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# Recent Technological Advancements in Laparoscopic Surgical Instruments

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**Abstract.** Laparoscopy was a progressive step to advancing surgical procedures as it minimised the scars left on the body after surgery, compared to traditional open surgery. Many years later, single-incision laparoscopic surgery (SILS) was created where, instead of having multiple incisions, only one incision is made or multiple small incisions in one location. SILS, or laparoendoscopic single-site surgery (LESS), may produce lesser scars but drawbacks for the surgeons are still present. This paper aims to present related literature of the recent technological developments in laparoscopic tools and procedure particularly in the vision system, handheld instruments. Tech advances in LESS will also be shown. Furthermore, this review intends to give an update on what has been going on in the surgical robot market and state which companies are interested and are developing robotic systems for commercial use to challenge Intuitive Surgical's da Vinci Surgical System that currently dominates the market.



## INTRODUCTION

Laparoscopy, also known as minimally invasive surgery (MIS), is a revolutionary procedure that has benefitted both the patients and the doctors [1]–[3]. Johnson [1] considered it then to be the greatest advance since ether anaesthesia. It makes use of a video camera and specific thin instruments for the procedure [4]. What happens inside is almost the same as the open surgery procedure but with a different method of access [1]. Its demand has grown over the years due to its major advantages such as faster wound healing, less morbidity, less discomfort, quicker recovery time, and better outcomes. These mean less pain, shorter hospital stay, and slight scarring for the patients. Many advancements both in procedure and in the instruments used have occurred in the recent decades. This paper aims to focus on and to detail the recent improvements on the tools used in laparoscopic surgery specifically on laparoscopic instruments where developments have been done to increase manoeuvrability and decrease the costs for the surgeons from hand-assisted articulating, flexible forceps to fully robotic equipment [5], [6].

Compared to traditional open surgery, laparoscopy only needs up to 3 small incisions in the abdomen of the patient to do the procedure. Conventional laparoscopic tools involve the use of but not limited to a laparoscope, slide lock graspers, axial needle holders, forceps, scissors, probes, dissectors, hooks, and retractors [7], [8].

Developments in laparoscopic procedure have been done over the years and it is still ongoing. This paper will discuss these developments based on what they focused on which are on the vision system or camera, and instruments (i.e. grasper, forceps).

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# TECHNOLOGICAL ADVANCEMENTS IN LAPAROSCOPIC TOOLS

In this paper, the product and literature found on the progress of laparoscopic tools can be segregated into two categories specifically the application of vision system, and the redesigning or automation of instruments. While examples of companies who are developing robotic surgical systems and are trying to enter the market will be stated.

## Application of Vision System

The camera has been considered to be a critical instrument in doing laparoscopic surgery since it acts as the eyes of the surgeon [4], [9]. Interest in the improvement and innovation of imaging devices has grown over the years. Recent literature has revealed that researchers are focused on enhancing the experience of surgeons through 3D technologies, and improving the image quality and field of vision of endoscopic cameras.

### *Computer Vision Application*

One research focused on providing multiple views for surgeons using 3D display technologies. In 2012, Silvestri et al. [9] made use of the multi-view autostereoscopic devices (ADs). The technology helps medical professionals inside the surgery room to view different points of view without the need for extra accessory to be inserted inside the patient's body. However, it still has no direct surgical application. Authors tried to take advantage of this technology by developing a miniaturized acquisition system for minimally invasive surgery (MIS). Tests were done on a commercial human phantom. While another research built a micro-camera array that has a considerably larger Field of View (FoV) than common laparoscopic cameras. This was developed by Kanhere et al. [10] in 2013. It was a micro-panoramic vision system which had four simultaneously controlled micro-cameras. Image stitching from one configuration could give the surgeons a horizontal FoV of 45$^{o}$ while dynamic stitching of panoramas provided a horizontal FoV of up to 130$^{o}$. In 2014, Durr et al. [11] proposed utilizing 3D imaging techniques to be applied in colonoscopy to improve sensitivity, wound resection, training, and automated lesion detection. Authors suggested that for the technology to be adopted, it needs to have minimal hardware changes without sacrificing the robustness and quality of normal 2D imaging.

### *Mechanical Robotic Application*

Simi et al. [12] designed and fabricated a new vision system based on a magnetically-activated 5-DOF wired robot with stereoscopic vision. It also featured an actuated mechanism that adjusts the horizon which then prevents visual discomfort. An *in vivo* in a LESS environment test was done and validated its advantages which allows for another instrument to be introduced with no conflict with operative tools. While a system called MARVEL or Miniature Anchored Robotic Videoscope for Expedited Laparoscopy which aims to be the first step in developing semiautonomous wirelessly controlled and networked MIS devices and other smart tools was presented by Castro et al. [13]. The system comprised of three modules namely master control module (MCM), wireless human-machine interface (HMI), and the system's camera modules (CM). The multiple CMs enabled a full hemisphere field of view inside the abdominal cavity, wirelessly adjustable focus, and a multiwavelength illumination control system. The MCM provided a zero-latency communications link and the HMI gave surgeons full control on the CM.

In 2014, Leonard et al. [14] provided a proof-of-concept Smart Tissue Anastomosis Robot (STAR) which was a vision-guided robotic system for laparoscopic suturing. STAR's architecture and interface allowed surgeons (1) to manually select and track incisions and the placement of stitches or (2) automatically performed equally-spaced stitches based on the contour of the incision. Another research by Liu et al. [15] designed a robotic capsule camera system for single-site laparoscopic surgery which can anchor, navigate, and rotate using externally generated rotational magnetic field. The capsulated camera was put in a one-piece housing with two tail-end magnets and one central magnet on board that serve as a rotor. The first prototype produced was 12.7 mm in diameter and 68 mm in length. Test results show that the design provided a reliable camera fixation and locomotion capabilities.

Last Feb. 2017, Cogal and Leblebici [16] presented a miniaturized vision system for endoscopic applications. Inspired by an insect eyes, the authors could develop an imaging system from off-the-shelf miniature cameras integrated with a digital circuit to achieve real-time image processing. The device had a large 180$^{o}$ x 180$^{o}$ FOV high definition pictures, and had a smaller radius but capable of 1000x resolution increase. The system was verified using a human colon model.

## Automation of Instruments

Surgical robotic systems have been and are continually being developed and improved to further enhance its design and capabilities as well as overcome challenges in safety, sterility, and adaptation [17]–[19]. The focus now is on teleoperated surgical robots and improvement on the instruments (i.e. graspers, forceps) itself that come with it. Some research focused on the gripping system like the one by Lee et al. [20] in 2014. It was designed and implemented a pneumatic gripping system that solves the non-uniform gripping force of existing systems. The 6-axis robot provided force like other robotic systems and near real-time control. Another is from Choi et al. [21] in 2015 where they presented a laparoscopic grasping tool that can sense all three manipulation force and a grasping force. The authors made use of a wrist force sensor and two torque sensors. The 4-DOF grasping tool was fabricated and achieved structural simplicity. Raven-II was exploited to simulate and test the prototype. Results validate the proof of the concept and the potential for robotic surgical application. In 2015, Haraguchi et al. [22] designed a flexible, articulated forceps manipulator that can be used by surgical robots. The 3-DOF model had an angle resolution of $1^{o}$ and was capable of three-axis force sensing. A dynamic model was also modelled that was tested and validated by open-loop control performance. Testing results showed that the designed 3-DOF manipulator and force estimator was an improvement from the tradition two-DOF force estimator.

The automation of instruments can go as far as being fully automated. The closest would be by Quaglia et al. [23]. The authors designed and fabricated a compact, highly efficient bimanual robot that weighs approximately 6 kg. It was developed specifically for SILS to solve the problems in using conventional surgical tools. Initial tests validated the potential of the design but the authors suggested steps on how to better improve the current design. Another application was done by O'Shea et al. [24] who developed an atraumatic laparoscopic retractor that effectively retracts the bowels from the operating field. It is an inflatable laparoscopic retracted that was tested and performed computer simulation, and *pre-clinical animal* investigation. Experimental results showed that the retractor met the simulated expectations and was effectively tried for safety and technical feasibility using a porcine model. Furthermore, the device could lessen the Trendelenburg position since test also showed that the bowels can be removed while the model was in the supine position.



## Industrial Robot-Assisted Surgical System

In 2000, Robotic-Assisted Surgery (RAS) for general laparoscopic surgery was first introduced by the company Intuitive Surgical® with its device, the da Vinci Surgery System, the most famous robotic surgical system. It was the first of its kind to be approved by the US Food and Drug Administration (FDA) [25]. The da Vinci Surgical System has four (4) interactive robot arms – one (1) for camera control, three (3) for manipulating instruments – which are operated by the surgeon from the surgeon's console. These arms can be a combination of different tools that can either grasp, cut, and cauterize. Since its inception, the company has been releasing new models of the surgery system further improving the features and enhancing the capabilities of the system. Most recent of which is the da Vinci Xi ®. It was released in 2014 and its core technology involved a magnified 3D HD vision, EndoWrist® instrumentation & intuitive motion, and enhanced ergonomics [26]. A study by Columbia University in 2014 found that in some conditions, RAS had little to no advantage over conventional procedures. Other than the cost and longer operative time [27], it also slightly but significantly increased complications during operation [28]–[30].

Today, Intuitive Surgical still dominates the surgical robot market especially the US market, but there are companies who are trying to enter the competition with some already having US FDA clearance [28], [30]. SurgiBot™ by TransEnterix is a type of a LESS instrument which allows multiple tools to pass through a single incision on the abdomen [31]. However, around April 2016, the FDA rejected the company's application [32]. Medtronic minimally invasive therapies (Medtronic), formerly Covidien and under Medtronic Plc, has announced that it will launch a surgical robot by the 2019 fiscal year. The company aims to lower the costs of doing robotic surgery [33].

In December 2016, Cambridge Medical Robotics Ltd unveiled its Versius robotic surgery system, a robotic system for universal minimal access surgery. It is currently undergoing cadaver trials to test its application on upper GI, gynaecological, colorectal, and renal surgery where 32 surgeons have used the system. Furthermore, it has separate robotic arms that can be placed around the patient's table unlike the Intuitive Surgical's da Vinci system [34]. Avateramedical®, a German company founded in 2011, has been developing a robot-assisted surgical robot and has lately announced the developments on their robotic system. The company confirmed that the robot will be mobile and lightweight, and will have 4 robotic arms which has 5mm articulated instruments with 7 degrees of freedom, next-gen 3D Visualization, and an open design for close interaction [35]. Revo-i, a robotic system from South Korea, has been being developed by the Meere company in Korea in partnership with Yonsei University College of Medicine Professor Lee Woo-jung since 2007. In 2015, the platform performed a robot-assisted partial nephrectomy using porcine models. The test was conducted successfully and results showed that the robotic system was safe and could benefit the urologic field [36], [37]. Verb Surgical Inc., a company collaboration between Johnson & Johnson and Alphabet Inc., announced in January 2017 that it revealed its digital robotic surgery system prototype to its collaboration partners at Ethicon Endo-Surgery, Inc. and Verily Life Sciences. The platform will feature robotics, visualization, advanced instrumentation, data analytics, and connectivity [38]. These robots that are being developed are expected to perform minimally invasive surgeries and to expand its application to other surgical procedures.

From fully robotic systems, there also have been improvements in hand-assisted surgical instruments that features articulating end-effectors which increases manoeuvrability. In 2011, a team of undergraduate researchers from De La Salle University, Philippines developed an articulating laparoscopic instrument that achieved 4 degrees of freedom. It has been filed for patent at the Intellectual Property Office of the Philippines (IPOPHL) in 2013 [39]. FlexDex Inc., a laparoscopic device platform company, is currently developing a similar device that features a technology that precisely translates the surgeon's hand, wrist, and arm movements without any electronic component [40].

Single-incision laparoscopic surgery (SILS), for example, is not new but revolutionary. Although, challenges with equipment triangulation and doing complex procedures make surgeons opt to do multi-port surgeries [41]. From the name itself, it is a laparoscopic procedure wherein only one incision is done for the instruments to have access to the abdomen [3], [42]. Figure 1 shows a sample of an SILS port with three (3) holes. Selecting and performing this procedure would be beneficial to patients which include lesser and smaller scars, less blood loss, less postoperative pain, and faster recovery time. However, disadvantages are mainly for the surgeons which involve lack of instrument triangulation and steeper learning curve [43]. SILS is also known as laparoendoscopic single-site surgery (LESS), single port access (SPA) surgery, natural orifice transluminal endoscopic surgery (NOTES), minimally invasive single site (MISS) surgery, among others [3], [42], [44].

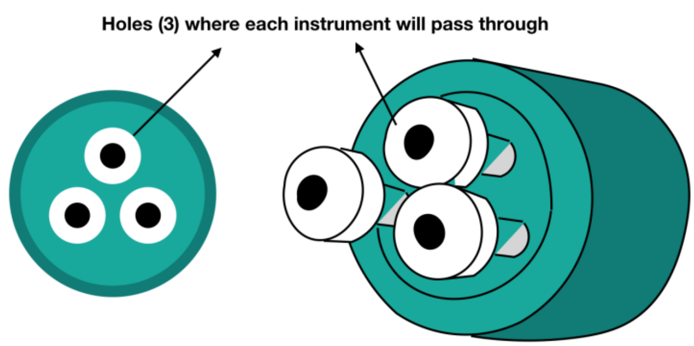


**FIGURE 1. Sample sketch of an SILS**

**TABLE 1. Literature summary of other recent developments in SILS and RAS**

| Author/s Year | Summary |
|---|---|
| Shin and Kwon (2013) [46] | Proposed a novel joint mechanism for single-port robotic surgical systems which is suitable for multiple degrees of freedom (DOF). A prototype was made to test and validate the system. |
| Takeda et al. (2014) [47] | Verified that gasless LESS surgery for adnexal masses is a safe alternative to multiport laparoscopy. It eliminates the use of carbon dioxide that may have a negative effect on the mother and the fetus. |
| Rivas-Blanco et al. (2014) [48] | Presented a miniature robotic system for SILS which comprises of a voice-controlled miniature camera and a lighting robot, and a teleoperated robotic grasper with haptic feedback. External robotic arms with magnetic holders guide the components inside the body along the abdominal wall. |
| Kanno et al. (2015) [49] | Developed a 4-DOF forceps manipulator that is lightweight and has a high power-to-weight ratio. |
| Xu et al. (2015) [50] | Presented a complete guide from design, construction, kinematic modeling, to experimental characterization of the SJTU unfoldable robotic system (SURS) for SILS. The device enters through a 12mm incision, folded but once inside, it unfolds to be able to perform the surgery. |

## CONCLUSION AND FUTURE DIRECTIVES

Laparoscopy may have been around for more than a century but there are still a lot of areas to improve on. Novel and innovative solutions to improve laparoscopic procedure will likely continue to be developed in the following years. This paper presents some of the notable recent developments in laparoscopic technology from its imaging system, to the enhancement of conventional laparoscopic tools and parts as well as advances done by researchers that involve robotic surgical systems and SILS. Moreover, this paper reports some updates on which companies are currently developing a product of their own to enter the surgical robot market.

So far, developments were done for the vision system of laparoscopy include improvement of viewing angle and field of view, and clarity of images. While for laparoscopic instruments, improvements include increased DOF for articulated manipulators, manipulators with haptic feedback, and improvement of gripping and movement. Succeeding researches should continue to work on the enhancement of the surgeon's experience and capability where he will take less effort. At the same time, it should be efficient in performing the doctor's tasks, and affordable and accessible for middle-level medical institutions. Researchers can also consider applying a current trend today in vision systems which is the 360$^{o}$ camera. It can be applied to construct a 3-D interpretation of what's inside the abdomen of the patient for easy assessment and planning of the procedure.

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