5 Robotic Systems in Laparoendoscopic Single-Site Surgery

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Introduction

Despite the increasing interest in LESS worldwide, the actual role of this novel approach in the field of minimally invasive urologic surgery remains to be determined [1].

One major technical disadvantage in LESS is the "sword fighting" among instruments. During standard LESS, as laparoscopic instruments are inserted into the abdominal cavity through a single incision, there can be a tendency to cross them just below the abdominal wall to obtain a separation between instrument tips without external collision of the handpieces. This crossing of the instruments allows a better range of motion, but the resultant reversal of handedness introduces a major mental challenge for the surgeon.

Novel non-robotic systems have been tested to offer intuitive instrument maneuverability and restored triangulation without external instrument clashing, but their use remains experimental (Fig. 5.1) [2].

To overcome the current constraints of LESS, it has been postulated that robotic technology could be applied [3]. In 2009, Kaouk et al. reported the first successful series of single-site robotic procedures in humans, and the authors noted improved facility for intracorporeal dissecting and suturing because of robotic instrument articulation and stability [4]. Since then, there has been a growing interest from investigators in different surgical specialties.

In this chapter an overview of current and future robotic systems for application in urologic LESS is provided.

da Vinci® S and da Vinci® Si Platform

The da Vinci® surgical system was the first robotic system cleared by the Food and Drug Administration for use in general and urologic laparoscopic surgery. Some of its benefits over conventional laparoscopy include superior ergonomics, optical magnification of the operative field, enhanced dexterity, and greater precision.

It has been largely demonstrated by Kaouk and collaborators at the Cleveland Clinic that a variety of robotic LESS urologic procedures can be performed using different trocar configurations or purpose-built multichannel devices [5] (Fig. 5.2). In their initial experience, the da Vinci® S system

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Fig. 5.1 SPIDER™ Platform: this platform features a main body port/cannula, extended flexible instrument delivery tubes, four working channels, and ports for insufflation/smoke evacuation (Photo courtesy of Transenterix Inc.)

Fig. 5.2 Setup for robotic LESS prostatectomy using the da Vinci® Si platform and the SILS® multichannel port

was used. However, since the introduction of the Si system, this was preferred, given its enhanced visualization and ability to customize the console settings ergonomically. To reduce instrument clashing, instruments and, therefore, the robotic arms, were positioned parallel to the robotic camera. This subsequently required the camera lens and instruments to be moved in near unison to optimize range of motion.

To address limitations related to the coaxial arrangement of instruments, Joseph et al. [6] conceived a “chopstick” technique enabling the use of the robotic arms through a single incision without collision (Fig. 5.3). The robotic instruments cross at the abdominal wall to have the right instrument on the left side of the target and the left instrument on the right. 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 hand effector. In this way, collision of the external robotic arms is prevented.

da Vinci Single-Site® Platform

Intuitive Surgical developed a novel set of single-site instruments and accessories specifically dedicated to LESS (Fig. 5.4). The set includes a multichannel access port with room for four cannulas and an insufflation valve. Two curved cannulas are for robotically controlled instruments, and the other two cannulas are straight; one cannula is 8.5 mm and accommodates the robotic endoscope, and the other cannula is a 5-mm bedside-assistant port. The curved cannulas are integral to the system, since their configuration allows

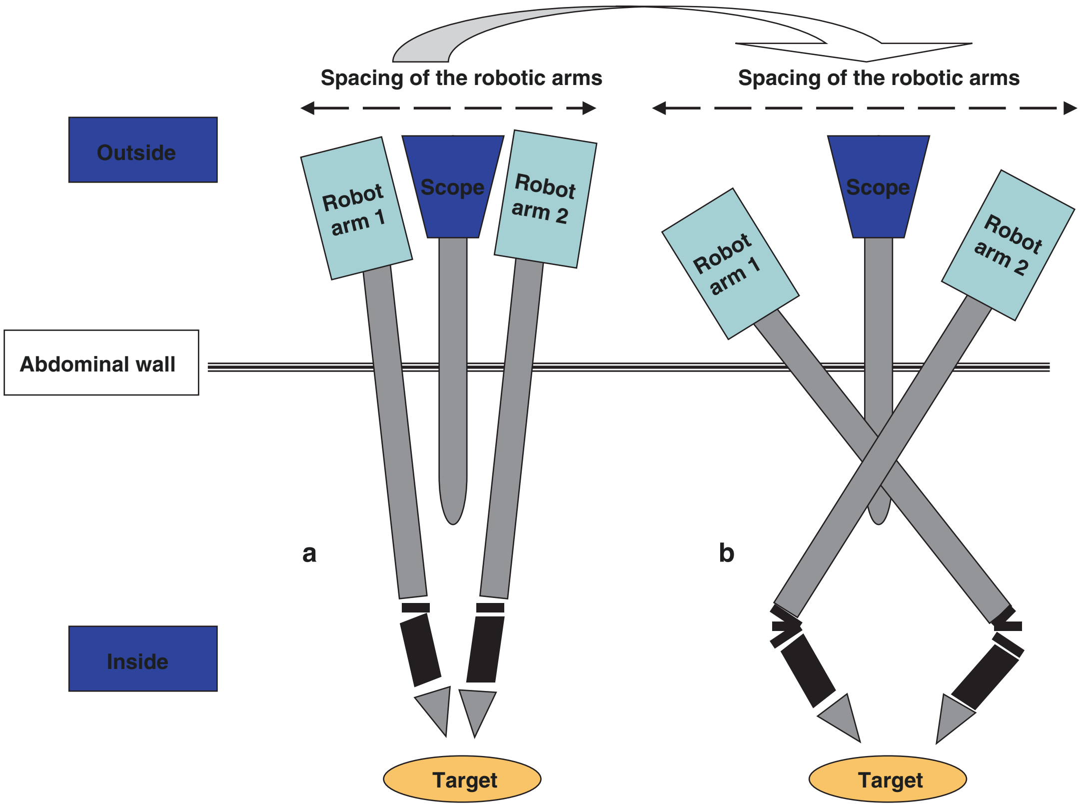

Fig. 5.3 Concept of "chopstick" surgery applied to robotic laparoendoscopic single-site surgery: (**a**) standard configuration and (**b**) chopstick configuration to minimize external clashing

the instruments to be positioned to achieve triangulation of the target anatomy. This triangulation is achieved by crossing the curved cannulas midway through the access port. Same-sided hand–eye control of the instruments is maintained through assignment of software of the Si system that enables the surgeon's right hand to control the screen right instrument even though the instrument is in the left robotic arm and, reciprocally, the left hand to control the screen left instrument even though the instrument is in the right robotic arm (Fig. 5.5). The second part of the platform is a set of semirigid, nonwristed instruments with standard da Vinci® instrument tips (Fig. 5.6).

The semirigid, flexible shaft allows for insertion down the curved cannula and triangulation of the anatomy. Robotic arm collisions are minimized externally because the curved cannulas angle the robotic arms away from each other. Internal collisions with the camera are avoided because the camera is designed to be placed into the middle of the curved cannula zone and is not in a parallel arrangement. The single-site instruments and accessories are intended to be used with the da Vinci® Si surgical system and are of similar construction to existing EndoWrist instruments, except they do not have a wrist at the distal end of the instrument.

Haber et al. described the first laboratory experience with VeSPA robotic instruments by assessing their feasibility and efficiency for urological applications [7]. Sixteen procedures (including four pyeloplasties, four partial nephrectomies, and eight nephrectomies) were performed without additional ports or need for conversions. During this feasibility evaluation, limitations of the platform were noted, including the lack of articulation at the tip of the instruments compared with the Endowrist™ instruments afforded by current da Vinci Si, making intracorporeal suturing more challenging.

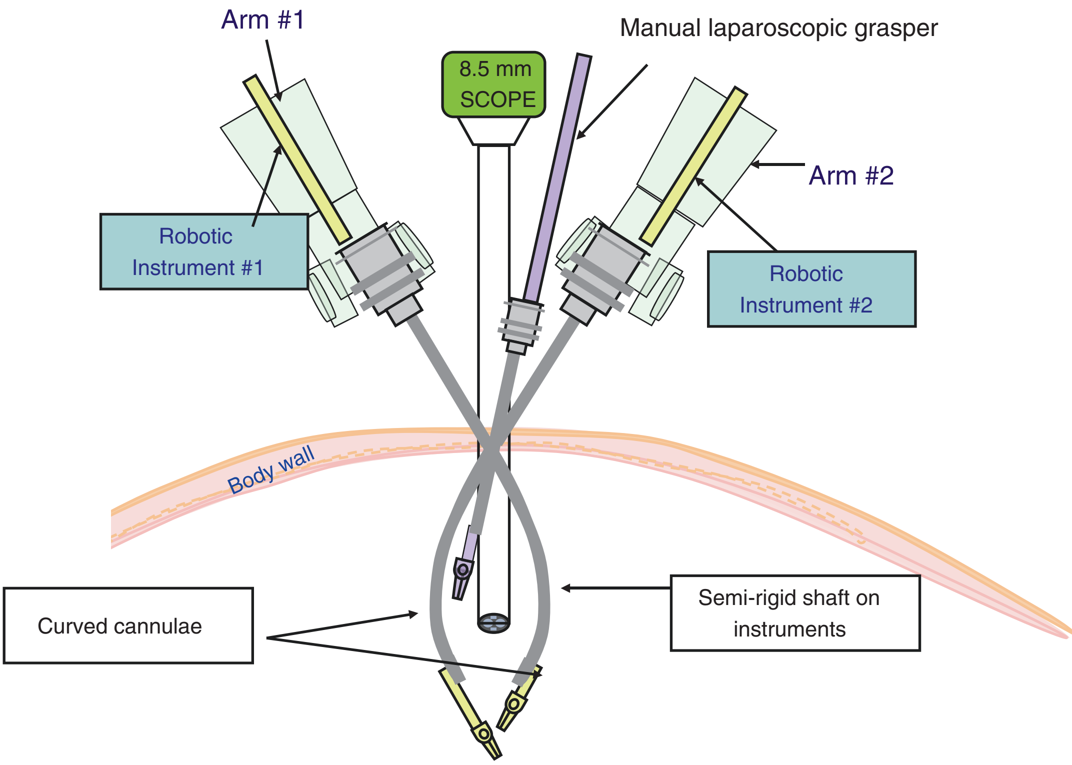

Fig. 5.4 da Vinci Single-Site® platform: schematic illustration

More recently, Kaouk et al. also reported the use of a second generation of da Vinci single-site instruments for robotic LESS to perform different kidney procedures in the cadaver model [8]. Three types of left side kidney procedures were successfully performed (one pyeloplasty, one partial nephrectomy, and one nephrectomy) in a female cadaver without the addition of extra ports.

Robotic Platforms for Single-Site Surgery: Open Issues

While the current da Vinci® system has shown to be a valuable ally in LESS, this is not what it was specifically designed for. The introduction of the da Vinci Single-Site® instrumentation has represented a step forward on one side, as it addresses some of the current drawbacks, mainly the clashing and lack of triangulation. However, the lack of EndoWrist® technology at the instrument tips, which probably has represented the main feature of robotic surgery as compared with standard laparoscopy, remains a major limitation. The ideal robotic platform for LESS should have a low external profile, the possibility of being deployed through a single-access site, and the possibility of restoring intra-abdominal triangulation while maintaining the maximum degree of freedom for precise maneuvers and strength for reliable traction. A number of robotic prototypes are currently being developed and might be available in the near future for urologic LESS applications.

SPORT™ (Single-Port Orifice Robotic Technology) Surgical System

This novel prototype developed by Titan Medical works via a 25-mm single-access port which contains two snakelike robotic instruments and a 3D HD camera. Once inserted into the abdomen, the camera and instruments can then extend into the abdominal cavity. Similarly to the da Vinci®, the

SPORT™ is a master/slave system operated by the surgeon through a special nearby console (Fig. 5.7).

SPRINT (Single-Port lapaRoscopy bImaNual roboT)

It has been developed within the ARAKNES (Array of Robots Augmenting the Kinematics of Endoluminal Surgery) program coordinated by Dario and Cuschieri and funded by the EU Framework 7 program [9]. This is a novel teleoperated bimanual robot specifically designed for single-access interventions. The system comprises two high-dexterity six DOF robotic arms, each one provided with a surgical tool, a stereoscopic camera, and a dedicated console for surgical tasks execution. The robotic arms may be placed inside the abdomen of the patient through a 30-mm access port (Fig. 5.8) [10].

At this stage of development, the SPRINT robot is less technically advanced than the da Vinci® system in terms of precision and easiness of surgical manipulation. However, it presents some unique features: it is intended to be assembled inside the patient and does not clutter the operating room to any extent; the surgeon operates closely to the patients within the sterile area and can intervene directly in the event of a major intraoperative complication, not relying on the assistant [11].

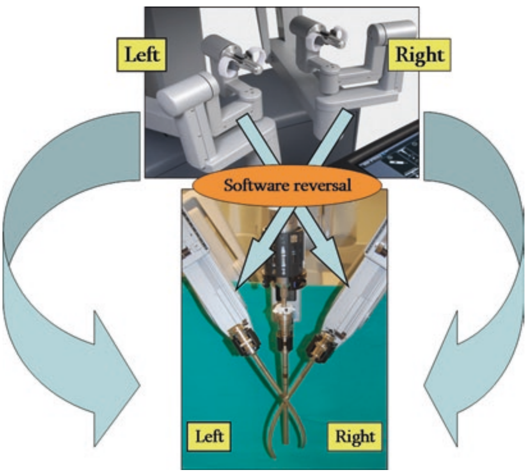

Fig. 5.5 Schematic explanation of the restored triangulation achieved through assignment of the Si system software that enables the surgeon's right hand to control the screen right instrument and, reciprocally, the left hand to control the screen left instrument

ALF-X (Advanced Laparoscopy Through Force-RefleCT(X)ion)

This system is the result of the research and development collaboration between the Italian pharmaceutical company SOFAR S.p.A. and the Joint Research Centre, the European Commission's in-house research body. The ALF-X is a four-armed surgical robotic system that uses eye tracking to control the endoscopic view and to enable activation

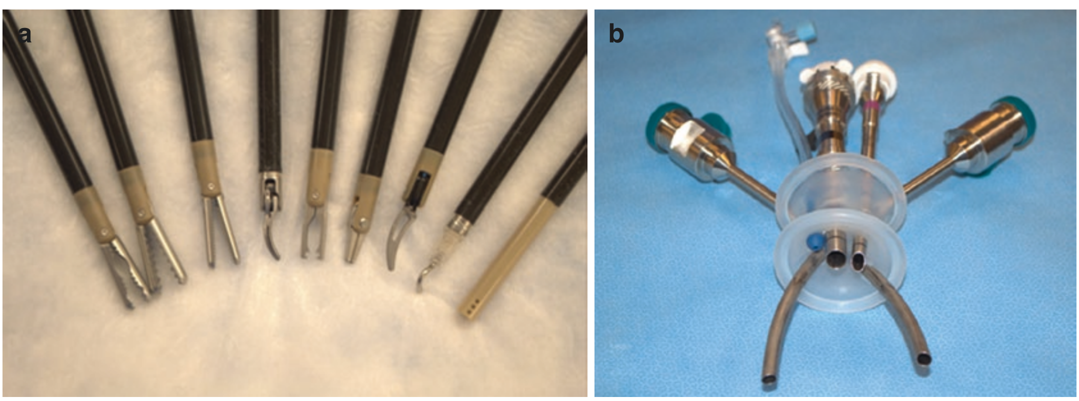

Fig. 5.6 Da Vinci Single-Site® instrumentation: (**a**) instruments; (**b**) the setup including the 8.5-mm camera, the two 5-mm robotic instruments through the curved cannulas, and the 5-mm assistant port, all inserted through the five-lumen port

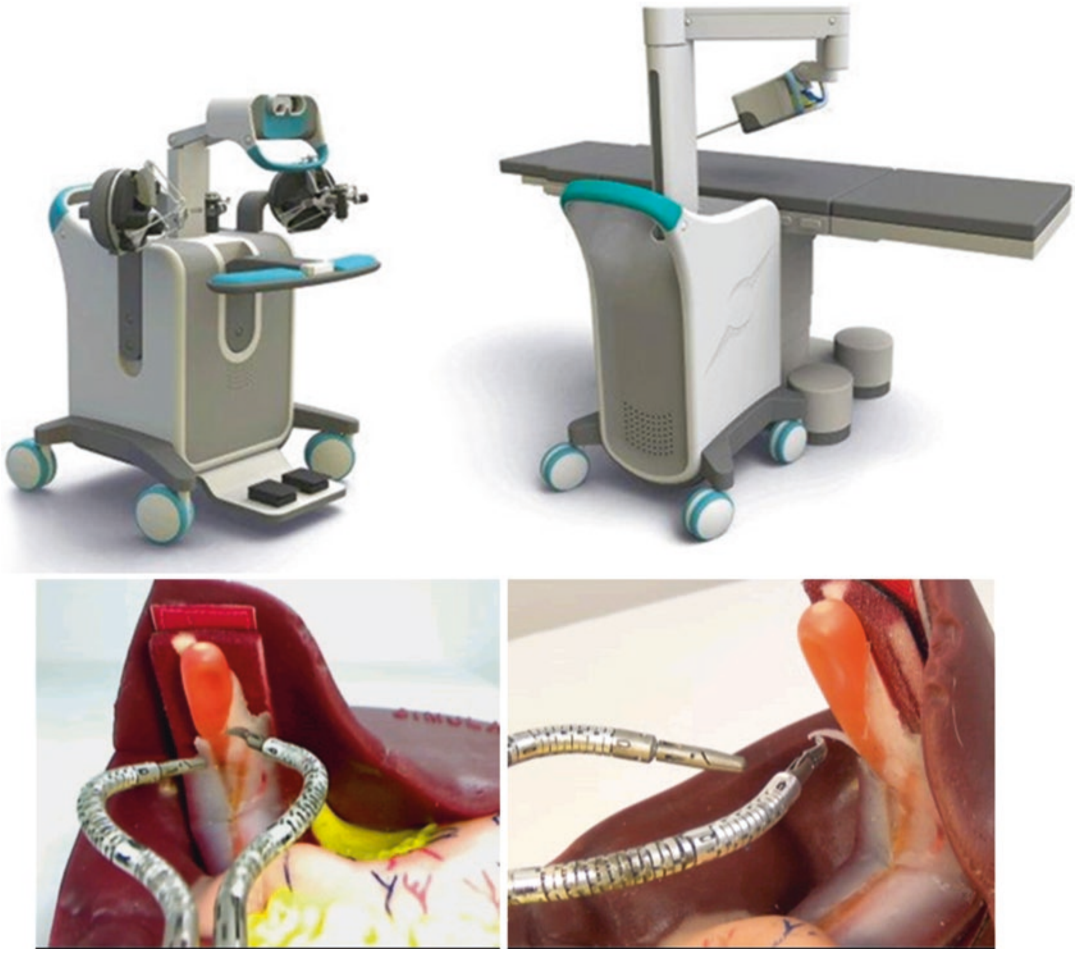

Fig. 5.7 SPORT™ (Single-Port Orifice Robotic Technology) Surgical System (Photos courtesy of Titan Medical Inc.)

of the various instruments. Compared to the da Vinci®, the system moves the base of the manipulators away from the bed (about 80 cm) and has a realistic tactile-sensing capability due to a patented approach to measure tip/tissue forces from outside the patient, with a sensitivity of 35 g (Fig. 5.9) [12].

HVSPS (Highly Versatile Single-Port System)

The concept of this platform is presented in Fig. 5.10. It features two hollow 12-mm manipulators that provide the introduction of flexible endoscopic instruments up to 4 mm and a double-bending 10-mm telescope [13]. Both manipulators and the telescope are inserted independently through an insert with three lumens. This ensemble is introduced gas tightly into the abdominal cavity using a 33-mm trocar and guided over a telemanipulator attached to the insert. The drive system is placed to the periphery, 2 m away from the patient.

IREP (Insertable Robotic End-Effectors Platform)

This platform can be inserted through a 15-mm trocar into the abdomen, and it uses 21 actuated joints for controlling two dexterous arms and a

Fig. 5.8 SPRINT robot. (**a**) Illustration of the insertion sequence into the patient abdomen: umbilical access port with the introducer, insertion of the first arm through the introducer, insertion of the second arm, the SPRINT robot in the operative configuration (Courtesy of Prof. Paolo Dario, Scuola Superiore Sant'Anna, University of Pisa, Italy)

stereo-vision module. Each dexterous arm has a hybrid mechanical architecture comprised of a two-segment continuum robot, a parallelogram mechanism for improved dual-arm triangulation, and a distal wrist for improved dexterity during suturing (Fig. 5.11) [14].

Waseda University Robot

A new surgical prototype robot is being developed and tested by investigators from Japan. The robot consists of a manipulator for vision control, and dual tool tissue manipulators can be attached at the tip of a sheath manipulator (Fig. 5.12) [15]. The diameter of the insertable component is approximately 30 mm, and this part in its folded and straight configurations can be inserted into the abdomen through a 30-mm skin incision. The diameter of the flexible endoscope is 5 mm. The diameter of the tool manipulator for gripping is 8 mm; for cautery, its diameter is 6 mm. The length of the sheath manipulator, which is a two DOF snakelike continuum manipulator, is 50 mm.

Fig. 5.9 ALF-X (Advanced Laparoscopy through Force-RefleCT(X)ion) (Courtesy of SOFAR spa)

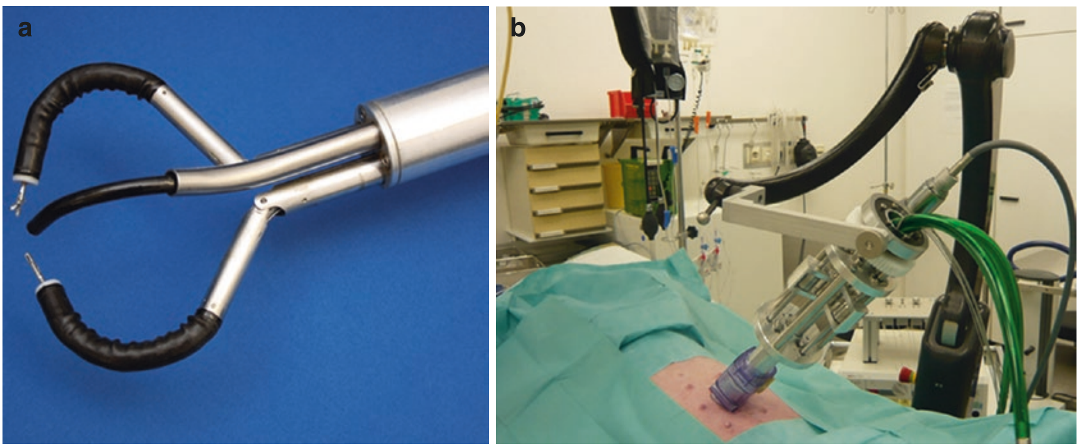

Fig. 5.10 (**a**) HVSPS (**b**) In vivo evaluation in an animal study (Courtesy of Research Group MITI, Klinikum r.d. Isar der TUM, Germany)

Nebraska University Robot

The group of Oleynikov is also developing a multidexterous miniature in vivo robotic platform that is completely inserted into the peritoneal cavity through a single incision (Fig. 5.13) [16, 17]. The platform consists of a multifunctional robot and a remote surgeon interface. The robot has two arms and specialized end effectors that can be interchanged to provide monopolar cautery, tissue manipulation, and intracorporeal suturing capabilities.

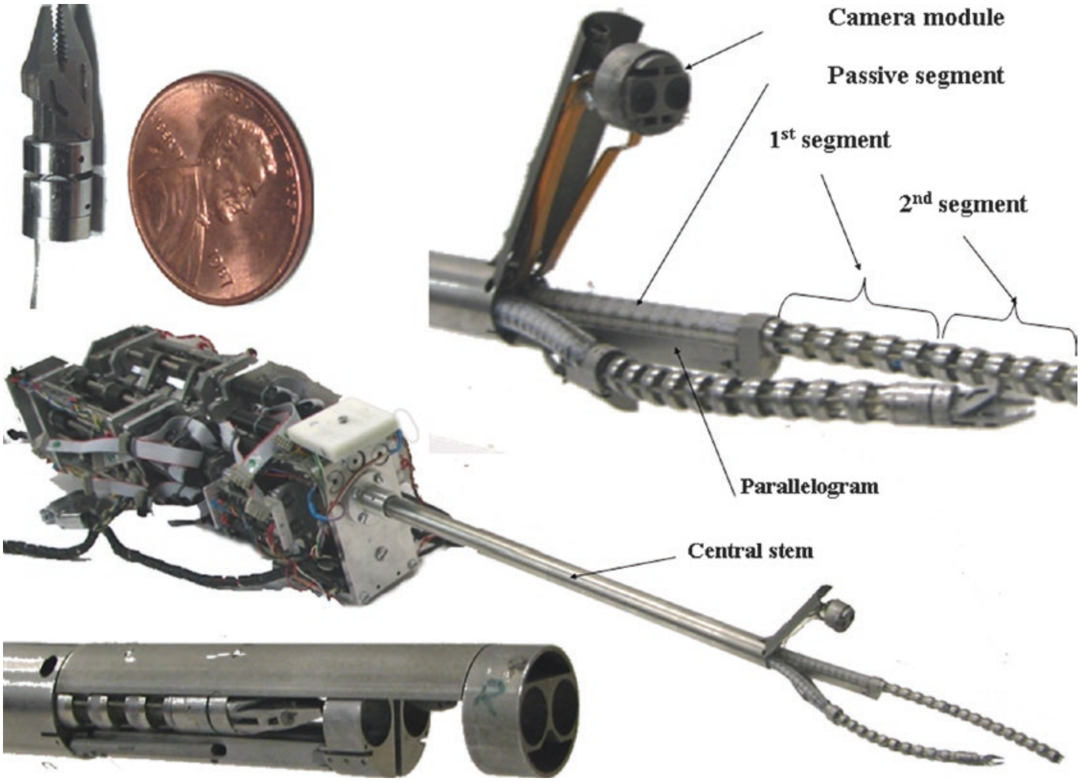

Fig. 5.11 The Insertable Robotic Effectors Platform (IREP) (Courtesy of Dr. Nabil Simaan)

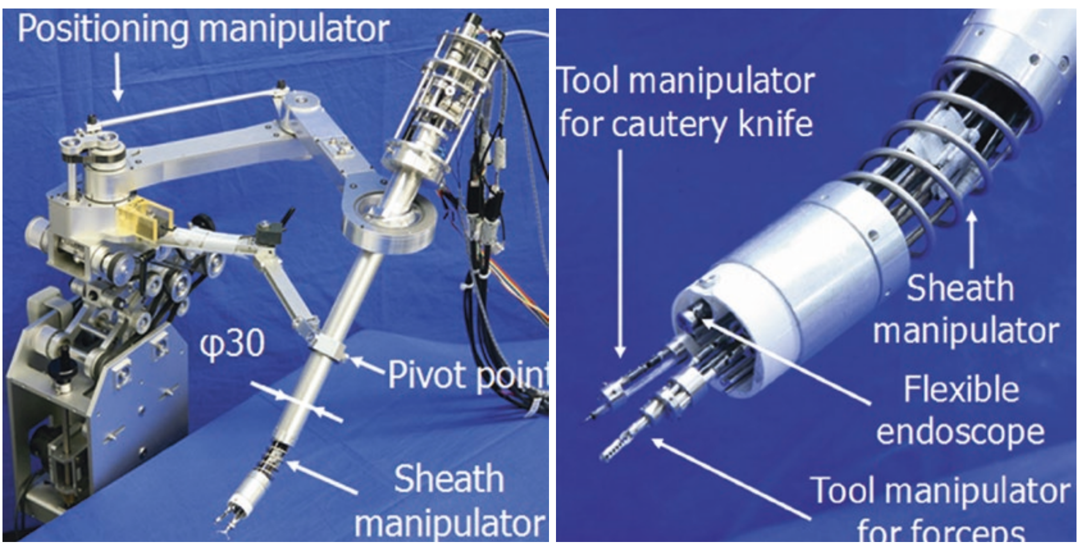

Fig. 5.12 Waseda University Robot (Courtesy of Dr. Yo Kobayashi, Waseda University, Japan)

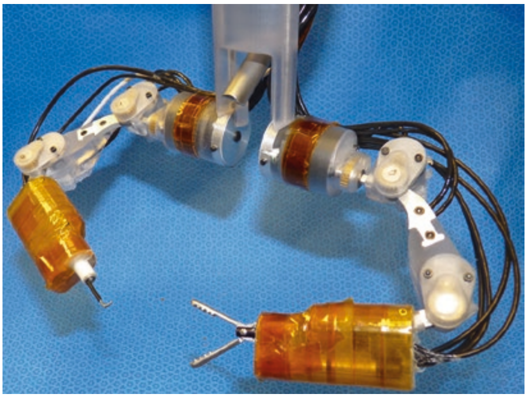

Fig. 5.13 Miniature robot for LESS (Courtesy of Drs Dmitry Oleynikov and Shane Farritor, University of Nebraska, Omaha, NE)

Conclusions

Significant advances have been achieved in the field of robotic LESS. The recent introduction of a purpose-built da Vinci® instrumentation represents a step forward. However, we are still far from the ideal robotic platform, as the currently available robot is bulky and not specific for what is necessary in single-site surgery. Further advances in the field of robotic technology are expected to overcome current limitations and provide the optimal interface to facilitate LESS.

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