Robotic single port surgery: Current status and future considerations

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ABSTRACT

Introduction and Objectives: It has been established that robotic-assisted laparoscopic surgery has several advantages when compared with standard laparoscopic surgery. Optics, ergonomics, dexterity and precision are all enhanced with the use of a robotic platform. For these reasons, it was postulated that the application of robotics to laparoendoscopic single-site surgery (LESS) could overcome some of the constraints seen with the conventional laparoscopic approach. Issues such as instrument clashing, inability to achieve effective triangulation for dissection and difficulties with intracorporeal suturing have limited the widespread adoption of conventional LESS. The application of robotics has eliminated many of the constraints experienced with conventional LESS; however, challenges still remain.

Materials and Methods: A systematic literature review was performed using PubMed to identify relevant studies. There were no time restrictions applied to the search, but only studies in English were included. We used the following search terms: Robotic single site surgery, robotic single port surgery, robotic single incision surgery and robotic laparoendoscopic single site surgery.

Results: A number of centers have published their experience with robotic-laparoendoscopic single-site surgery (R-LESS); however, no prospective studies exist. What is clear is that R-LESS minimizes several of the difficulties experienced with conventional LESS, including intracorporeal suturing and triangulation during dissection. Outcomes are comparable to standard robotic surgery, with a trend toward improved cosmesis and reduced pain. However, a significant advantage with regard to these two factors has yet to be demonstrated.

Conclusions: R-LESS is technically feasible and the benefits of robotic surgery eliminate many of the challenges seen with conventional LESS. However, despite the advantages of the robotic platform, R-LESS is not free of challenges. Instrument clashing remains an issue due to the bulky profile of the current robotic system. Other issues include lack of space for the assistant at the bedside, inability to incorporate the 4th robotic arm for retraction and difficulties with triangulation. Although solutions for some of these issues are currently under development, R-LESS is still very much in its infancy.

Key words: Laparoendoscopic single-site surgery, robotics, single port surgery

INTRODUCTION

Laparoendoscopic single-site surgery (LESS) has been developed to further minimize the morbidity associated with laparoscopic surgery. By reducing the number and length of skin incisions, it was hypothesized that this would lead to less pain, faster convalescence and improved cosmesis following minimally invasive surgery. The first LESS procedure was reported by Hirano et al. [1] in 2005. They performed a retroperitoneoscopic adrenalectomy through a single incision with standard laparoscopic instruments. Subsequently, the LESS approach was applied to a range of urologic procedures, including radical nephrectomy and prostatectomy. [2-4] There have since been a number of comparative analyses comparing standard laparoscopic urologic procedures to their LESS counterparts. [5-9] Overall, these studies suggest that LESS is not inferior to conventional laparoscopic surgery with regard to perioperative outcomes, with a trend toward improved cosmesis and less post-operative pain. However, it has been found that LESS is significantly more challenging.
especially when complex reconstruction or intracorporeal suturing is required. The need to cross instruments at the abdominal wall to facilitate dissection results in a significant mental challenge due to the resulting reverse handedness. Other challenges include instrument collision, lack of triangulation and in-line vision. Using Guilloneau et al.’s scoring system for laparoscopic operations in urology,[10] Autorino et al.[11] determined a degree of difficulty for a number of LESS urologic procedures. Both radical prostatectomy and cystectomy were classified as “Extremely Difficult.” A number of strategies were developed to combat these difficulties, including curved and articulating instruments, flexible endoscopes and needleless accessory ports/instruments to allow triangulation.[12] Despite these advances, conventional LESS remains challenging and requires extensive surgeon experience in laparoscopy and stringent patient selection to achieve successful outcomes.[13]

It has been established that robotic-assisted laparoscopic surgery has several advantages when compared with standard laparoscopic surgery. Optics, ergonomics, dexterity and precision are all enhanced with the use of a robotic platform for a number of urologic procedures. For these reasons, it was postulated that the application of robotics to LESS (R-LESS) could overcome some of the aforementioned constraints. We reported the first experience with R-LESS in 2008[14] (radical prostatectomy and nephrectomy, pyeloplasty), and found that intracorporeal suturing and dissection were easier as compared with standard LESS. Since then, there have been numerous reports and refinements in technique from our center for a number of different urologic procedures.[15‑17] Typically standard robotic instruments and ports have been used [Table 1]. However, despite the advantages of the robotic platform, R-LESS is not free of challenges, which is similar to conventional LESS. Instrument clashing remains an issue due to the bulky profile of the current robotic system. Other issues include lack of space for the assistant at the bedside, inability to incorporate the 4th robotic arm for retraction and difficulties with triangulation. Although solutions for some of these issues are currently under development,[18,19] R-LESS is still very much in its infancy. The aim of this paper is to review the current status of R-LESS and explore future directions.

**MATERIALS AND METHODS**

We performed a literature review on PubMed using the following search terms in free-text protocol: Robotic single site surgery, robotic single port surgery, robotic single incision surgery and robotic laparoendoscopic single site surgery. We only included English publications. Review articles, editorials, commentaries and letters to the editor were included only if deemed to contain relevant information.

| Instrument                              | Features                                      | Benefits                                           | Drawbacks                                         |
|-----------------------------------------|-----------------------------------------------|---------------------------------------------------|--------------------------------------------------|
| 8-mm EndoWrist monopolar shears (Intuitive Surgical) | 7 degrees of freedom 90 degrees of articulation tremor reduction and motion scaling | EndoWrist technology allows for effective dissection | Bulky external profile leads to instrument clashing |
| 8-mm EndoWrist hook cautery              | 7 degrees of freedom 90 degrees of articulation tremor reduction and motion scaling | EndoWrist technology allows for effective dissection | Bulky external profile leads to instrument clashing |
| 8-mm EndoWrist Prograsp grasper          | 7 degrees of freedom 90 degrees of articulation tremor reduction and motion scaling | EndoWrist technology allows for effective dissection | Bulky external profile leads to instrument clashing |
| 8-mm EndoWrist Hem-o-lok applier         | Gives operating surgeon control of clip placement | Access to difficult angles for clip placement       | Bulky external profile leads to instrument clashing |
| 5-mm EndoWrist Schertel grasper          | Motion scaling and tremor reduction            | Lower profile Increased triangulation d/t instrument deflection | No instrument articulation                        |
| SILS port (Covidien)                    | Flexible Three-port design                    | Easy to insert Utilization of different-sized ports | Difficult to use with large abdominal walls       |
| GelPoint port (Applied Medical)         | GelSeal cap and Alexis wound retractor with self-retaining trocars | PseudoAbdomen platform allows for increased instrument spacing and restored triangulation | Gas leakage during longer procedures              |
| Robotic Harmonic Scalpel (Ethicon Endosurgery) | Non-wristed instrument Cuts and coagulates simultaneously | Applied by the operating surgeon                   | Lack of articulation Bulky external profile      |

Table 1 adapted from White MA, Autorino R, Spana G, et al. Robotic laparoendoscopic single-site radical nephrectomy: Surgical technique and comparative outcomes. Eur Urol 2011;59:815-22. SILS: Single Incision Laparoscopic Surgery
RESULTS

Access devices and port placement
An important distinction must be made with regard to access in LESS, and that is single port versus single site. Single port access utilizes a single skin and fascial incision through which a multi-channel access platform is placed [Figure 1]. The endoscope and instruments are all placed through the access platform. Single site access also utilizes a single skin incision; however, multiple fascial incisions are made through which the access platform and low profile ports are placed [Figure 2]. The point of access can be umbilical or extra-umbilical. The umbilical access point has been most commonly utilized as the scar can more easily be hidden and cosmesis maximized. Pneumoperitoneum can be achieved by either a standard or a modified veress needle technique or by the open Hassan technique.

The SILS port (Covidien, Mansfield, MA, USA) is made of foam and expands after insertion to prevent air leakage. It is placed through a 2-cm incision and can accommodate three 5-mm ports or two 5-mm ports and a 10-12 mm port. The SILS port was used by White et al.[17] in one of the larger R-LESS radical prostatectomy series. The GelPort (Applied Medical, Rancho Santa Margarita, CA, USA) was used by Stein et al.[15] to perform a number of upper tract R-LESS procedures. The GelPoint is smaller than the GelPort and has an insufflation port on the side. It also lacks perforations in the gel cap and attaches to the wound protection device with a suture to facilitate removal. Experience with a home-made device was also reported.[20] A standard surgical glove was stretched over an Alexis wound retractor (Applied Medical) after it had been placed in the peritoneal cavity. Trocars were then inserted through the fingers of the glove and fixed in place. All of the procedures performed in these series were on the upper urinary tract [i.e., partial nephrectomy (PN), nephroureterectomy, etc.].

One of the biggest issues with R-LESS is instrument clashing due to the coaxial arrangement of instruments and the bulky external profile of the current generation robot. This problem was also encountered with standard LESS, and one solution that was proposed was to cross the instruments at the abdominal wall. As a result of this, the external handles of the instruments were separated in space extracorporeally thus reducing “sword fighting.” However, as a result, the instruments were crossed intracorporeally and the left instrument on the video screen was actually controlled by the surgeon’s right hand and vice versa. This created a mental challenge for the operating surgeon and added another level of complexity to the case. Joseph et al.[18,21] applied this concept to R-LESS in the laboratory setting and in a porcine model. The robotic instruments were crossed at the abdominal wall to minimize collision. However, the controls at the console were switched such that the left actuator was driving the right arm, and vice versa. This eliminated the confusion that was experienced with crossed instruments and standard LESS.
Intuitive Surgical Inc. has also addressed the problem of instrument collision and developed a set of R-LESS-specific instruments. The set consists of a multi-channel access platform with channels for four ports and an insufflation valve [Figure 3]. The ports themselves consist of two ports with curved cannulas for the robotic instruments, and two ports with straight cannulas for the endoscope and assistant instruments. The robotic instruments are also curved and are designed to cross at the abdominal wall, effectively separating the arms in space extracorporeally. Furthermore, the design of the system also minimizes internal instrument collision with the camera as they are not arranged in parallel. We described the first urologic applications in the laboratory at our center.\[19,22\] Both the porcine model and the human cadavers were used to perform a number of upper tract procedures (i.e., pyeloplasty, PN, etc.). Set up and docking times were comparable with the standard robotic system and there were no significant complications. All procedures were completed successfully without the need for completion. Major limitations included collision with the assistant instruments, which at times limited suction and retraction, and the lack of articulation of the robotic instruments, which made suturing difficult when required. The majority of clinical experience with the single-site instruments has been with cholecystectomy\[23,24\]; however, Cestari et al.\[25\] reported their experience in a highly selected group of nine patients with a ureteropelvic junction obstruction UPJO. Exclusion criteria included body mass index (BMI) > 30 kg/m\(^2\), a large renal pelvis, previous abdominal/renal surgery and concomitant stone disease. All procedures were performed successfully without the need for conversion or additional ports. The mean operating room (OR) time was 166 min.

**Upper tract urologic surgery**

There has been considerable experience with upper tract urologic surgical procedures, including radical nephrectomy, PN, donor nephrectomy and dismembered pyeloplasty. We reported the first experience with robotic single-port upper tract surgery at our center in 2008\[14\] using the DaVinci S robot. A radical nephrectomy and pyeloplasty were performed without complication and minimal clashing of the robotic arms. Pediatric instruments and a 30 upward-directed lens were used. For the nephrectomy, the specimen was extracted through the umbilical incision. White et al.\[16\] performed a retrospective, comparative analysis of 10 patients who underwent R-LESS radical nephrectomy. They were matched to a similar cohort of 10 patients who underwent conventional laparoscopic radical nephrectomy. Patients were similar at baseline, with no significant difference in ASA score, BMI or tumor size. The SILS port and the GelPort were both used and the robot was docked in a three-arm approach. There was no difference between R-LESS and conventional laparoscopic nephrectomy with regard to median operative time, estimated blood loss, visual analogue scale or complication rate. The R-LESS group had a lower median narcotic requirement during hospital admission (25.3 morphine equivalents vs. 37.5 morphine equivalents; P = 0.049) and a shorter length of stay (2.5 days vs. 3.0 days; P = 0.03). Stein et al.\[17\] described using the GelPort device for R-LESS radical nephrectomy, which they found was beneficial for specimen extraction.

PN has become the gold standard for the treatment of small renal mass and, as a result of this, there has been more published series with R-LESS PN. Lee et al.\[20\] described 68 consecutive R-LESS procedures using a home-made port, 51 of which were R-LESS PN. The mean tumor size was 3.0 cm and the mean estimated blood loss EBL was 322 mL. The authors noted that the transfusion rate was 14%, largely due to bleeding during tumor resection, and a single renal vein injury. Also, two patients required conversion to a mini-incisional open procedure, one due to persistent hilar bleeding post resection and the other for inability to access the tumor. Arkoncel et al.\[26\] compared a “hybrid” R-LESS PN technique in 35 patients with 35 patients who underwent standard robotic PN. The “hybrid” technique consisted of a home-made port (surgical glove stretched over a wound retractor) at the umbilicus, which housed the two 8-mm robotic ports and a 12-mm camera port, and a separate 12-mm assistant port. Patients were similar at baseline, with equivalent tumor complexity. The OR time (187.5 min vs. 171.7 min, P = 0.110), warm ischemia time (29.5 min vs. 28.8 min, P = 0.209), blood loss (257 mL vs. 242.5 mL, P = 0.967), complication rate (17.1% vs. 11.4%, P = 0.495) and transfusion rate (8.6% vs. 2.9%, P = 0.303) were comparable in both groups. Furthermore, pain scores, length of hospitalization and morphine equivalents used were also comparable. There was no significant difference in complication rates or need for conversion. Of note, the authors found that there was noticeable restriction of the robotic arms with the R-LESS approach, which required timely adjustment and angulation by the bedside assistant for successful completion of the case.

R-LESS nephroureterectomy has also been described, although in smaller numbers. Lee et al.\[20\] included 12 patients in their aforementioned R-LESS series of 68 patients. The mean OR time was 227 min and EBL was 248 mL. There were no complications or conversions to standard robotics, laparoscopy or open surgery. The ureter was dissected down to the bladder, clipped and divided and then a cuff of bladder was resected. The bladder was then closed in two layers with absorbable suture. No repositioning/re-docking of the robot was required for the pelvic portion according to the authors. R-LESS adrenalectomy has also been reported by Park et al.\[27\] They performed a retroperitoneoscopic R-LESS adrenalectomy for benign adrenal adenoma. The access port was a surgical glove, and was placed below the 12th rib, after the retroperitoneal space had been developed.

It has been postulated that patients undergoing minimally invasive pyeloplasty might be ideal candidates for LESS.
as they are usually young with benign pathology and
the procedure is non-extirpative, thereby not requiring
a larger incision for specimen extraction. To overcome
the challenges associated with standard LESS, the robotic
platform has been applied (R-LESS). Despite the fact that
the current generation robotic system was not designed for
single-site surgery, surgeons noticed that dissection and
suturing were easier. We described our early experience
with R-LESS pyeloplasty and since then there have been a
number of other series using various access ports. The
unifying conclusion from all authors is that use of the robotic
system helps to reduce the technical difficulty of LESS
pyeloplasty and shortens the learning curve associated with
the procedure. Otwyny et al. compared 10 patients who
underwent conventional LESS (C-LESS) pyeloplasty with
10 patients who underwent R-LESS. Perioperative outcomes
were analyzed, including OR time, EBL, complications,
Morphine usage and length of stay in hospital (LOS).
Cosmetic and long-term functional outcomes were not
included in the analysis. There was no significant difference
between R-LESS and C-LESS except for OR time, which
was significantly longer for R-LESS (226 min vs. 188 min,
\( P = 0.007 \)). Additionally, there were two conversions to
standard laparoscopy in the C-LESS group as compared
with none in the R-LESS group. Despite there being no
clear advantage for R-LESS with regard to outcomes, the
authors found the superior optics and endo-wrist technology
of the robotic system beneficial. Cestari et al. tested the
feasibility and short-term perioperative outcomes of the
DaVinci single site surgery platform in nine patients with a
UPJO. The system uses a novel single port access device with
curved cannulas and robotic instruments. Additionally, the
instruments are crossed at the abdominal wall to minimize
classing and improve triangulation. All cases were completed
successfully, without any complication or conversion.
However, the authors noted that the main limitation of the
system was the lack of articulation of the instruments, which
is the principal advantage gained with the application of the
robotic system to LESS.

Pelvic urologic surgery

A number of groups have reported their experience with
R-LESS radical prostatectomy, the largest including
20 patients by White et al. They used a single-site approach,
with a SILS port and two 8 mm standard robotic trocars (or
one 8 mm and one 5 mm trocar) placed through separate
fascial incisions. Standard 8 mm EndoWrist (Intuitive Surgical)
monopolar shears and a 5 mm EndoWrist Schertel
grasper were used during dissection. The majority of patients
were D’Amico low risk (45%). The mean age of the patients
was 60.4 years and the mean BMI was 25.4 kg/m². Because
the fourth arm was not used, retraction was accomplished
by assistant suction or marionette sutures. The mean
OR time was 187.6 min and EBL was 128.8 mL. There
was one conversion to standard robotic prostatectomy
because of a large median lobe and need for more effective
retraction. Also, two cases required an additional 8 mm port
placed outside of the umbilical incision due to issues with
triangulation and leakage of gas from the SILS port. There
were four positive margins, but no patients experienced
biochemical recurrence at 1-year follow-up. The authors
also reported a trend toward improved urinary continence,
with five patients completely pad free over the follow-up
period. Three patients underwent an interfascial nerve
sparing technique and one had Sexual Health Inventory
for Men SHIM score of >21 at 3 months post-operatively.
Five patients had a leak at the urethrovaginal anastomosis
on cystogram performed 1 week post-surgery and required
an additional week of catheterization. One patient
experienced urosepsis and was admitted to the Intensive
Care Unit (ICU) 45 days post-operatively, but recovered
with intravenous antibiotics. The authors concluded that
R-LESS is feasible and less challenging than conventional
LESS. Instrument clashing was virtually eliminated by
staggering the robotic trocars, and marionette sutures
allowed for effective retraction despite inability to use the
4th arm. Assistant-driven retraction with the suction was also
important and was facilitated by placing a 15-30 downward
bend in the distal 1/3rd of the instrument.

The open simple prostatectomy remains the gold standard in
surgical therapy for prostates larger than 80 g. However, there
is still the potential for significant morbidity associated with
this procedure, including significant hemorrhage. A number
of centers have recently reported their experience with
single-port transvesical nucleation of the prostate (STEP) as
a minimally invasive alternative. For this procedure, ports
are placed through the bladder and the prostate adenoma
is enucleated. Fareed et al. reported their experience
with STEP using the DaVinci surgical robot. Nine patients
underwent R-STEP with a GelPort (Applied Medical) as the
access platform. Robotic instruments consisted of a 5-mm
Schertel grasper and a harmonic scalpel. The mean gland size
was 146.4 mL (83-304 mL) based on trans-rectal ultrasound.
The mean OR time was 3.8 h (2.75-4.75 h) and EBL was
584.4 mL (150-1200 mL). One patient required conversion to an
open prostatectomy and was excluded from the analysis. Two
patients required cystoscopy, fulguration and clot evacuation
post-operatively for clot retention. Additionally, one patient
developed a deep vein thrombosis DVT that required
anti-coagulation and one patient suffered a peri-operative
myocardial infarction, requiring admission to the ICU. At
1-month follow-up, the mean International Prostate Symptom
Score IPSS was 4.83 (2-15), Qmax was 20.1 mL/s (6-36) and post
void residual PVR was 75.75 mL (0-360). The authors concluded that
although R-LESS is technically feasible and effective in
treating bladder outlet obstruction, they found a high rate of
complications in their study.

Future directions

While the application of robotics to LESS has been beneficial,
there are still several drawbacks, such as instrument clashing

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and reduced space for the bedside assistant. This is largely due to the fact that the current DaVinci system has not been specifically designed for the single site application. Additionally, the R-LESS-specific robotic platform lacks the endo-wrist technology, which has obvious limitations. It is clear that an R-LESS-specific design would incorporate a low external profile and articulating instruments and allow sufficient space for the bedside assistant. There are currently a number of LESS-specific robotic prototypes under development, including one that is completely deployed into the peritoneal cavity.\textsuperscript{[33-35]} However, R-LESS remains in its infancy and much development is needed for a flawless, task-specific system that effectively mimics standard robotic surgery.

**CONCLUSION**

The application of robotics to LESS (R-LESS) has addressed many of the limitations seen with the conventional technique. The endowrist technology allows for superior dissection, triangulation and intra-corporeal suturing. However, R-LESS is still in its infancy as the current iteration of the DaVinci robotic platform has not been designed for LESS. As a result of the bulky extracorporeal profile, instrument clashing and limited space at the bedside remain important issues. Solutions such as the DaVinci Single-site\textsuperscript{TM} platform have been designed to address these challenges; however, their full clinical potential has not yet been reached as further testing is required. The ideal robotic platform for R-LESS would be low profile and task specific and would allow for deployment through a single incision. Additionally, the instruments would be articulating and there would be effective triangulation and retraction. Further advancements in the field of robotic surgery are necessary before truly scarless LESS becomes widely adopted.

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