Chapter 6

Handheld Devices for Laparoscopic Surgery

Francisco M. Sánchez-Margallo,
Juan A. Sánchez-Margallo and Amir Szold

Additional information is available at the end of the chapter

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Abstract

Despite the well-known benefits of minimally invasive surgery (MIS) to the patients, this surgical technique implies some technical challenges for surgeons. These technical limitations are increased with the introduction of laparoendoscopic single-site (LESS) surgery. In order to overcome some of these technical difficulties, new handheld devices have been developed, providing improved functionalities along with precision-driven and articulating instrument tips. In this chapter, we will review the current status of handheld devices for laparoscopy and LESS surgery. Devices that provide additional and innovative functionalities in comparison with conventional surgical instruments will be considered. Results will be based on studies published in the scientific literature and our experience. These surgical devices will be organized into two main groups, mechanical devices and robotic-driven devices. In general, these instruments intend to simulate the dexterity of movements of a human wrist. Mechanical devices are cheaper and easier to develop, so most of the available handheld instruments fall into this category. The majority of the robotic-driven devices are needle holders with an articulating tip, controlled by an interface implemented on the instrument handle. In general, these handheld devices claim to offer an enhancement of dexterity, precision, and ergonomics.

Keywords: handheld instruments, laparoscopic surgery, mechanical instruments, robotic instruments, robotic surgery

1. Introduction

The reduction of invasiveness in surgery has led to numerous benefits to the patients. However, minimally invasive surgery (MIS) implies some technical challenges for surgeons.

The less invasive the surgery, the more difficult it is to reach the surgical targets. MIS requires a close proximity of surgical instruments and the endoscopic camera, leading to a loss of instruments triangulation, restriction of maneuverability inside the abdominal cavity, and the adoption of uncomfortable body postures for long periods of time. These technical limitations are increased with the introduction of laparoendoscopic single-site (LESS) surgery, in which the freedom of movements of the surgical instruments is more restricted due to the single surgical access.

Conventional laparoscopic instruments have limited dexterity, making some surgical maneuvers challenging. The use of surgical ports creates a pivot point for the instruments in the body wall, which reduces the degrees of freedom (DoF) of the surgical instruments, from six (free motion) in conventional surgery to four in laparoscopic surgery, as illustrated in **Figure 1**. Besides, laparoscopic instruments suffer from ergonomically inadequate handle designs and inefficient transmission of force and tactile feedback from the handle to the instrument tip [1, 2].

All the aforementioned restrictions of surgeons' dexterity, in conjunction with the performance of repetitive tasks and the adoption of awkward and static postures during surgery, contribute to the onset of muscular fatigue and other musculoskeletal problems [2–4].

In order to overcome some of these technical limitations, new handheld devices have been developed for laparoscopic surgery and LESS surgery. These novel devices provide precision-driven and articulating instrument tips in combination with improved functionalities. They

Figure 1. Illustration of the four degrees of freedom when using laparoscopic instruments.

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aim at enhancing surgical dexterity, increasing instrument triangulation, and thus, improving the performance of certain surgical maneuvers. This optimization and improvement of the surgical instruments arise as a response to the complex surgical procedures that are now possible through laparoscopic and single-site surgical approaches.

Although there are other innovative alternatives such as the robotic surgical platforms (e.g., the da Vinci® Surgical System), these systems are associated with substantial financial and maintenance costs [5]. Therefore, a great interest in both academic and commercial institutions has arisen in creating devices that can provide some of the advantages of these robotic surgical platforms, but at a lower cost, filling the space between conventional surgical instruments and surgical robotics. In this context, innovative handheld laparoscopic devices have emerged. These devices are mainly divided into two categories: handheld mechanical instruments and handheld robotic devices. Systems falling into each category will be described in the following sections. This article will give an overview of the state-of-the-art in handheld instruments for laparoscopic surgery and LESS surgery. Only surgical instruments that provide a clear evidence of significant development and additional features when compared to conventional MIS instruments will be addressed.

2. Handheld mechanical instruments

Control interfaces for mechanical surgical instruments with articulating end effectors can be mainly classified as handle control, thumb control, and mixed control [5, 6]. For the handle control interface, the instrument handle is articulated relative to the instrument shaft, which makes the instrument tip steer. In the thumb control method, the movements of the instrument tip are controlled by a thumb interface generally paced on the instrument handle. The mixed control interface consists of a combination of the handle and the thumb control, including knobs and levers to control the instrument tip [6].

2.1. Laparoscopic surgery

Most of the handheld devices have been developed for their use during laparoscopic surgery. However, as it will be shown below in this section, some of them have been also tested in LESS surgery.

2.1.1. Radius r2 DRIVE (Tuebingen Scientific Medical GmbH, Tübingen, Germany)

The previous version of the r2 DRIVE instrument was the Radius Surgical System [7], which was a reusable needle holder with a shaft diameter of 10 mm but slightly shorter than conventional laparoscopic instruments with 50 cm in length. The r2 DRIVE instruments provide a 90-degree deflectable and infinite rotatable tip. They have a handle with a lever that deflects unidirectionally with respect to the shaft, in order to control the flexion of the instrument tip and a knob for the tip rotation, providing a total of seven DoF. One of the main advantages of the Radius Surgical System is that it can be sterilized and disassembled for cleaning. Improvements of this device over conventional laparoscopic instruments have been shown regarding safety and ergonomics [7]. However, it seems that the instrument is not very intuitive, and it requires a significant amount of practice to learn how to be used [8]. This instrument has already been tested in LESS surgery for suturing and ligation during a common bile duct exploration with C-tube drainage for choledocholithiasis [9] and for suturing during a laparoscopic transabdominal preperitoneal hernioplasty [10].

The new version, the r2 DRIVE, has a handle design similar to the Radius Surgical System and with the same mechanism of actuation but with a shaft diameter of 5 mm and the possibility of bipolar electrocautery [11]. A multifinger trigger on the handle operates the opening and closing actions of the jaws. The operating mechanism of this instrument is based on gears to deflect and rotate the end effector (**Figure 2**). This device enables to use different type of instruments, including scissors, dissectors and needle holder. However, the r2 DRIVE version is not sterilizable and has only one use.

There are no studies proving the feasibility of the r2 DRIVE instruments in an actual surgical setting. The technical utility and training effect of these instruments were evaluated during laparoscopic gastro-jejunal anastomoses in an ex vivo porcine model performed by a group of three experienced surgeons and four novices [12]. During this surgical task, execution time and anastomotic quality were analyzed. Results showed that after a limited number of cases, a stable mean anastomotic times and a fast learning curve were obtained.

2.1.2. FlexDex® (FlexDex Inc., Brighton, MI, USA)

The FlexDex® surgical instrument precisely translates the surgeon's hand, wrist, and arm movements from outside the patient into the respective movements of the end effector inside the patient's body in an intuitive manner. This instrument is based on a simple and mechanical

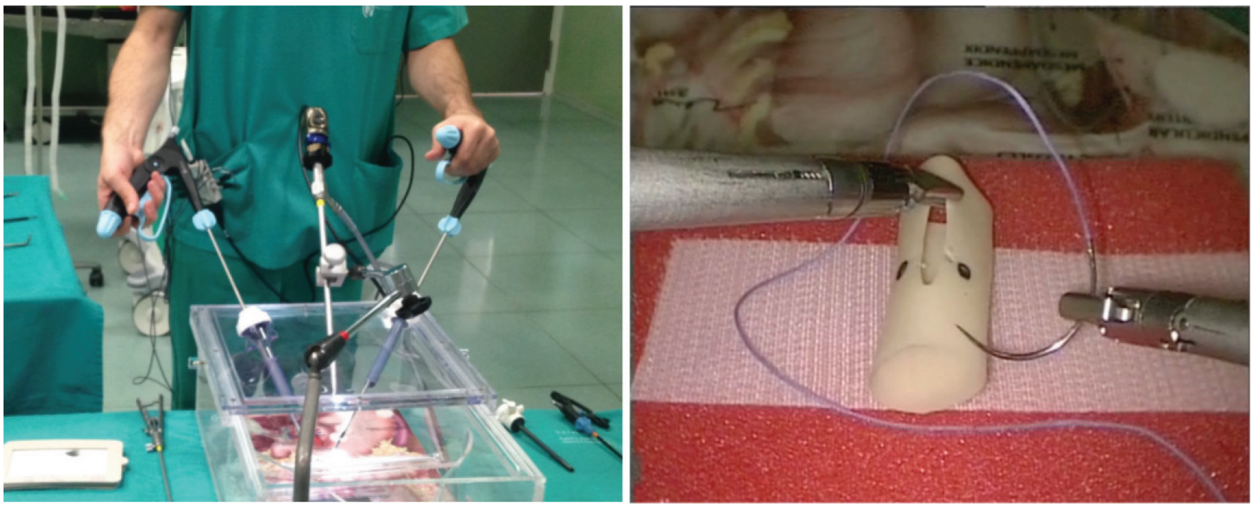

Figure 2. Use of the r2 DRIVE instruments on a box trainer (left). Performance of a laparoscopic suturing task (right).

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design with no electrical components. This has a tool frame attached to the user's forearm which acts as an interface to transmit the movements from the forearm, wrist, and hand to the instrument tip. This interface mechanism provides a direct transmission of the three translations and roll rotation of the surgeon's forearm to the tool shaft and the end effector. In addition, the two wrist rotations of the surgeon's hand are transferred to the end-effector via transmission strips, pulleys, and cables [13]. The opening and closing movements of the instrument tip are controlled by a thumb lever on the instrument handle. Consequently, it allows FlexDex® to provide similar degrees of freedom to the surgeon's wrist.

As regards limitations of this instrument, the use of the forearm-brace may be time consuming to wear for surgery and wear off when the surgeon wants to change the surgical instrument. Besides, the tool frame keeps the instrument shaft parallel to the forearm, which may conflict with other instruments, reducing the location options of the instruments' entry ports into the patient's abdominal cavity [5, 14].

Criss et al. presented the initial use of the FlexDex® needle holder in a case of a reoperative laparoscopic Nissen fundoplication in a 2-year-old male patient [14]. They reported that the instrument provides articulated and intuitive control and successfully enables suturing and knot tying in limited spaces. However, additional studies are needed in order to analyze the reliability and learning curve of this instrument. This device is a commercial product, but it is currently only sold in the territory of the United States.

2.2. LESS surgery

Conflict of instruments, lack of triangulation, and difficult retraction are some of the biggest factors that limit the use of current surgical instruments during LESS surgery [15, 16]. Most of the surgical instruments for laparoscopic surgery are not completely suitable for LESS surgery, hampering its use during surgery. Articulating instruments have been designed to deal with some of these challenges inherent in LESS surgeries, improving the triangulation of the instruments inside the patient. In this section, we will review some of the most popular mechanical handheld instruments for LESS surgery. We have kept outside of this article the pre-bent shape instruments. These instruments do not allow to change their shape during its use in surgery, and they do not provide other additional functionalities.

2.2.1. RealHand® (Novare Surgical System, Cupertino, CA, USA)

These handheld instruments have 5 mm of shaft diameter with a pistol handle with rings and wrist control. The end effector is cable-driven with reverse kinematic mapping, which enables 360 degrees of articulation and a total of seven degrees of freedom (DoF). The instruments comprise a cautery, a grasper, a dissector, and a ThermaSeal (seals and separates tissue). The instrument design has a locking mechanism that allows for its use as a regular straight instrument or with multiple DoF [15].

The use of these instruments was evaluated in 10 patients who underwent a laparoscopic-assisted vaginal hysterectomy for the treatment of stage I uterine cancer [17]. Results showed no intraoperative or postoperative complications and normal levels of blood loss. Surgeons indicated that the instrument articulation appears to allow for more accurate targeting of nodes. Another study analyzed the joint forces of this flexible instrument and compared them with the actual force required to secure surgical ties for the ureter, renal artery, and renal vein [18]. They concluded that the joint forces developed by articulating instruments are not sufficient to meet the usual operative needs.

2.2.2. SILS® Hand (Medtronic, Minneapolis, MN, USA)

The SILS® Hand instruments offer different articulated surgical devices specially designed for LESS surgery in the form of hook, clinch, shears, and dissectors. These instruments have a pistol handle with rings and an articulation lock lever. They provide, by means of a reverse kinematic mapping, infinite positions of dynamic articulation of the tip. The instrument shaft can be articulated up to 80 degrees, and the tip has 360 degrees of rotation [16]. These articulated instruments have been widely used in LESS surgery for procedures such as colectomy [19], myomectomy [15], and partial nephrectomy [20], among others.

2.2.3. Radius r2 CURVE (Tuebingen Scientific Medical GmbH, Tübingen, Germany)

These instruments are 10-mm disposable instruments, which have a curved rotatable shaft, expressly designed for LESS surgery. As the r2 DRIVE version, these instruments have the same handle design and actuation mechanism, providing a 90-degree deflectable and infinite rotatable tip [21]. The flexion of the instrument tip is performed by deflecting the instrument handle and its rotation by using the knob on the handle. The specific shaft/tip design helps to avoid conflicts between instruments and the laparoscope during surgery, avoiding to occlude the view of the surgical field.

The feasibility of using this type of instruments was tested during LESS nephrectomy in a porcine model [12]. All LESS nephrectomies performed in a total of three pigs using the r2 CURVE instruments were successful without major complications. No conflicts between the handles of the two instruments used were reported. Besides, in order to avoid potential clashes between the camera and the instrument handles, an extra-long laparoscope was used during surgery.

2.2.4. Autonomy Laparo-Angle® (Cambridge Endoscopic Devices, Framingham, MA, USA)

This articulating instrument has a sword-like ergonomic handle shape, with reverse kinematic mapping between the instrument handle and the end effector, a 5-mm instrument shaft, and a flexible instrument tip. The axial rotation of the instrument tip is controlled by a knob mechanism implemented on the handle. This instrument has a locking system of the angle of flexion integrated in the handle. This may reduce the surgeons' muscle fatigue when they have to keep the instrument flexed. The distal instrument tip bends at any direction and turns 360 degrees at any angle, allowing for seven DoF. Unlike other flexible instruments for LESS surgery, this instrument enables to rotate, open and close the distal jaws after locking the instrument [15].

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A retrospective study presented by Kim et al. [22] analyzed the medical records of 59 patients who underwent a myomectomy through a LESS approach and 59 patients using a traditional multiport approach. For the LESS myomectomy, surgeons used the Autonomy Laparo-Angle® for intracorporeal suturing, in combination with a handmade surgical port made out of a surgical glove and commercial trocars. In order to consider the surgeon's learning curve, records for the LESS approach were collected after 100 surgeries performed. Both approaches obtained similar results as far as operative time, estimated blood loss, postoperative hemoglobin drop, postoperative hospital stay, and postoperative pain scores are concerned.

3. Robotic-driven devices

Novel motor-driven, handheld devices that offer improved handle designs, functionalities, and precision-driven articulating end effectors have recently been introduced on to the medical market. The interface to control the instrument tip and other functionalities is usually located on the instrument handle. Some of these devices also allow surgeons to adjust the speed of the instrument movements according to their preference.

3.1. Laparoscopic surgery

3.1.1. Robot DEX™ (Dextérité surgical, Annecy, France)

This robotic instrument is a motor-driven laparoscopic needle holder, available on the market with a 10-mm instrument shaft. This consists of a console, a wired ergonomic handle, and a flexible tip with unlimited rotation. The flexion and rotation of the instrument tip are controlled by an interface on the handle. The instrument handle is a grip-type handle, which is connected by a mechanical joint to the instrument shaft. This grants surgeons greater freedom of movements, since the handle works independently from the shaft, which helps avoid forced movements of the wrist. This surgical tool provides a total of seven DoFs [23].

This device has been tested during a set of three different intracorporeal suturing tasks on a box trainer [23]. Precision using the surgical needle, quality of the intracorporeal suturing performance, execution time, and leakage pressure for the urethrovesical anastomosis, as well as the ergonomics of the surgeon's hand posture, were analyzed and compared with the use of a conventional laparoscopic needle holder. Results showed that, although both instruments offer similar technical performance, the robotic-driven instrument results in better ergonomics for the surgeon's hand posture during intracorporeal suturing. Besides, we recently conducted a study in which five experienced laparoscopic surgeons performed an urethrovesical anastomosis in a porcine model using the DEX™ system (unpublished study) (**Figure 3**). Participants used both a conventional axial-handled laparoscopic needle holder and the robotic instrument. Execution time, surgeon's posture, and pressure exerted by the surgeon's hand were assessed. Results revealed that the DEX™ system led to better ergonomics for the surgeon's hand, without differences in muscle fatigue between instruments. The robotic device required applying less pressure on the handle by the surgeons during surgery.

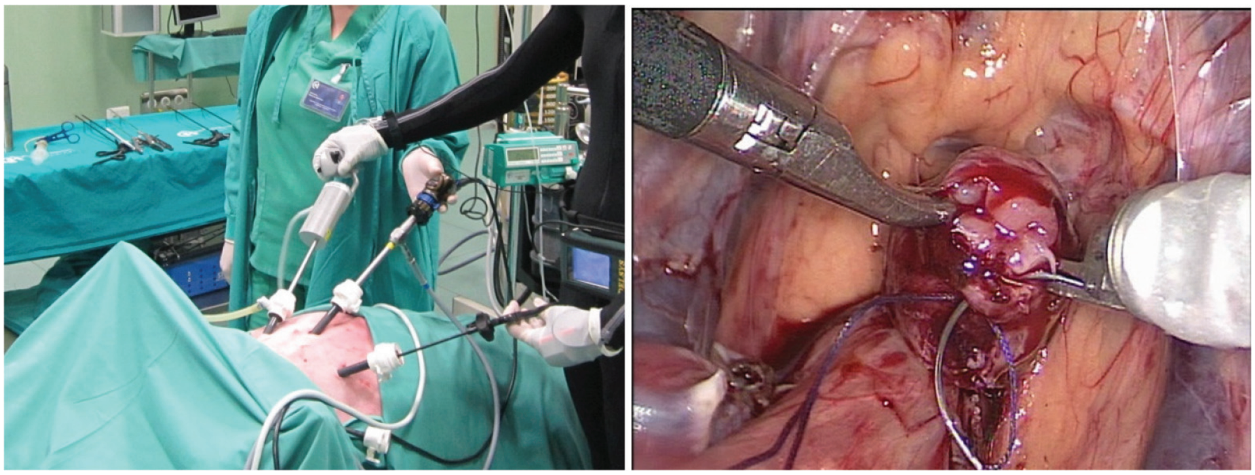

Figure 3. Use of the Robot DEX® robotic needle holder during an urethrovesical anastomosis in a porcine model.

3.1.2. JAiMY (Endocontrol, Grenoble, France)

This device is a 5-mm robotized needle holder available on the market with two additional intracorporeal DoF: yaw and roll. This instrument has a joystick placed on the handle to control the end effector, which can be used by right-handed and left-handed surgeons. The instrument tip can be bent up to 80 degrees and rotated, including speed control, by means of the joystick on the instrument handle.

Bensignor et al. [24] evaluated the effect of this instrument on the surgeon's skills and ergonomics during the performance of three basic suturing tasks on simulator. Performance outcomes, skills outcomes, and ergonomics were assessed. Performance outcomes were measured using a quantitative and qualitative score, and skills outcomes were measured by the number of movements and the path length traveled by the instrument. The RULA method was used for the surgeon's postural analysis [2, 25]. Muscular activity was assessed by means of electromyography of six muscular groups. The performance score was higher for the conventional instrument during the peg transfer task and for the JAiMY® instrument during the frontal suture task. Results showed an improved posture using the robotic instrument, but the muscular workload was lower for the conventional needle holder regarding the flexor carpi ulnaris and the triceps. The flexor carpi ulnaris is used for the opening and the closing of the jaws through the instrument trigger. The total path traveled by the instrument during the three tasks was shorter with the robotic device. Another study showed that an end effector with additional degrees of freedom combined with improved handle design increases ergonomics during laparoscopy and facilitates the performance of complex gestures [26].

3.1.3. Kymerax™ (Terumo Europe NV, Leuven, Belgium)

The Kymerax™ system is a handheld laparoscopic instrument with articulating and interchangeable instruments (scissors, dissector, needle holder, and L-hook) with a shaft diameter

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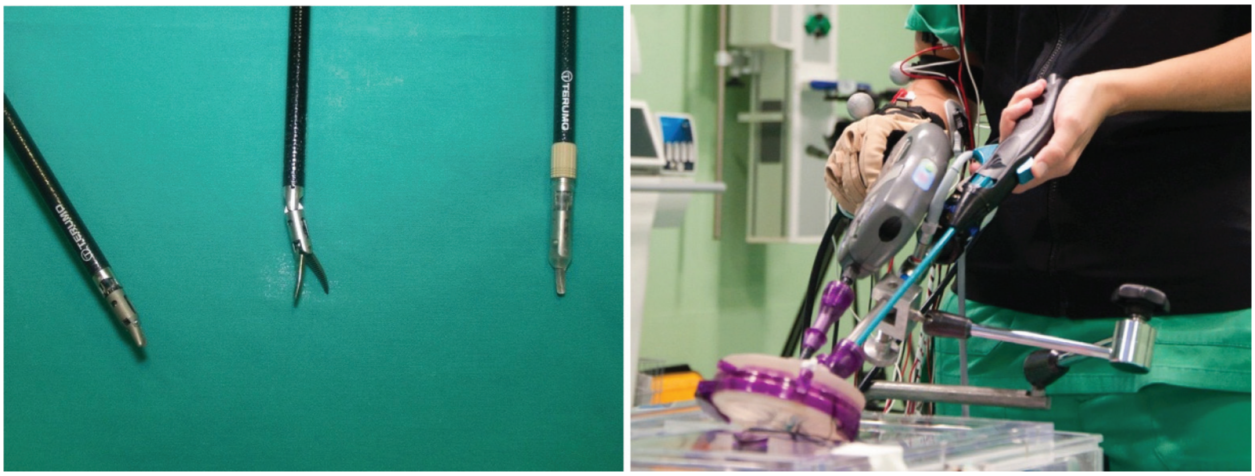

Figure 4. Interchangeable instruments (needle holder, dissector, and scissors) of the Kymerax® system. Use of the robotic device during LESS training tasks on a box trainer.

of 8.8 mm, which are driven by robotic technology (**Figure 4**). Surgeons control the movements of the instrument tip through the joystick interface implemented on the handle.

The efficacy of this robotic instrument has been tested with the European training in basic laparoscopic urologic skills (E-BLUS) and anastomosis tasks on a box trainer [27, 28]. During these tasks, surgeons used both 2D and 3D visualization systems. Results of this study showed that the combination of this device with 3D visualizing system led to a more successful completion of E-BLUS tasks for the novice surgeons and an increase of performance and quality of tasks during the anastomosis. Although surgeons rated the weight of this instrument as appropriate [27], analysis of the muscular intervention revealed a higher activity of the biceps muscle using the robotic device in comparison to a conventional needle holder, which may be associated with the increase of weight of this instrument [29].

This robotic device has been also used during clinical cases in laparoscopy. The first clinical use of this device in gynecological laparoscopy for malignant disease was described by Iacoponi et al. [30]. They presented the use of the Kymerax® instrument during laparoscopic hysterectomy for uterine sarcoma. They reported an operative time of 80 min, which is comparable to the time required for conventional laparoscopy, but less than the time required for robotic surgery [30, 31]. This robotic device has also been successfully used in LESS urological surgery [29, 32]. These studies will be discussed in the next section.

3.2. LESS surgery

The number of handheld robotic devices, excluding robotic platforms, specifically designed or employed in LESS surgery is scarce. The only robotic device commercially available that has been used during LESS urological and digestive procedures is the Kymerax™ system.

Device	Type	Instrument	Handle	DoF	Diameter (mm)	Clinical setting	Tasks/ procedures	References
Autonomy Laparo-Angle® (Cambridge Endoscopic Devices, Framingham, MA, USA)	Mechanical	Needle holder	Pistol	7	5	OR	LESS myomectomy	[22]
FlexDex® (FlexDex Inc., Brighton, MI, USA)	Mechanical	Needle holder	Forearm mounted	6	—	OR	Laparoscopy Nissen fundoplication	[14]
Jaimy® (Endocontrol, Grenoble, France)	Robot-driven	Needle holder	Pistol	6	5	Box trainer	Peg transfer Suturing tasks	[24]
Kymerax® (Terumo Europe NV, Leuven, Belgium)	Robot-driven	Scissors Dissector Needle holder L-hook	Pistol	5	8.8	Box trainer Ex vivo porcine model OR	European training in basic laparoscopic urological skills (E-BLUS) Anastomosis tasks Laparoscopic hysterectomy LESS partial nephrectomy LESS sigmoidectomy LESS radical prostatectomy	[27–30, 32]
r2 CURVE (Tuebingen Scientific Medical GmbH, Tübingen, Germany)	Mechanical	Scissors Dissector Needle holder	Pistol with a lever mechanism	7	5	Animal model	LESS nephrectomy	[12]
r2 DRIVE (Tuebingen Scientific Medical GmbH, Tübingen, Germany)	Mechanical	Scissors Dissector Needle holder	Pistol with a lever mechanism	7	5	Box trainer Ex vivo porcine model	Cutting and suturing tasks Gastro-jejunal anastomoses	[12]
RealHand® (Novare Surgical system, Cupertino, CA, USA)	Mechanical	Cautery Grasper Dissector ThermaSeal	Handle with rings	7	5	OR	Laparoscopic-assisted vaginal hysterectomy	[18]
Robot DEX® (Dextérité Surgical, Annecy, France)	Robot-driven	Needle holder	Grip-type	7	10	Box trainer	Precision task Suture on porcine stomach Urethrovesical anastomosis	[23]
SILS® Hand (Medtronic, Minneapolis, MN, USA)	Mechanical	Dissector Sears Clinch Hook	Handle with rings	7	5	OR	Colectomy Myomectomy Partial nephrectomy	[15, 19, 20]

Table 1. Summary of the handheld surgical instruments for laparoscopic and LESS surgery.

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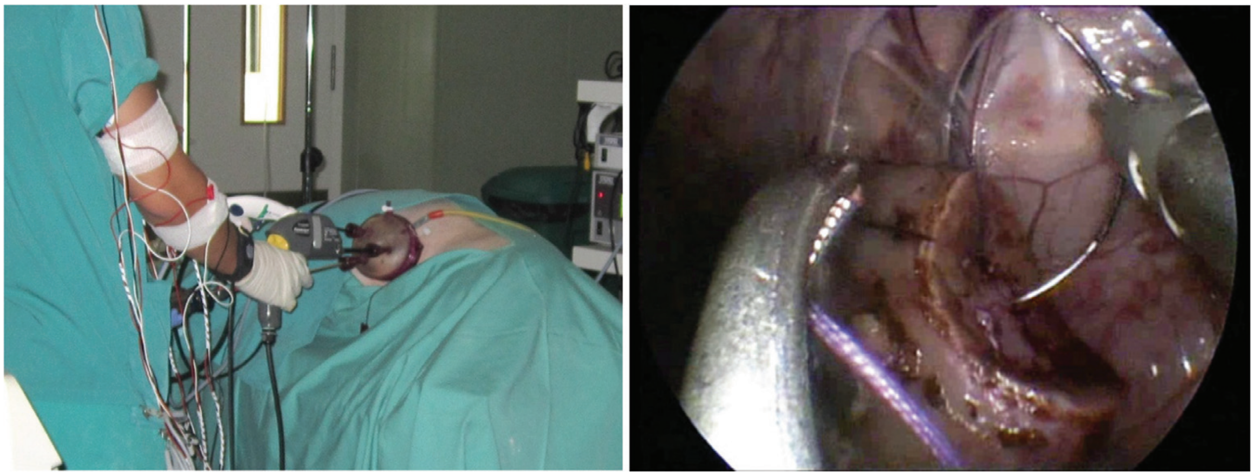

Figure 5. Partial nephrectomy in a porcine model using the Kymerax™ device.

Apart from the previous studies in laparoscopic surgery, the feasibility of this handheld robotic device has been also proved in LESS surgery [29]. The surgeon's performance and ergonomics using this robotic system during intracorporeal suturing tasks and digestive and urological procedures using a LESS approach were assessed. Surgeons performed an urethrovesical anastomoses on a simulator using an ex vivo porcine bladder, and a partial nephrectomy and a sigmoidectomy, in an in vivo experimental porcine model (**Figure 5**). Execution times, leakage pressure for the anastomosis, surgical complications, and surgeons' muscle intervention were measured and compared with the use of conventional laparoscopic instruments. Results showed similar outcomes in surgical performance and ergonomics using conventional laparoscopic instruments and the handheld robotic device. Muscle activity of the biceps was significantly higher using the robotic instrument during both surgical procedures. This may be due to the increased weight of the robotic device. Pérez et al. also presented a video article describing a laparoendoscopic hybrid single-site radical prostatectomy assisted by the Kymerax™ system [32]. The reported negative surgical margins and 0.03 ng/mL of PSA for the first month postoperative.

Table 1 shows a summary of the handheld devices analyzed in this chapter, including some of their main features and their relevant associated studies.

4. Other handheld devices

In this section, we will review the handheld devices for laparoscopic surgery that are still in a prototype phase or there is a lack of studies that demonstrate their feasibility in surgery.

4.1. Intuitool (University of Nebraska, Lincoln, NE, USA)

This laparoscopic instrument is a prototype with an ergonomically designed handle. This device has a thumb trackball placed on the instrument handle to control the end effector, which enables up to 60 degrees of articulation. The opening and closing actions of the jaws are controlled by a trigger implemented on the handle.

Trejo et al. [33] conducted a user study to evaluate this prototype. They found that 58% of the respondents believed the Intuitool would relieve hand/wrist pain due to inappropriate postures, and 53% believed the tool would reduce hand/wrist stiffness. In another study, Rousek et al. [34] analyzed different configurations in order to implement an electrosurgical hand control on the instrument handle. They sought preventing from causing poor ergonomic posture and physical discomfort due to the electrosurgical equipment operated by means of one or more foot pedals [34].

4.2. Hand-Held Robotic Device for Laparoscopy (University of Minho, Braga, Portugal; Polytechnic Institute of Cavado and Ave, Barcelos, Portugal)

This is a robotic device that includes disposable instruments with a bipolar system. The device weighs 730 g, has two speed modes (normal and fast speed), and can operate with a battery [35]. The rotation of the instrument tip is controlled by a joystick placed on the left side of the instrument handle. Surgeons interact with this joystick using their thumb. This device was designed only for right-handed surgeons. Besides, this only provides one additional DoF and the instrument tip cannot be flexed.

This robotic instrument in combination with 3D laparoscopic vision was tested by 26 surgeons during the performance of three basic laparoscopic tasks in a box trainer such as peg transfer, wire chaser, and knot tying [35]. Results showed that this device helps novice surgeons in reducing the time to complete the laparoscopic knot tying task. Novice surgeons stated that the combination with three-dimensional vision made their laparoscopic performance easier.

4.3. The Human Extensions Tool (Human Extensions, Netanya, Israel)

This instrument consists of a handheld electromechanical system that can support several end effectors with articulating tip. The system is cordless, lightweight, does not require any set up time, and can be easily moved between laparoscopic trocars and perform complex movements in a wide variety of complex minimally invasive operations. The instrument is composed of a sophisticated user interface that enables unrestricted hand movements. The surgeon operates the tools by using natural hand motions as if he/she was performing direct manual surgery on the patient.

4.4. OptiGrip™ (Endoscopic Force-reflecting Instruments B.V., Malden, The Netherlands)

This is the first grasper with haptic feedback for laparoscopic surgery. The main aim of this technology is to overcome the lack of tissue feedback in laparoscopic surgery when compared to traditional open surgery. This instrument translates the viscoelastic tissue feeling from the instrument tip to the trigger of the handle, resulting in more control and safer tissue manipulation. The instrument handle is available in small and large sizes to optimally fit in hands with different anthropomorphic features. This device can be set to different sensitivity levels for specific tissue types and with different visco-elastic properties. A study showed that enhanced haptic feedback may reduce the interaction force between instrument and tissues during surgery. Therefore, this may lead to less tissue damage, fewer complications, shorter operation times, and improved ergonomics [36].

4.5. Articulated Universal Joint for Minimally Invasive Surgery (Imperial College London, London, UK)

This is an articulated robotic device based on universal joints with embedded micromotors for minimally invasive surgery. This device provides a flexible tip with seven DoF, and it has two internal channels of 3 mm of diameter, one for an on-board camera for visualization and the other for passing interventional instruments. The articulated design allows the robot to explore the large areas of the peritoneal cavity. The handle can be decoupled from the articulated shaft, so it can be used to manipulate other instruments when it is necessary. The surgeon interacts with the instrument by means of a handle featuring a thumb-stick with an embedded push switch [37].

This handheld device has been used during a natural orifice transluminal endoscopic surgery (NOTES) tubular ligation procedure on an ex vivo model [37]. Surgeons reported some complications passing an endoscopic clip through the instrument channel due to the sharp edges at the tip. They solved the problem replacing the internal sheath of the instrument.

4.6. Maestro (Vanderbilt University, Nashville, TN, USA)

This prototype for laparoscopic surgery has been developed at the Vanderbilt University, and one of its main features is that it allows both parallel and reverse kinematic mappings between the instrument handle and the tip [5]. The end effector of the instrument is driven by tendons, and the open and close actions of the jaws are controlled by squeezing the two handle arms toward one another. This device also includes a locking mechanism for suturing tasks.

5. Discussion

Despite the numerous advantages associated with minimally invasive surgery (MIS), there are some technical limitations during its practice. These constraints are, in some cases, augmented by the use of novel surgical techniques such as LESS surgery. In this sense, the application of technology in surgery can make a huge contribution in order to address some of these limitations, such as the development of novel handheld devices for MIS with articulating end effectors. Handheld steerable instruments are preferred by surgeons due to their maneuverability during surgical procedures [6]. In general, the handheld surgical instruments presented in this chapter provide cost-effective methods of articulation, increasing the surgeon's intra-abdominal DoF. Most of these devices are articulated manual laparoscopic instruments which provide wrist-like dexterity to surgeons. These new mechanical and robotized handheld devices seem to be the future of MIS as they can increase both ergonomics and dexterity, resulting in an improvement of the quality of the surgical procedure.

Previous research has shown that ergonomics of the instrument handle influences on the task performance achieved with articulating laparoscopic instruments [38]. In this sense, Zahrahee et al. suggested that a finger-operated joystick control handle is easier to use and leads to a less fatigue than an articulating handle such as the RealHand® [39]. Besides, Fan et al. found no differences between thumb control and wrist control in terms of task performance [40]. We consider that it is fundamental to analyze the effect of a novel surgical instrument on the surgeon's ergonomics and performance. In this regard, several studies have been published for some of the handheld instruments that have been recently introduced in the market [23, 24, 29]. However, we consider that these studies should be done at an early stage prior to the final production and market launch.

Regarding the kinematic mapping of the mechanical instruments, the best direction of kinematic mapping is currently under discussion. For surgical approaches such as LESS, where instrument shafts must be near, parallel, and close to one another, a parallel mapping can potentially reduce the risk of the conflicts between instruments [5].

Both the instrument joints and the user interface for controlling the end effector are crucial aspects for the application of handheld articulating instruments in MIS. Flexible instruments with one or two steering segments at the tip allow for six DoF in the surgical scenario. Multiple steering segments can shape curved pathways inside the patient's abdominal wall. However, the development of multisegmented maneuverable instruments is still at an early stage [6]. Regarding the user interface, some instruments rotate the shaft itself, while others rotate the end effector using internal mechanisms controlled by a thumb knob or a wheel. In the case of the robotic devices, they operate the rotation of the instrument tip by means of a set of controls implemented on the handle.

Concerning the mechanical handheld instruments, not all of them incorporate a locking mechanism, which can be an inconvenient for some surgical tasks such as suturing. One positive aspect of using robotic-driven instruments is that surgeons can keep the instrument jaws closed without high physical demand. This action is assisted by the electromechanic technology of these devices.

The articulating power of articulating instruments is usually considered as suboptimal [18, 41]. Some of these instruments have some limitations to maintain the configuration of the instrument joints to grasp, carry, and transmit force [18]. Therefore, many surgeons prefer to use an articulating laparoscopic instrument in one hand and a conventional laparoscopic instrument in the other hand. One of the main reasons for this shortcoming is that articulating mechanisms are similar to those used for flexible endoscopes, so they are based on bendable plastics, steered by wires [18]. Some alternatives have been developed to cope with this problem such as solid joint frameworks, motor driven technologies, or pre-bent instruments. The main limitation of the latter is that they have limited degrees of freedom, which make some complex surgical maneuvers difficult to be accomplished [18].

Thanks to robotic technology, laparoscopy can offer equivalent wrist motion and three-dimensional vision as open surgery. However, although haptic technology has evolved a lot in the last 10 years, it is still in its early stages. Besides, this is still unclear how to certify haptic feedback as completely safe and stable. The main difference between handheld surgical devices, including mechanical instruments and some of the robotic-driven instruments, and telemanipulated surgical systems such as da Vinci is that handheld devices provide haptic feedback during the surgical performance. For instance, in suturing, haptic feedback offers fundamental information about the tension during the knot tying [24]. There are some laparoscopic devices in the market, for example the OptiGrip® grasper, that provide innovative solutions to deal with this lack of this haptic sense in minimally invasive surgery.

The learning curve is another crucial aspect when new surgical instruments are introduced in the field of surgery. In this regard, experienced surgeons have a tendency to obtain better results in surgical performance with a traditional surgical instrument [24]. This fact can be explained because expert surgeons have more experience with the classic instruments, which takes longer to learn new gestures and maneuvers for the new devices. For instance, during suturing tasks, experienced surgeons usually have a tendency to use the rotation of the forearm, even if the surgical instrument includes some kind of rotation mechanism [24]. Results from a retrospective study suggested that proficiency in LESS myomectomy using the RealHand® or the Laparo-Angle® (for suturing) is achieved after about 45 operations [42]. Therefore, the introduction of new handheld devices in surgery may require a training period in order to reach the appropriate level of surgical competence.

Many of the presented handheld instruments for minimally invasive surgery are still in early stages of development. Further efforts should be done in order to improve their functionality and make them more institutive and easy to use. A consensus on basic principles that make surgical instruments versatile and easy to use should be established. Ergonomic guidelines on the instrument handle design have been previously described by several studies [43–45]. Besides, innovative solutions to exploit the full potential of LESS surgery and address some of their technical limitation for surgeons should be explored.

6. Conclusions

In this chapter, we have reviewed some of the most extended handheld devices available in the market and described in the scientific literature for laparoscopy and LESS surgery. These devices seek to increase the surgeon's dexterity, precision, and ergonomics. They allow for easier access to otherwise difficult intracorporeal areas and improved instrument triangulation, thereby reducing the risk of potential mistakes and complications, which may also result in a reduced hospital stay. These handheld devices use different technologies, some purely mechanical and some other based on robotics or mechatronics technology. Mechanical devices are in general cheaper and easier to develop, so most of the available handheld instruments fall into this category. Regarding the instrument design, it seems that instrument handles with finger-operated joystick are more ergonomic and easier to use than a wrist control, providing similar surgical performance. Studies showed that handheld articulating devices facilitate intracorporeal suturing with similar surgery time and outcomes to conventional laparoscopy. Many of the presented handheld instruments are still in early stages of development. Additional efforts should be done in order to improve their functionalities and make them more intuitive. Besides, further innovative solutions should be explored in order to exploit the full potential of LESS surgery. The introduction of novel handheld devices in MIS should be accompanied by a comprehensive training period in order to reach the appropriate level of surgical proficiency.

Author details

Francisco M. Sánchez-Margallo[1]*, Juan A. Sánchez-Margallo[1] and Amir Szold[2]

*Address all correspondence to: msanchez@ccmijesususon.com

1 Jesús Usón Minimally Invasive Surgery Centre, Cáceres, Spain

2 Assia Medical Group, Tel Aviv, Israel

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