

# Robotic laparoendoscopic single-site surgery: From present to future

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## ABSTRACT

The continued effort of improving cosmesis and reducing morbidity in urologic surgery has given rise to novel alternatives to traditional minimally invasive techniques: Laparoendoscopic Single-site Surgery (LESS) and Natural Orifice Transluminal Endoscopic Surgery (NOTES). Despite the development of specialized access devices and instruments, the performance of complex procedures using LESS has been challenging due to loss of triangulation and instrument clashing. A robotic interface may represent the key factor in overcoming the critical restrictions related to NOTES and LESS. Although encouraging, current clinical evidence related to R-LESS remains limited as the current da Vinci<sup>®</sup> robotic platform has not been specifically designed for LESS. Robotic innovations are imminent and are likely to govern major changes to the current landscape of scarless surgery.

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

## INTRODUCTION

Urologic surgery has evolved from its origin almost 2500 years ago with the drainage of renal abscesses and removal of calculi from renal fistulas to the milestone in the last decade of the 20<sup>th</sup> century of laparoscopic nephrectomy as described by Clayman *et al.*<sup>[1,2]</sup> This new era of minimally invasive urologic surgery has gained wide acceptance clinically and has become the method of choice for many procedures. Minimally invasive surgery has resulted not only in improving cosmesis but also decreasing morbidity with decreased pain and shorter convalescence. Most recently the urologic field was introduced to robotic surgery<sup>[3]</sup> and in a relatively short period of time the great majority of prostatectomy procedures in the United States are now being performed with this technology.

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The continued effort of improving cosmesis and reducing morbidity in urologic surgery has given rise to novel alternatives to traditional minimally invasive techniques: Laparoendoscopic Single-site Surgery (LESS) and Natural Orifice Transluminal Endoscopic Surgery (NOTES). Special note should be taken that in terms of nomenclature, the term LESS has been accepted as the official moniker used to refer to single-site procedures.<sup>[4,5]</sup> In order to describe LESS procedures performed using the Da Vinci robot<sup>®</sup> (Intuitive Surgical, Sunnyvale, CA, USA) the term robotic LESS (R-LESS) has been adopted.

### *Robotic laparoendoscopic single-site surgery: Lights and shadows*

Despite the development of specialized access devices and instruments, the performance of complex procedures using LESS has been challenging due to loss of triangulation and instrument clashing. R-LESS would seem to be uniquely suited to help overcome some of these limitations with technological advantages such as instruments with articulating wristed motion, tremor filtration, and overall ergonomic benefits that could improve surgeon comfort significantly. Furthermore, the stereoscopic three-dimensional view and the associated appreciation of the relative position of structures is a noted benefit of robotic technology.<sup>[6]</sup> The result is evidence of decreased learning curves and reduced perioperative complications for robotic compared to laparoscopic procedures.<sup>[7]</sup>

A major limitation of R-LESS is that the hardware and software of the standard robotic systems are not specifically designed for LESS and therefore clashing is still experienced and incisions may need to be somewhat larger than for conventional LESS.<sup>[8]</sup> Nevertheless, though still accounting for a small percentage of total LESS publications, there appears to be a relative increase of R-LESS procedures being performed when considering all clinical LESS cases since 2008. As will be discussed elsewhere in this review, R-LESS may be controversial since most procedures are extirpative or ablative rather than reconstructive and commonly lack ancillary procedures such as lymph node dissection during radical prostatectomy and hilar clamping during partial nephrectomy.<sup>[9,10]</sup>

### Access techniques

In terms of access, transvaginal, transrectal and transumbilical routes have been used either clinically or experimentally for R-LESS as well as hybrid NOTES approaches.<sup>[10]</sup> The present access technique for upper tract R-LESS involves a periumbilical “omega” Ω-like skin incision in a range of 4-5 cm after placing the patient in 60-90° flank position with a slight break in the table. For pelvic R-LESS procedures the patient is placed in the Trendelenburg dorsal lithotomy position and an “omega”-like or midline umbilical incision is created.<sup>[11]</sup> Due to pneumoperitoneum leakage commonly experienced with robotic trocars placed through a single-port device, it is suggested to place the robotic instrument trocars via separate fascial stabs alongside the device or use a single-incision, multiport technique without a commercially available device. The authors prefer a 30° downward viewing robotic scope for upper tract procedures and a 0° scope for pelvic procedures. Five and 8-mm robotic ports may be used but the authors prefer using 8-mm instruments for both robotic arms. Thus far, the use of a fourth arm has not been described. Short length of the instruments may be another issue theoretically as the ports are positioned caudally, especially for dissection of the upper pole of the kidney. As the da Vinci S and Si systems® offer 5-cm longer robotic arms compared to the standard version the authors have not noted difficulty in terms of reach.<sup>[12]</sup> Of note, as with all LESS procedures patient selection is important and the body mass index (BMI) of initial reported R-LESS patients was in the range of 23-30 kg/m<sup>2</sup>.<sup>[13]</sup>

### Robotic NOTES

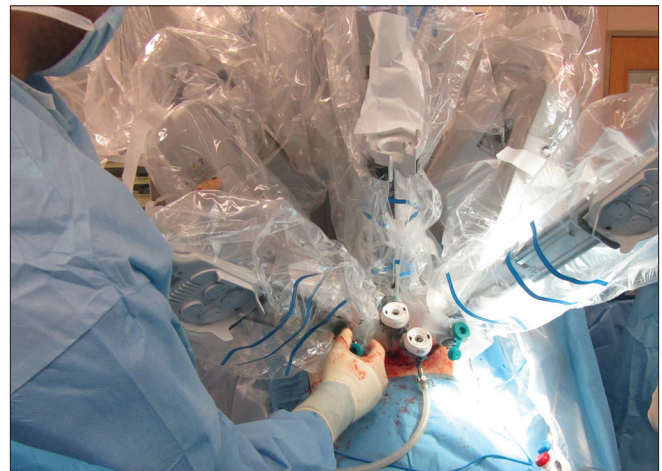
Potential advantages for robotic NOTES (R-NOTES) include even better cosmesis, improved access in obese patients or for those with abdominal wall pathologies, less pain, and avoidance of abdominal wall trauma. Although to date there has been no clinical report of R-NOTES in urologic surgery, Kaouk *et al.*, reported a pure NOTES transvaginal nephrectomy with articulating and conventional laparoscopic instruments.<sup>[14]</sup> All in all, unlike R-LESS which appears to be gaining some clinical momentum, R-NOTES is still largely in a developmental stage.

### Access platforms

A wide variety of access platforms from homemade to commercially available have been used in R-LESS. The most common are, i) Quadport® (Advanced Surgical Concepts, Wicklow, Ireland) which contains 5(1), 10(2) and 15(1)-mm ports and is placed through a 2-7 cm incision,<sup>[15]</sup> ii) SILS® port (Covidien, Mansfield, MA, USA) which contains four sites for port placement and is introduced through a 3-4cm incision, iii) GelPort/GelPoint® (Applied Medical, Rancho Santa Margarita, California, USA) which include a GelCap through which various ports in any arrangement may be introduced.<sup>[16]</sup> The optimal incision for placement of these ports is “3-7 cm, and iv)” Homemade access platforms composed of a wound retractor as an inner ring covered by an intact surgical glove with trocars introduced through the fingers of the glove.<sup>[17,18]</sup> Besides these, a novel robotic device has recently been approved for clinical use in Europe and is used with a multichannel port designed for placement of an 8.5-mm scope, an assistant 12-mm cannula and two additional curved cannulas for the robotic arms<sup>[8]</sup> [Figure 1]. For all commercially available ports, a disadvantage includes the cost of the device.<sup>[19]</sup> Presently, the majority of devices average approximately \$400 in the United States with differences depending upon institutional negotiation. In the author’s experience, when using the SILS port, placement of the robotic trocars through the same incision but through separate fascial stabs alongside the port helps with increased instrument spacing and decreased leakage of insufflant. Also, use of multiple ports introduced through separate fascial stabs using a single incision can be successful and is more cost-effective [Figure 1].

### Initial experimental studies

Initial experimental studies have been conducted on pigs and human cadavers. Box *et al.*, performed R-NOTES nephrectomy on a female farm pig with robotic arms docked through the umbilicus, vagina and rectum. However, they reported that this atypical trocar configuration led



**Figure 1:** Port positioning and docking of the robot during R-LESS prostatectomy without a commercially available single-port device

to difficulty in instrument movement despite being able to supply effective traction for exposure and dissection.<sup>[12]</sup> Haber *et al.*, reported performing 30 urologic R-LESS procedures in 10 female farm pigs with transumbilical access for the camera and one robotic arm and transvaginal access for the other robotic arm.<sup>[7]</sup> Procedures performed included dismembered pyeloplasty, partial nephrectomy, and radical nephrectomy. The authors concluded that the robot enhanced intracorporeal suturing but that there remained significant clashing of the arms despite greater separation by using the vagina as an access site. They also noted that R-NOTES performed on pigs was likely technically easier than on humans due to the anatomy of the porcine model such as minimal Gerota's fat, smaller renal vessels and shorter distance between the kidney and vaginal access for upper tract R-NOTES/LESS. Haber *et al.*, in a more recent report explored the feasibility and efficiency of a novel modification of the da Vinci Si surgical system for R-LESS (VeSPA) with a single-port device and curved cannulas [Figure 2]. They performed 16 procedures including radical nephrectomy (n=8), partial nephrectomy (n=4), and dismembered pyeloplasty (n=4) and reported that while no extracorporeal clashing between the robotic arms occurred, the articulating function of the endo-wrists was not included on the present prototype.<sup>[18]</sup>

R-LESS was used to perform transvesical robotic radical prostatectomy in two human cadavers by either a multiport device with four separate ports introduced percutaneously into the bladder or by a Quadport® device. After radical

excision of the prostate, urethrovesical anastomosis could be completed but with some difficulty.<sup>[20]</sup> The authors encourage future attempts using the transvesical route for R-LESS based on experience of a large intravesical working space upon establishment of pneumovesicum. However, inability to perform lymph node dissection indicated for moderate and high-risk prostate cancer cases was a limitation for this novel method.

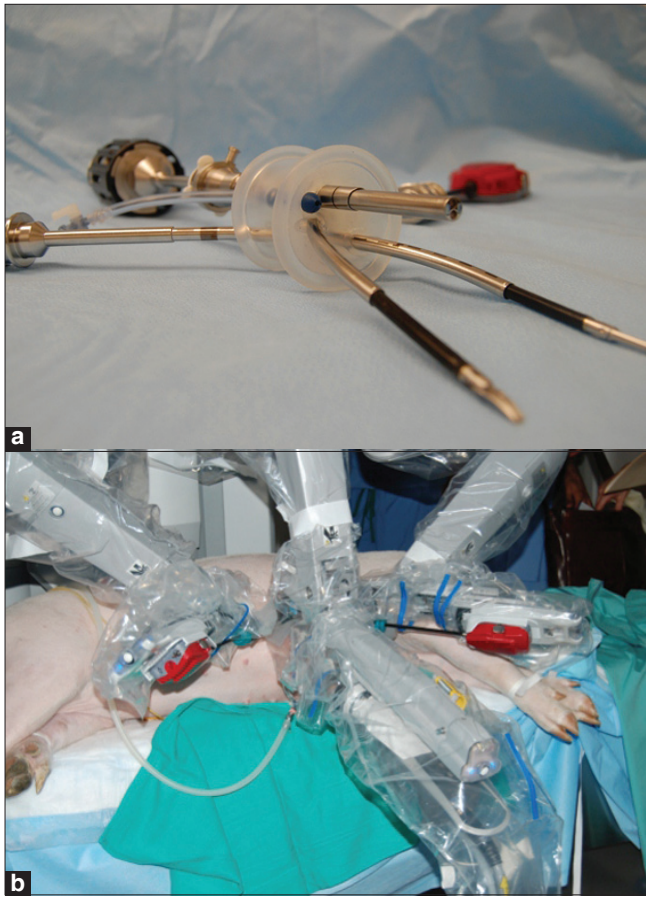
### Human experience

Based on these initial experimental studies, Kaouk *et al.*, published their initial R-LESS case series [Table 1] involving upper and lower tract common urologic extirpative and reconstructive procedures including radical nephrectomy, pyeloplasty and radical prostatectomy.<sup>[21]</sup> Procedures were performed through a transumbilical incision with the insertion of a robotic 12-mm scope and a 5-mm instrument port via the R-Port system. Additionally, a 5 or 8-mm robotic port was introduced through a separate fascial stab within the same skin incision. The authors suggested that the learning curve for R-LESS would likely be shorter in comparison with standard LESS. Furthermore, the same center soon after published their experience of R-LESS partial nephrectomy for two patients.<sup>[21]</sup> The authors introduced a Triport (Advanced Surgical Concepts, Wicklow, Ireland) through a 1.8-cm umbilical incision. The platform provided a 10-mm port for introduction of the robotic camera and an additional 5-mm robotic instrument was introduced through the device. A separate robotic port was placed through a separate fascial stab alongside the device and through the same

**Table 1: Robotic urologic LESS: reported clinical series\***

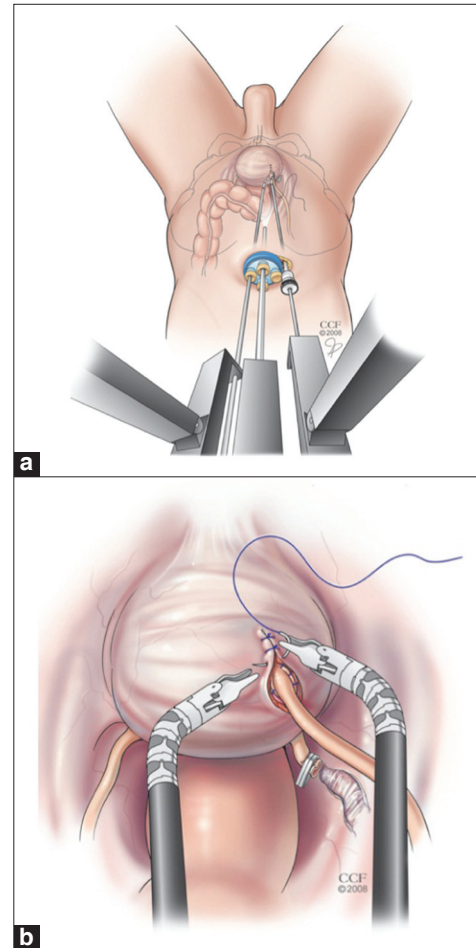
Author, Year [Ref.]	Number of cases	Da Vinci™ platform	Access technique	Access port	Procedures (n)	OR time, min	Complications or Conversions (n)	Comment
Kaouk, 2008	3	S	Umbilical Single-site	R-port	RP (1) Pyeloplasty (1) RN (1)	345 270 150	No	No extra-umbilical ports; Urethrovesical anastomosis 45 min
Kaouk, 2009	2	S	Umbilical Single-site	Triport™	PN	170 <sup>^</sup>	No	Pediatric instruments used: Unclamped procedures
Stein, 2010	4	S	Umbilical Single-port	Gelpoint™	RN (1) PN (1) Pyeloplasty (2)	200#	Transfusion (1)	No extra ports; Larger incision for specimen extraction
White, 2010	20	S or Si	Umbilical Single-site	SILS™	RP	189.5#	Ileus (1); transfusion (1); PE (1); urosepsis (1)	Additional extra-umbilical 8 mm ports used in two cases. Positive margin rate 23%
White, 2011	10	S or Si	Umbilical Single-site	SILS™ Gelpoint™	RN	167.5#	Skin infection (1)	No trocars or additional instruments required outside of the single incision
Han, 2011	14	S	Umbilical Single-port	Homemade single-port device	PN	233#	Conversion to open surgery (2)	Additional extra-umbilical 5 mm ports used in 10 cases.
Won Lee, 2011	68	S	Umbilical Single-port	Homemade single-port device	PN (51) NU (12) RN (2) AD (2) SN (1)	217 <sup>^</sup> 227 <sup>^</sup> 225 <sup>^</sup> 167 <sup>^</sup> 128 <sup>^</sup>	Intraoperative complication (3); Transfusion (9); Conversion to open surgery (3)	Mean warm ischemia time for PN 27 min; Use of additional extra-umbilical ports not specified

\*Single case reports not included. <sup>^</sup>Mean values. #Median values, RP: Radical prostatectomy; SN: Simple nephrectomy; RN: Radical nephrectomy; PN: Partial nephrectomy; NU: Nephroureterectomy; STEP: Single-port transvesical enucleation of the prostate; AD: Adrenalectomy; NU: Nephroureterectomy



**Figure 2:** (a) Curved trocars, flexible instruments, and specially designed port of the VeSPA robotic system, (b) Patient cart docked to the VeSPA robotic system

incision. The procedures were done without hilar clamping and the procedure was suggested only for exophytic and middle and lower pole tumors. To expand the indications for partial nephrectomy, Arkoncel *et al.*, suggested a two-incision hybrid R-LESS partial nephrectomy.<sup>[22,23]</sup> The procedure was used to perform 35 partial nephrectomies and the additional 12-mm port was placed 8 cm caudal to the homemade umbilical access device and used for assistance and placement of hilar clamps. Another clinical series described the use of the GelPort platform for R-LESS in 11 patients undergoing robotic prostatectomy, partial/radical nephrectomy, ureteroneocystostomy [Figure 3] and dismembered pyeloplasty.<sup>[16]</sup> The GelPort was noted to facilitate the procedures by providing greater spacing of ports and greater flexibility in terms of optimal trocar positioning. Barret *et al.*, described their initial experience with extraperitoneal R-LESS radical prostatectomy in a cadaver followed by a clinical case. No commercial access device was used as they placed all robotic ports through separate fascial punctures transumbilically. An additional 5-mm port through a separate skin incision was used by the bedside assistant.<sup>[24]</sup> R-LESS prostatectomy has also been described for a patient who underwent neoadjuvant hormonal deprivation therapy.<sup>[25]</sup> Seo *et al.*, reported a hybrid R-LESS approach for simultaneous bilateral upper



**Figure 3:** (a) Illustration of port positioning for R-LESS ureteroneocystostomy. Note the placement of one robotic trocar beside the Quadport through the same incision but a separate fascial stab, (b) Illustration of R-LESS ureteroneocystostomy using two 5-mm robotic needle drivers

tract procedures.<sup>[26]</sup> They performed partial nephrectomy for a 51-year-old man (BMI 23 kg/m<sup>2</sup>) for bilateral renal masses with a 3-cm umbilical incision using a homemade access device. An additional 11-mm trocar was added for the bedside assistant. While one of the partial nephrectomies required renal vascular clamping, the other did not. External or internal clashing was the most common difficulty for the surgeons with R-LESS. Joseph *et al.*, described a ‘chopstick’ technique used in the laboratory in order to reduce instrument clashing. The technique involves crossing of the robotic arms inside the patient and modifying the outputs of the robot such that the ‘left’ instrument is controlled with the right hand effector and vice versa.<sup>[27]</sup> In our experience this technique can be useful but oftentimes cannot be used for entire procedures.

#### *The future of NOTES and LESS*

R-LESS indeed offers many potential advantages over standard LESS such as superior ergonomics and easier instrument articulation, yet there are still significant limitations including the need for a somewhat larger incision with the present robot, clashing, lack of haptic feedback, and

limited space for the assistant to maneuver. The advantages of LESS for urologic procedures are still undefined and somewhat controversial.<sup>[28]</sup> What is clear is that LESS is being performed increasingly as the techniques are refined.

NOTES and LESS, in their robotic form, are rapidly developing new techniques that inevitably depend on cooperative support from engineers, clinical researchers and minimally invasive surgeons. This enormous, multidisciplinary effort will be more likely directed towards the development of more sophisticated robotic devices, such as flexible robots and *in vivo* wireless controlled miniature robots.<sup>[29]</sup> Several flexible robotic systems have been already introduced primarily for intravascular catheter-based applications. Multiple remotely controlled surgical instruments and scopes through a common channel can give the opportunity to the surgeon to perform complex intra-abdominal procedures by providing the necessary triangulation, degrees of freedom, and tensile strength. The working channels of this robotic instrument could carry computer-controlled flexible graspers, needle drivers, mono-bipolar coagulators and even ultrasonic scalpels and suction arms. The initial version of this flexible robotic system has been used experimentally for ureterorenoscopy.<sup>[30,31]</sup> Also, *in-vivo* mini robots have been introduced into the peritoneal cavity experimentally *via* transgastric incision to perform NOTES small bowel dissection.<sup>[32,33]</sup>

Magnetic Anchoring and Guidance system (MAGS) is another interesting technology in the development of LESS. Basically, the system is composed of intracorporeal LESS instruments anchored through the abdominal wall with extracorporeal magnetic devices. This system was successfully tested in performing a LESS nephrectomy.<sup>[34]</sup> It was claimed that the MAGS camera results in fewer instrument collisions and allows for an adequate working space despite its current obstacles such as a fixed zero-degree lens and focus, as well as magnets that require a thin abdominal wall.<sup>[35]</sup>

Newer robotic surgical systems are on the horizon. The ViKY® system (EndoControl, Grenoble, France) with a compact camera holder will have the ability of supplying a 5-mm endoscope without decreasing viewing capacity, and 3-mm trocars.<sup>[6,31]</sup> The SPIDER® surgical system (TransEnterix, Durham, North Carolina, USA) is designed to be introduced through a small incision but has curved trocars through which flexible instruments can be introduced. It has been recently experimentally and clinically tested by means of performing simple LESS cases and the authors were impressed by its performance due to its superior triangulation without clashing. However, the authors had great difficulty in basic maneuvers such as dissecting, retracting, grasping, cutting and cauterizing. The second-generation SPIDER system evolved to a vertebral design in order to increase the forces generated at the distal instrument tips and thereby overcome the tensile strength limitations.<sup>[36]</sup>

## CONCLUSIONS

A robotic interface may represent the key factor in overcoming the critical restrictions related to NOTES and LESS. Although encouraging, current clinical evidence related to R-LESS remains limited as the current da Vinci® robotic platform has not been specifically designed for LESS. Robotic innovations are imminent and are likely to govern major changes to the current landscape of scarless surgery.

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