DOI:10.3724/SP.J.1008.2011.01050

· Expert forum ·

Robotic laparoendoscopic single-site surgery(R-LESS): current status in urology

Riccardo Autorino[1*], YANG Bo[2], Jihad H. Kaouk[1]

1. Section of Laparoscopic and Robotic Surgery, Glickman Urological and Kidney Institute, Cleveland Clinic, 9500 Euclid Avenue Q10, 44195-Cleveland, Ohio, USA

2. Department of Urology, Changhai Hospital, Second Military Medical University, Shanghai 200433, China

[**Abstract**] Laparoendoscopic single-site surgery (LESS) is technically challenging; it can reduces instrument triangulation and robust retraction and is associated with a steep learning curve. The instruments of the daVinci® surgical system (Intuitive Surgical) are designed with seven degrees of motion mimicing the dexterity of the human hand and wrist. This inherent feature of the robotic arm provides superior ergonomics when performing LESS, especially for complex reconstructive surgery. This review analyzes the evidence supporting current and future application of robotic technology in the field of urologic LESS.

[**Key words**] da Vinci surgery; laparoendoscopic single-site surgery; robotic surgery; urologic surgical procedures

[Acad J Sec Mil Med Univ, 2011, 32(10): 1050-1055]

1 Introduction

Laparoendoscopic single-site surgery (LESS) has been developed with the specific aims of preventing port-site complications, decreasing discomfort, and improving cosmetic outcomes as compared to standard laparoscopic/robotic surgery[1-2]. Several terms and acronyms have been used to refer to this technique until a consensus statement agreed to use the term "LESS"[3-4].

Although early experience with *LESS* is promising, advanced laparoscopic skills are essential for its safe and effective completion. Close proximity of laparoscopic instruments and camera lens often result in intracorporeal instrument collision, hindering the surgeons from operating dextrously within the operative field. Visibility of the operative field afforded by the camera assistant is also limited due to the restriction in freedom to manoeuvre the camera lens to minimize instrument clashing. Finally, intracorporeal dissection and suturing are also challenging, also due to the limited range of movement of the laparoscopic instruments working in parallel with lack of triangulation. Articulating or pre-bent instruments have been developed to partially overcome these constraints[1].

The da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA) was the first surgical robotics system cleared by the US Food and Drug Administration (FDA) for use in laparoscopic surgery. Some of the benefits of the da Vinci robot-assisted laparoscopic techniques over conventional laparoscopy include superior ergonomics, larger optical magnification of the operative field, enhanced surgeon dexterity within the field of view, and greater precision of surgical manipulation[5].

Robotic manipulation of instrumentation during LESS has been studied to address current constraints and limitations. This review analyzes the evidence supporting current and future application of robotic technology in the field of urologic LESS.

2 Robotic LESS: current clinical experience in urology (Table 1)

In 2009, Kaouk *et al*. reported the first successful series of single-port robotic procedures in humans, including radical prostatectomy, dismembered pyeloplasty and radical nephrectomy[6]. A robotic 12-mm scope and 5-mm grasper were intro-

[**Received**] 2011-09-08 [**Accepted**] 2011-09-30 [**Available online**] 2011-10-20

[**Biography**] Riccardo Autorino, MD, PhD, FEBU, Glickman Urological and Kidney Institute, Cleveland Clinic, 9500 Euclid Avenue Q10, 44195-Cleveland, Ohio, USA.

* Corresponding author. E-mail: ricautor@tin.it; autorir@ccf.org

duced through a multi-channel single port (R-Port), while an additional 5-mm or 8-mm robotic port was introduced through the same umbilical incision (2 cm) alongside the multi-channel port to facilitate entry of robotic instruments. The authors noted an improved facility for intracorporeal dissecting and suturing due to robotic instrument articulation and stability.

Table 1 Robotic urologic LESS: reported clinical series

[Ref.]	Number of cases	Da Vinci™ platform	Access technique	Access port	Procedures (*n*)	OR time (min)	Complications (*n*)	Notes
Kaouk	3	S	Umbilical single-site	R-port	RP(1); Pyeloplasty(1); RN(1)	345 270 150	No	No extra-umbilical ports
Kaouk	2	S	Umbilical single-site	TriPort™	PN	170 (mean)	No	Pediatric instruments used; unclamp procedure
Stein	4	S	Umbilical single-port	GelPort™	RN(1); PN(1); Pyeloplasty(2)	200 (median)	Transfusion(1)	No extra ports; larger incision for specimen extraction
Han	14	S	Umbilical single-port	Homemade single-port device	PN	233 (median)	Two conversions to open surgery	Additional extra-umbilical 5-mm ports used in 10 cases
White	20	S or Si	Umbilical single-site	SILS™	RP	189.5 (median)	Ileus(1); transfusion(1); PE(1); urosepsis(1)	Additional extra-umbilical 8-mm ports used in two cases; positive margin rate 23%
White	10	S or Si	Umbilical single-site	SILS™ Gelpoint™	RN	167.5 (median)	Skin infection(1)	No trocars or additional instruments required outside of the single incision

Legends. RP=Radical prostatectomy; RN=Radical nephrectomy; PN=Partial nephrectomy; PE=Pulmonary embolus

Together with their preliminary experience in a cadaver model, Barret *et al*. also reported their experience with a *hybrid* LESS robotic-assisted radical prostatectomy in a single patient[7]. They placed two 8-mm robotic ports and a 12-mm port for the robotic camera into a 4-cm umbilical incision. An additional 5-mm port was placed at the right lower abdomen. More recently, the same authors reported their initial case of a complete robotic LESS radical prostatectomy[8]. They utilized a single umbilical incision and placed a 12-mm port for the robotic scope, a 5-mm port for the assistant, and two 8-mm ports for the robotic arms arranged in a rhomboid fashion. No intraoperative complications occurred and surgical margins were negative. Significant external robotic arm collision was experienced as well as a reduced space for the assistant to work.

Further expanding the application of robotics to LESS, Kaouk and Goel reported an initial experience with single-port robotic partial nephrectomy in two patients[9]. A multi-channel port (TriPort™) was utilized. Pediatric 5-mm robotic instruments, including graspers, electrocautery hook, and harmonic scalpel, were used for tumor exposure and excision. A 30° robotic lens placed in the upward configuration minimized clashing between the scope and instruments. A 2.8 cm left lower pole anterior medial tumor and a 1.1 cm right lateral lower pole tumor were excised without renal hilar clamping using the harmonic scalpel. Both patients had confirmed renal cell carcinoma with negative margins, and there were no intraoperative complications.

In another study, Stein *et al*. reported robotic LESS using a GelPort™ (Applied Medical, Rancho Santa Margarita, CA, USA) as access platform[10]. Four procedures were performed, including two pyeloplasties, one radical nephrectomy, and one partial nephrectomy. All procedures were successfully completed. The use of the GelPort™ as an access platform provided adequate spacing and flexibility of port placement and acceptable access to the surgical field for the assistant.

More recently, Han *et al*. described a series of 14 robot-assisted LESS partial nephrectomies[11]. Mean tumor size was 3.2 cm, mean ischemic time was 30 min, and mean operative time was 233 min.

A hybrid homemade port technique was used in 10 cases. All surgical margins were negative for malignancy. No port-related complications were reported. Two cases required conversion to mini-incisional partial nephrectomy. The authors concluded that robot-assisted LESS partial nephrectomy allows meticulous suturing on the renal parenchyma using articulating robot arms and ready access to the surgical field for the assistant.

The first robotic LESS radical prostatectomy series was reported by White *et al*. in 2010[12]. A total of 20 procedures were scheduled. Single-port access was achieved *via* a commercially available multi-channel port. The da Vinci S and da Vinci Si surgical platforms were used with pediatric and standard instruments. The mean operative time was 189.5 min; estimated blood loss was 142.0 ml. The average length of stay was 2.7 days, and the visual analog pain score at discharge was 1.4 of 10. Four focal positive margins were encountered, with two occurring during the first three cases. There were a total of four complications according to the Clavien system including one grade 1, two grade 2, and one grade 4. Study limitations include the small sample size, the short follow-up, and the lack of comparative cohort. Authors concluded that robotic LESS radical prostatectomy is technically feasible and reduces some of the difficulties encountered with the conventional LESS counterpart.

Later on, the same group of investigators reported an early experience with robotic LESS radical nephrectomy. A total of 10 procedures were performed and subsequently matched to 10 conventional laparoscopic procedures. The mean patient age was 64 years of age for both groups, and BMI was 29.2 kg/m^2. There was no difference between robotic LESS and conventional laparoscopy cases in median operative time, estimated blood loss, visual analogue scale, or complication rate. The robotic LESS group had a lower median narcotic requirement during hospital admission and a shorter length of stay. Study limitations include the small sample size, short follow-up period, and all the inherent biases introduced by a retrospective study design [13].

In a large multi-institutional worldwide series of LESS in urology, Kaouk *et al*. analyzed 1 076 cases done at 18 participating institutions. The da Vinci robot was used to operate on 143 patients (13%) with a significant increase over time[14].

3　da Vinci™ robotic system: recent advances for LESS applications

Even if the addition of da Vinci system to LESS has improved limitations experienced with conventional LESS (Table 2), a reduction in the range of motion of the instruments still exists and we still do not have a perfect system and are in the infancy of robotic single-site surgery. Currently available robotic platforms remain bulky, as they have not been specifically designed for LESS (Figure 1).

Table 2　LESS vs robotic LESS

	LESS	Robotic LESS
Scope (vision)	2D; HD; unstable	3D; HD; stable
Instrument	Straight; pre-bent; articulating	Articulating
Triangulation	Lacking(cross hand or chopstick surgery)	Lacking(chopstick surgery)
Range of motion	Limited	Enhanced (endowrist technology)
Collision	Significant	Significant
Dissection	Challenging	Limited at steep angles
Suturing	Extremely challenging	Accurate
Key assistant's role	Camera manouvering	Managing collisions
Learning curve	Steep	Reduced

A surgical robot with *wristed* instruments, as the currently available da Vinci, partially overcome existing constraints of conventional LESS, but, still, robotic arms significantly collide when working coaxially. To address limitations related to the coaxial arrangement of instruments, Joseph *et al*. recently tested in a new technique of "chopstick" surgery enabling the use of current da Vinci robotic

arms through a single incision without collision [15]. A preliminary study was conducted in the dry lab by performing fundamentals of laparoscopic surgery tasks in order to determine the optimal set-up for LESS to be a triangular port arrangement with 2-cm trocar distance and remote center at the abdominal wall. Then, experiments were conducted utilizing the da Vinci S™ robot (Intuitive Surgical, Sunnyvale, CA) in a porcine model with three laparoscopic ports (12 mm, 2-5 mm) introduced through a single incision. Cholecystectomy and nephrectomy were performed in a porcine model utilizing the "chopstick" technique. This arrangement crosses the instruments at the abdominal wall so that the right instrument is on the left side of the target and the left instrument on the right. In this way, collision of the external robotic arms is prevented. To correct for the change in handedness, the robotic console is instructed to drive the "left" instrument with the right hand effector and the "right" instrument with the left. According to the investigators, "chopstick" surgery significantly enhances the functionality of the surgical robot when working through a small single incision and is likely to enable surgeons to utilize the robot for LESS.

Figure 1 da Vinci Si robot™ docked for a robotic LESS cystectomy

In an attempt to minimize clashing of instruments, Crouzet *et al*. recently presented their initial translational animal study in which a low-profile robot was used to assist one surgeon to complete LESS reconstructive and extirpative renal procedures[16]. After a 2-cm umbilical incision was made, through which a single port was placed and pneumoperitoneum obtained, an operative 5-mm 30° rigid high-definition laparoscope was introduced and securely held using a novel low-profile robot under foot and/or voice control (Light Endoscope Holder Robot, LER, EndoControl, Grenoble, France). Using articulating instruments, each pig had bilateral reconstructive partial nephrectomy and bilateral pyeloplasty before a completion of bilateral radical nephrectomy. There were no intraoperative complications and there was no need for additional ports to be placed.

More recently, a novel single-site robotic instrument (VeSPA, Intuitive Surgical, CA, USA) were specifically developed for LESS surgery (Figure 2). These instruments have been designed to offset many of the limitations encountered with standard LESS and can be deployed through a single skin and fascial incision alleviating the need for a multi-cannula approach. The VeSPA curved cannulae and semi-rigid instrument design allows the cannulae and instruments to be inserted in close proximity while allowing approximate triangulation intra-abdominally. As such, instrument collisions are minimized. Currently this system is under investigation in experimental setting [17].

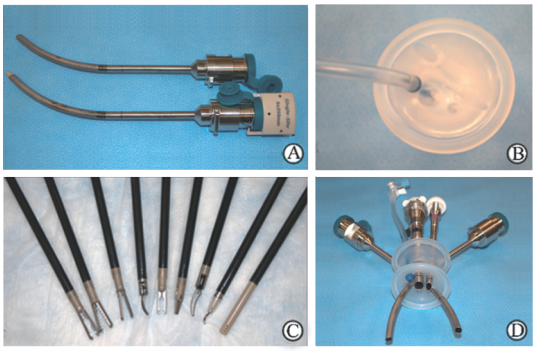

Figure 2 Single-site robotic instrumentation (Intuitive Surgical, Sunnyvale, CA)

A: Curved cannulae; B: Multi-channel port; C: Semi-rigid instruments; D: Trocar disposition into the multi-channel port

Kroh *et al*. presented the first human experience with this new device used to perform single-incision laparoscopic cholecystectomy[18]. A total of 13 consecutive operations were completed successfully. One patient required placement of an additional extra-umbilical trocar for appropriate visualization secondary to gallbladder necrosis, and this incision also was used for eventual drain place-

ment. For two patients, an intraoperative choloangiogram was performed. The mean operative time was 107 min, and the mean docking time was 15 min. Discharge for 11 patients was within 24 h. No significant complications occurred. According to the authors, the availability of this new semi-rigid, robotic surgery platform may increase access to the potential advantages of single-site surgery.

Dolghi *et al*. from University of Nebraska developed a multi-dexterous robot capable of generating the required forces and speeds to perform surgical tasks intra-abdominally[19]. The basic robotic design consists of two arms each connected to a central body. Each arm has three degrees of freedom and rotational shoulder and elbow joints. This combination allows a surgeon to grasp, manipulate, cauterize, and perform intracorporeal suturing. Its versatility was demonstrated in four procedures performed in a porcine model: cholecystectomy, partial colectomy, abdominal exploration, and intracorporeal suturing. Once inserted into the peritoneal cavity, the robot provides a stable platform for visualization with sufficient dexterity and speed to perform surgical tasks.

From Japan, Kobayashi *et al*. described a surgical prototype robot with dynamic vision field control and a master controller to manipulate the endoscopic view[20]. It uses positioning (4 degrees of freedom) and sheath (2 degrees of freedom) manipulators for vision field control, and dual tool tissue manipulators (gripping, 5 degrees of freedom; cautery, 3 degrees of freedom). *In vitro*, cut and vision field control (using tool manipulators) was suitable for precise cutting tasks in risky areas; cut by vision field control (using the vision field control manipulator) was effective for rapid macro cutting of tissues. A resection was performed using a combination of both methods. Further studies are needed to address its performance *in vivo*.

4　Conclusions

The currently available da Vinci™ system offers several advantages when applied to LESS. Early clinical experience has been encouraging as some of the constraints encountered during conventional LESS can be overcome. Nevertheless, the current da Vinci™ robotic platform remains bulky, as it has not been specifically designed for LESS. Robotic innovations are imminent and are likely to govern major changes to the current landscape of LESS.

[References]

[1] Gettman M T, White W M, Aron M, Autorino R, Averch T, Box G, et al. Where do we really stand with LESS and NOTES? [J]. Eur Urol, 2011, 59: 231-234.

[2] Autorino R, Cadeddu J A, Desai M M, Gettman M, Gill I S, Kavoussi L R, et al. Laparoendoscopic single-site and natural orifice transluminal endoscopic surgery in urology: a critical analysis of the literature[J]. Eur Urol, 2011, 59: 26-45.

[3] Box G, Averch T, Cadeddu J, Cherullo E, Clayman R, Desai M, et al. Nomenclature of natural orifice translumenal endoscopic surgery (NOTES) and laparoendoscopic single-site surgery (LESS) procedures in urology[J]. J Endourol, 2008, 22: 2575-2581.

[4] Gill I S, Advincula A P, Aron M, Caddedu J, Canes D, Curcillo P G 2nd, et al. Consensus statement of the consortium for laparoendoscopic single-site surgery[J]. Surg Endosc, 2010, 24: 762-768.

[5] Ran A, Tan G Y, Tewari A K. Laparo-endoscopic single-site surgery in urology: is robotics the missing link? [J]. BJU Int, 2009, 104: 1041-1043.

[6] Kaouk J H, Goel R K, Haber G P, Crouzet S, Stein R J. Robotic single-port transumbilical surgery in humans: initial report[J]. BJU Int, 2009, 103: 366-369.

[7] Barret E, Sanchez-Salas R, Kasraeian A, Benoist N, Ganatra A, Cathelineau X, et al. A transition to laparoendoscopic single-site surgery (LESS) radical prostatectomy: human cadaver experimental and initial clinical experience[J]. J Endourol, 2009, 23: 135-140.

[8] Barret E, Sanchez-Salas R, Cathelineau X, Rozet F, Galiano M, Vallancien G. Re: Initial complete laparoendoscopic single-site surgery robotic assisted radical prostatectomy (LESS-RARP) [J]. Int Braz J Urol, 2009, 35: 92-93.

[9] Kaouk J H, Goel R K. Single-port laparoscopic and robotic partial nephrectomy[J]. Eur Urol, 2009, 55: 1163-1169.

[10] Stein R J, White W M, Goel R K, Irwin B H, Haber G P, Kaouk J H. Robotic laparoendoscopic single-site surgery using GelPort as the access platform[J]. Eur Urol, 2010, 57: 132-136.

[11] Han W K, Kim D S, Jeon H G, Jeong W, Oh C K, Choi K H, et al. Robot-assisted laparoendoscopic single-site surgery: partial nephrectomy for renal malignancy[J]. Urology, 2011, 77: 612-616.

[12] White M A, Haber G P, Autorino R, Khanna R, Forest S, Yang B, et al. Robotic laparoendoscopic single-site radical prostatectomy: technique and early outcomes[J]. Eur Urol, 2010, 58: 544-550.

[13] White M A, Autorino R, Spana G, Laydner H, Hillyer S P, Khanna R, et al. Robotic laparoendoscopic single-site radical nephrectomy: surgical technique and comparative outcomes [J]. Eur Urol, 2011, 59: 815-822.

[14] Kaouk J H, Autorino R, Kim F J, Han D H, Lee S W, Yinghao

S, et al. Laparoendoscopic single-site surgery in urology: worldwide multi-institutional analysis of 1076 cases[J]. Eur Urol, 2011 Jun 12. [Epub ahead of print]

[15] Joseph R A, Goh A C, Cuevas S P, Donovan M A, Kauffman M G, Salas N A, et al. "Chopstick" surgery: a novel technique improves surgeon performance and eliminates arm collision in robotic single-incision laparoscopic surgery[J]. Surg Endosc, 2010, 24: 1331-1335.

[16] Crouzet S, Haber G P, White W M, Kamoi K, Goel R K, Kaouk J H. Single-port, single-operator-light endoscopic robot-assisted laparoscopic urology: pilot study in a pig model[J]. BJU Int, 2010, 105: 682-685.

[17] Haber G P, White M A, Autorino R, Escobar P F, Kroh M D, Chalikonda S, et al. Novel robotic da Vinci instruments for laparoendoscopic single-site surgery[J]. Urology, 2010, 76: 1279-1282.

[18] Kroh M, El-Hayek K, Rosenblatt S, Chand B, Escobar P, Kaouk J, et al. First human surgery with a novel single-port robotic system: cholecystectomy using the da Vinci Single-Site platform[J]. Surg Endosc, 2011 Jun 3. [Epub ahead of print]

[19] Dolghi O, Strabala K W, Wortman T D, Goede M R, Farritor S M, Oleynikov D. Miniature *in vivo* robot for laparoendoscopic single-site surgery[J]. Surg Endosc, 2011, 25: 3453-3458.

[20] Kobayashi Y, Sekiguchi Y, Tomono Y, Watanabe H, Toyoda K, Konishi K, et al. Design of a surgical robot with dynamic vision field control for single port endoscopic surgery[J]. Conf Proc IEEE Eng Med Biol Soc, 2010; 2010: 979-983.

[**Editor**] JIA Ze-jun

· 消　息 ·

Top 10 cited articles published in *Journal of Medical Colleges of PLA* in the last five years

Data from Scopus (on Oct. 10, 2011)

Ma L, Cai D, Li H, Tong B, Song L, Wang Y. Anti-fatigue effects of salidroside in mice. J Med Coll PLA, 2008, 23(2): 88-93.

Zhou Y, Li Y S, Pan F G, Liu Z S, Wang Z. The development and optimization of ELISA for the determination of tetrodotoxin. J Med Coll PLA, 2007, 22(6): 347-351.

Wang S, Jiang H, Chen J, Liu D, Li C, Pan B, An X, Zhang X, Zhou Y, Tong Y. Isolation and rapid genetic characterization of a novel T4-like bacteriophage. J Med Coll PLA, 2010, 25(6): 331-340.

Huo J, Zhou S W. New research on development of solid lipid nanoparticles. J Med Coll PLA, 2007, 22(6): 385-390.

Xin X. A model of Korotkoff sounds method electronic sphygmomanometer equivalent to the mercury one. J Med Coll PLA, 2010, 25(1): 19-23.

Shen X, Lv S, Zhang J, Li S, Gao J, Pan C. Effects of Res on proliferation and apoptosis of human cervical carcinoma cell lines C33A, SiHa and HeLa. J Med Coll PLA, 2009, 24(3): 148-154.

Cao L, Li X, Zhan J, Chen W. Automated lung segmentation algorithm for CAD system of thoracic CT. J Med Coll PLA, 2008, 23(4): 215-222.

Duan Z, Zhu G , Yang D, Zhang X, Gao Y. Molecular mechanism of Skp2 in promoting cervical cancer HeLa cell proliferation. J Med Coll PLA, 2008, 23(4): 199-208.

Guo S, Ren X, Jiang T, Ouyang Z. Effect of neurotrophin-3 on SOD and MDA in rats after acute spinal cord injury. J Med Coll PLA, 2007, 22(1): 28-30.

Jiang L, Wan X J, Xu H, Bian J J, Han W J, Zhu K M, Deng X M. Effect of diltiazem and lidocaine on arterial pressure or heart rate and the quality of extubation in patients undergoing uvulopalato-pharyngoplasty. J Med Coll PLA, 2007, 22(4): 230-233.

Journal of Medical Colleges of PLA (English edition, ISSN 1000-1948) is founded in 1986 and published bimonthly. It is cosponsored by the Second Military Medical University, Third Military Medical University, Fourth Military Medical University, and Southern Medical University. All of the four universities enjoy high reputation in medical science. The editorial office is in the Second Military Medical University in Shanghai. *Journal of Medical Colleges of PLA* publishes articles on basic medicine, clinical medicine, public health, epidemiology, military medicine, pharmacy, Traditional Chinese Medicine and emerging new areas. So far it has been indexed by several international and Chinese databases, including Chemical Abstracts (CA), VINITI Abstracts Journal, Index Copernicus(IC), Source Journal For Chinese Sci & Tech Papers and Citation. And the full text is available at Elsevier's ScienceDirect(*http://www.elservier.com/locate/ jmcpla*).

The journal publishes original articles, reviews, mini-reviews, case reports, and so on. We welcome your submissions to *Journal of Medical Colleges of PLA*.

E-mail: jydxxb@yahoo.com.cn

Address: 800 Xiangyin Road, Shanghai 200433, China

Tel: (86)21-81870783-818