] and some emergency departments have the RP-7 in the emergency department to provide a remote teleconsultation platform (►**Fig. 1**).

## Summary

Just as laparoscopy revolutionized the field of surgery, robotics is destined to provide the next major breakthrough for surgical patient well-being. The era of scarless surgery is on the horizon. Like computers, robots are becoming smaller, smarter, and more useful at an exponential rate. Surgical innovators in each specialty field must be encouraged to determine the ideal robotic platform for their given surgical task and pair with industry to develop it. Within colon and rectal surgery, robotic systems have multiple benefits and many emerging areas to be explored. Surgeons have always been at the forefront of innovation for improved patient care. As science and industry improve the systems available to the clinician, patients will benefit and our surgical armamentarium will be strengthened.

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