Review Article

Robotic assisted single site surgery: a decade of innovation

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Abstract: The dawn of the era of single incision minimally invasive surgery, or single port surgery, was first realized with laparoscopy. Beginning with simple procedures surgeons began to apply this concept to a growing variety of procedures. Despite demonstrating its feasibility and associated favorable patient outcomes, single port laparoscopy remained a challenging procedure and was unsuccessful in gaining significant traction. With the addition of the robotic surgery, single port surgery was dramatically changed. With the aid of the robotic platform, surgeons were able to overcome the challenges and limitations of laparoscopy. Since the first reports of robotic assisted single port surgery in 2009, surgeons across all specialties and subspecialties have found application in their practice. In this review, we highlight the last decade of single site robotic surgery and discuss the current challenges.

Keywords: Robotic single site surgery; single port surgery; reduced port surgery

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Introduction

Advances in minimally invasive surgery have led to the ability of surgeons to perform complex surgeries through a single incision, and is regarded as one of the surgical frontiers. In addition to improved cosmesis, single site surgeries are suggested to have less morbidity and are associated with improved patient satisfaction. With the addition of the robotic platform to minimally invasive surgery, the ability of surgeons to perform single site surgery makes this a more widely available option with applications in general surgery, urology, gynecology and otolaryngology.

History

The first single site surgery was a tubal ligation, first reported in 1969. The technique used a single scope with channels that could be used to introduce instruments to perform the ligation. Since then over 4,000 cases have been performed this way as an outpatient procedure. Single incision surgery later progressed to the ability to perform more advanced surgeries such as total hysterectomy and bilateral oophorectomy. Appendectomy was also performed, as reported in the early 1990s by Pelosi *et al.* Surgery was performed via a single umbilical incision, during which the cecum was mobilized and appendix brought up through the umbilicus (1-3). By the mid-1990s, cholecystectomy was also added to the growing list of procedures employing surgery via a single incision. Techniques described included using sutures to retract the gallbladder, and creation of umbilical flaps and using three separate subcutaneous port sites (4).

The technology to perform laparoscopic single site surgery evolved, with the addition of multiport devices to introduce multiple instruments through a single incision. Despite these advances, laparoscopic single site surgery was still challenging. The instruments were

difficult to maneuver with frequent clashing, there was difficulty providing exposure, and triangulation proved to be difficult. Efforts to curb these challenges included the use of articulating instruments, shorter trocars, and curved instruments. Even with these developments, use of laparoscopic single site surgery has not been widespread.

The advances and progress in laparoscopic single site surgery, although still a challenging procedure, were instrumental in the development of robotic single site surgery. Robotic surgery was introduced in 2000. Less than a decade later, surgeons began adapting the single site ports used in laparoscopic surgery to the robotic platform. The first reported single site robotic surgery was reported by Kaouk *et al.*, in which they utilized a 2 cm incision and an R-Port (Advance Surgical Concepts, Dublin, Ireland), a port originally developed for SILS. Using this adaptation, they performed a small series of urological procedures (radical prostectomy, pyeloplasty, nephrectomy) (5). Soon after, a key development was the ability to invert which hand controls which instrument to overcome the need to cross instruments at the entry point (6). Further improvements were made with ports and instruments specifically designed for the robotic system. The VeSPA instruments (Later Da Vinci Single-Site Platorm, DVSSP) instruments consisted of a single, multichannel port using curved instruments similar to the devices used in LESS (7). Reports of other adaptations, such as those using surgical gloves and wound protectors as makeshift ports have also been described (8). Through these adaptations, the ergonomic difficulties of LESS were dramatically reduced, paving the way for further developments in single site surgery.

Additional distinctions such as E-NOTES (embryonic natural orifice transumbilical endoscopic surgery) SILS (single incision laparoscopic surgery), SIMPLE (single-incision multi-port laparo endoscopic surgery) and LESS (Laparo-endoscopic single site) have been used to refer to single site surgery.

Robotic single site surgery: the tools

Da Vinci® single-site surgical platform (DVSSP)

Utilizing the concepts that evolved during LESS, the robotic platform was first adapted for single site surgery with a single multiport. The port fits in a 2.5 cm incision. The Single-Site system is a multiport system that was designed for the da Vinci® Xi and Si operative systems. The first reported successful surgery in a human was a cholecystectomy in 2011, demonstrating feasibility and potential for increased access to single-site surgery (9). Instruments are flexible and have a curved design which allows triangulation and avoids collision of instruments.

Da Vinci® SP™ system

While the Single-Site system overcame the challenges of LESS, the robotic platform evolved even further to overcome the problems with hernias and single site, with the development of the SinglePort (SP) system. With the SP system, a port is operated by a single robotic arm, and a single cannula. The same console used for the X, and Xi systems can be used with the SP system. Unlike with most of the instruments used in Single Site, the instruments including the camera articulate. At the time of writing, the SP system has been approved for urology procedures as of May 2018, and otolaryngologic procedures in 2019 (10).

Single port orifice robotic technology (SPORT) surgical system (Titan Medical)

Titan Medical has also adopted a single port robotic system, using articulating instruments. To date it has been applied to similar uses as the daVinci Single-Site system in animal models (11). At the time of writing, it has not received FDA approval (*Table 1*).

General surgery

While the use of robotic single site surgery has been controversial in common procedures such as cholecystectomy and appendectomy, the experience from performing these cases has contributed to the feasibility of performing complex procedures.

Cholecystectomy

The first series on single-port robotic cholecystectomy were published in 2011. Subsequent studies, including randomized prospective trials demonstrated no difference in complications compared to conventional laparoscopic cholecystectomy but an increased preference by patients (9,12,13). When compared to single site laparoscopy, the robotic approach is associated with less pain (14). Gonzalez *et al.* published a multi-institutional series of 465 single site cholecystectomies demonstrating feasibility and safety. Complication rate was 2.6%. They also described a decrease

Table 1 Evolution of robotic single site surgery 2009–2019

Authors	Years	N	Procedure	Notes
Kaouk *et al.*	2009	3	Radical prostectomy	First report of multichannel single port use
			Pyeloplasty	
			Radical nephrectomy	
Allemann *et al.*	2010	18	Nissen fundoplication	Animal model demonstrated feasibility of Nissen fundoplication
Wren and Curet	2010	9	Cholecystectomy	Da Vinci Single-Site platform
Kroh *et al.*	2011	13	Cholecystectomy	Da Vinci Single-Site platform
Shin *et al.*	2014	167	Partial nephrectomy	Alexis wound protector with Sterile surgical glove for multiport access
Komninos *et al.*	2014	3	Partial nephrectomy	R-LESS multiport, VeSPA instruments
Jones *et al.*	2015	16	Cholecystectomy	First report of single site cholecystectomy in children
Konstantinidis *et al.*	2015	1	Right colectomy	Single-Site platform
Chung *et al.*	2015	70	Cholecystectomy	Surgical resident involvement
Su *et al.*	2016	51	Cholecystectomy	Compared to laparoscopic single site. Demonstrates decreased postoperative pain.
Kubat *et al.*	2016	150	Cholecystectomy	Comparison of urgent *vs.* elective cases
Gonzalez *et al.*	2016	465	Cholecystectomy	Largest multi-institutional series of robotic single site cholecystectomy
Bosi *et al.*	2016	1	Bilateral inguinal hernia repair	Single site platform, bilateral hernia
Corrado *et al.*	2016	23	Hysterectomy	Feasible for early stage endometrial CA, Single-Site
Bae *et al.*	2017	1	Total mesorectal excision	Reduced port
Kudsi *et al.*	2017	83	Cholecystectomy	Outcomes reported—report improved cosmesis, satisfaction
Balachandran *et al.*	2017	415	Cholecystectomy	Largest single center/surgeon series
Cestari *et al.*	2017	3	Bilateral inguinal hernia	Single site platform, bilateral hernia, TEP
Kim *et al.*	2017	4	Distal pancreatectomy	Single-Site platform, Lasso technique, reduced port
Buckley de Meritens *et al.*	2017	82	Hysterectomy	Large series by single surgeon,
Moukarzel *et al.*	2017	30	Hysterectomy	Used in oncologic setting, required pelvic sentinel nodes, lymph node dissection
Mattevi *et al.*	2018	20	Cholecystectomy	Pediatric patients, Single-Site
Seo *et al.*	2018	40	Subtotal gastrectomy, lymph node dissection	Reduced port approach
Peng *et al.*	2018	10	Distal pancreatectomy	Used Lagiport
Jayakumaran *et al.*	2018	12	Hysterectomy	Single Site, da Vinci Xi
Chong and Kang	2019	1	Pancreatic enucleation	Reduced port

TEP, total extraperitoneal.

in operative time after the first 55–85 cases indicating a shallow learning curve (15).

In our experience, single site cholecystectomy is a favorable option when there is a preexisting umbilical hernia present. A single site multiport is used. Indocyanine green is administered, dose 2.5 mg, prior to the operation estimating approximately 20 minutes to allow for the dye to reach the bile. The daVinci provides Firefly imaging via emission of infrared light, highlighting the biliary system. The benefits of this modality eliminates the need for intraoperative radiography, additional dissection required for cannulation of the cystic duct, and overall ease of use. With difficult cases we found in our series there were less conversions to open compared to the laparoscopic approach (16). The gallbladder is removed via the umbilical defect which can then be repaired primarily or with mesh as indicated.

Inguinal hernia

Inguinal hernia repair is one of the most common surgical problems, with patients opting for techniques that result in cosmesis as well as shortened recovery. Similar to cholecystectomy, inguinal hernia saw a development from traditional open techniques to laparoscopic and LESS. Using DVSSP, both bilateral robotic transabdominal preperitoneal repair (rTAPP) and total extraperitoneal (DV-SS TEP) have been described. A 2.5 cm umbilical incision is used for introduction of the multiport, followed by dissection similar to those of conventional laparoscopic hernia repair (17,18).

Our practice is to perform rTAPP. Similar to our experience with cholecystectomy, this approach is favorable in patients presenting with previously existing umbilical hernias. A disadvantage of the single site over the multiport approach is inability to use the endowrist instrumentation.

Pediatric surgery

Single site surgery has also been described in pediatric patients. Procedures performed include cholecystectomy (19). The same benefits attributed to R-LESS in adults are applicable in this population. Series have demonstrated adequate feasibility and safety outcomes.

Gastric surgery

While true single port gastric surgery has not gained traction, "reduced port" surgery using single site concepts has been growing in popularity. Traditional laparoscopic gastric surgery can often utilize up to six 5–12 mm sized ports in addition to a small 5cm laparotomy incision. In this approach, a Single-Site port is used along with two additional 5 mm ports (20).

Pancreatic

Similar to gastric surgery, reduced port robotic surgery using the Single-Site ports have been described in small case series. Described is the utilization of one additional port for a 3rd robotic arm. Both distal pancreatectomy and pancreatic enucleations have been performed using this strategy. The additional port site is later used for drain placement, and the pancreatic specimen is delivered via the umbilical incision. Indications for surgery include both tumors, cystic neoplasms, and chronic pancreatitis. Conventional robotic endowristed instruments can be used, however, in one series, clashing of instruments led to conversion to multi-port in one case (21-23).

Colorectal surgery

The feasibility of single incision robotic colectomy (SIRC) has been described with multiple case series published in the last 5 years. Conditions that have been amenable to interventions utilizing SIRC include diverticulitis, colonic mass (including malignancy), familial adenomatous polyposis, and Crohn's disease. Right and left hemicolectomy, sigmoidectomy, total colectomy and low anterior resections have all been performed via SIRC with both extracorporeal anastomosis demonstrating its feasibility (24,25). Total mesorectal resection has also been reported, however similar to gastric and pancreatic techniques, is performed as a "reduced port" procedure with the use of an accessory port (26).

Additional applications

Robotic single site surgery has also been applied to additional surgical indications. While there are no large series, appendectomy has also been performed using the single site platform. An early case series of adrenalectomy has also demonstrated success in smaller <2 cm tumors (27).

Urology

Urology was an early pioneer in the field in the application

of R-LESS. The first series by Kaouk *et al.* was in 2009, in which a radical prostatectomy, pyeloplasty and radical nephrectomy were performed using an R-Port as described earlier (5). Over the last decade, R-LESS has become increasingly popular, with benefits including reduced postoperative pain in partial nephrectomy compared to the LESS approach (28).

Prostatectomy

There are several different R-LESS approaches. Instrumentation can be introduced via any of the previously describe SILS ports, engineered wound protectors with a sterile glove, or the da Vinci Single Site multiport. Alternatively, the VeSPA platform can also be used via a 2 cm incision, however may require an additional 12 mm port between the umbilicus and right iliac spine which can later be used as a drain site (29).

Prostatectomy is one of the first procedures FDA approved for the recent daVinci SP system. The Innovation, Development, Exploration, Assessment Long-term (IDEAL) study began in 2010, utilizing this system for prostatectomy and demonstrated early feasibility and safety (30). Despite the advances of the SP system, one series preferred their reduced port surgery utilizing a GelPoint multiport with an additional port because it allowed for the use of the endowrist® instruments (31).

Nephrectomy

The techniques for R-LESS in nephrectomy have evolved since the initial report. The use of the curved cannula and VeSPA instruments were later improvements in the ability to perform R-LESS nephrectomy and additional case series continued to demonstrate feasibility, although the lack of endowrist dexterity continued to pose a challenge (32). In the achievement of trifecta outcomes in partial nephrectomy (warm ischemia time <20 minutes, negative surgical margins, no complications), R-LESS was inferior to conventional multiport with longer ischemia times, and increased changes in post-operative GFR (33). One benefit was demonstrated in living donor nephrectomy, where patients had statistically better pain scores within the first week, correlating to better overall satisfaction for donors (34).

While the benefits of less pain and cosmesis are benefits to R-LESS the technical difficulties may outweigh the benefits and overcoming these limitations may be the next direction.

Gynecology

The first pilot study using R-LESS for hysterectomy was published by Vizza *et al.* (35). A series of 17 patients underwent robotic single-site hysterectomy (RSSH). A 2 cm umbilical incision was made to introduce the multiport. This series demonstrated that RSSH was feasible and safe. An additional early series utilizing R-LESS in a variety of gynecological procedures was published in 2015 by Schieb and Fader (36). In their prospective series, 40 patients underwent total or supracervical hysterectomy, salpingo-oophorectomy, ovarian cystectomy, and endometriosis excision. One report also included a hysterectomy combined with a cholecystectomy. In their series, there were no post-operative hernias. The addition of further study into R-LESS for gynecologic procedures have shown additional potential benefits. Operative time and blood loss have decreased in proportion to increasing experience (37,38). In addition to benign and early malignant disease, R-LESS has also been described for patients with advanced uterine cancer requiring combined hysterectomy and bilateral salpingo-oophorectomy and pelvic sentinel lymph node mapping and lymphadenectomy (39). One of the major benefits is the cosmesis associated with R-LESS with demonstrated improved patient satisfaction with scar appearance (40).

Considerations

Cost

As expected with new technology, cost comparisons show that R-LESS has increased compared to its laparoscopic predecessors. A study comparing traditional multiport laparoscopic colectomy with SIRC showed statistically significant higher costs associated with the latter (41). When compared to conventional laparoscopy, single-site adnexal surgery and benign hysterectomy incurred additional costs of approximately $3,000, and $6,800 respectively (42). When compared to robotic multiport, single-site demonstrated a potential cost reduction in hysterectomy for benign and early malignant disease (43,44). The costs however may be directly related to the novelty and over time, cost may decrease as additional manufacturers enter the market.

Port site hernias

Requirements for port site range from 2.5 cm up to 5 cm,

increasing the risk of port site hernias. The multiport undergoes increased forces from torque, which may be a source of additional trauma and possible ischemic insult to the fascia. Those at risk include obese patients, and smokers. We recommend that prior to closure appropriate assessment and visualization should be dedicated prior to closure.

The rates of incisional hernia for single site cholecystectomy in the literature range 0–19% (45-48). However further analysis dedicated to the actual rates of intervention *vs.* those that were observed is not well known. Given the early stages of R-LESS, it remains to be seen the true incidence of port site incisional hernias.

Education

The robotic platform is a valuable teaching tool. In addition to the training modules built in, and the ability to exchange "Control" between two tandem consoles, the platform allows trainees to experience surgery with natural ergonomic motion similar to that of open surgery, minimizes tremor, and has a favorable learning curve.

In a survey of program directors in general surgery, approximately 74% offered training in robotic surgery, with 63% supporting formal robotic surgery curricula in surgery residency (49). In our experience, when comparing conventional multiport laparoscopic to R-LESS cholecystectomy, total operating time was 111 *vs.* 106 minutes, demonstrating that the time to teach R-LESS is similar to that of laparoscopy (50). As the field evolves, similar to the advent of laparoscopic surgery, it will be increasingly imperative for residents to have a basic set of robotic skills. Several subspecialties including minimally invasive gynecology, minimally invasive general surgery, advanced general and oncologic urology, colorectal training fellowships incorporate robotic training.

Discussion

In the short time single site robotic surgery has been in practice its scope of application has shown promise. With applications to every surgical specialty, and appeal to patients, its continued evolution is inevitable. Retrospective reviews have demonstrated safety when compared to laparoscopic modalities. While infrastructure and cost may be prohibitive to its widespread use, a similar experience occurred during the transition to laparoscopic surgery and is expected with any developing technology. In anticipation for the growing use of robotic single site surgery, residents should have early exposure which can be further specialized in fellowship. Single site surgery offers both patient satisfaction in cosmesis and post-operative pain and as surgeons, patient centered outcomes are extremely valuable and worth our efforts to constantly improve.

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Footnote

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