Review Article

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Clinical status and future prospects of single-incision robotic-assisted surgery: a review

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Abstract

Since the advent of conventional multiport laparoscopic surgery, the prosperity of minimally invasive surgery has been thriving on the advancement of endoscopic techniques. Cosmetic superiority, recovery benefits, and noninferior surgical outcomes weigh single-incision laparoscopic surgery as a promising modality. Although there are surgical challenges posed by steep learning curve and technological difficulties, such as instruments collision, triangulation loss and limited retraction, the establishment of robotic surgical platform as a solution to all is inspiring. Furthermore, with enhanced instrument maneuverability and stability, robotic ergonomic innovations adopt the advantages of single-incision laparoscopic surgery and surmount its recognized barriers by introducing a novel combination, single-incision robotic-assisted surgery. As was gradually diffused in general surgery and other specialties, single-incision robotic-assisted surgery manifests privileges in noninferior clinical outcomes an satisfactory cosmetic effect among strictly selected patients, and has the potential of a preferable surgical option for minimally invasive surgery.

Keywords: general surgery, minimally invasive surgery, robotic surgery, single-incision robotic assisted surgery, single-incision surgery, single-site surgery

Introduction

Ever since the first advocation of conventional multiport laparoscopic surgery in 1980s, surgeons have always been pursuing preferable perioperative outcomes without concession on oncological safety and surgical purpose. With superior cosmesis, less postoperative pain and faster recovery, laparoscopic surgery rapidly spread out through various specialties.

HIGHLIGHTS

- The comprehensive literature review of single-incision robotic-assisted surgery (SIRAS) in the field of general surgery and abdominal surgery is lacking. And the combination of robotic technology and single-incision laparoscopic surgery is an upsurging trend in surgical exploration.
- This study reported the evolutionary process and developmental trends of robotic surgical platforms and customized instruments in a single-incision approach, and initially summarized the current clinical status of SIRAS in the field of general surgery and abdominal surgery.
- This study provided a readily comprehensible approach and an accessible presentation for elementary implantation in a novel and thriving area of surgical innovation.
- The SIRAS is a promising developing trend and will play an important role in the advancement of surgical technology in general surgery and abdominal surgery.

In addition to the advantages of declined analgesic requirements and shorter length of stay, conventional multiport laparoscopic surgery superseded traditional open surgery as the gold standard of treatment of surgical diseases soon after the validation of better perioperative outcomes and non-inferior surgical outcomes supported by several multicenter randomized controlled trials[1–8]. However, the pursuit for less invasiveness continues to inspire surgeons to further explore the path of minimally invasive surgery (MIS), which leads to the inception of natural orifice transluminal endoscopic

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surgery[9,10] and single-incision laparoscopic surgery (SILS)[11,12]. By operating through only one major incision, SILS is considered a feasible alternative with even less pain, avoidance of multi-incision complications, cosmetic satisfaction, and comparable surgical outcomes[13,14]. However, concerns and controversies of SILS cause considerable attentions in terms of the steep learning curve and noticeable technological barriers, such as confined surgical fields, collision of laparoscopic instruments, loss of surgical triangulation, limited exposure and retraction, and stringent indications and exclusion criteria[15–17].

Another flying leap of the surgical breakthrough was made by technological innovation. The invention of cutting-edge devices, such as industrialized ports, bent instruments, customized staplers, grasper forceps, energy devices, and vessel sealing devices, plays a crucial role in the widespread application of laparoscopic surgery. In addition, after first introduced in the late 1990s, robotic surgical platforms gradually led another revolution in surgery and brought the superiority of laparoscopic surgery into full play, with unique advantages of three-dimensional (3D) vision, reduction of tremor transmission, and instrument maneuverability and stability[18], especially in a narrow surgical field requiring delicate dissection. To overcome the recognized drawbacks of SILS, a novel integration of robotic technology and SILS, referred to as single-incision robotic-assisted surgery (SIRAS), has struck a considerable upsurge in public attention with its significant ergonomic improvement and simplified technological challenges (Fig. 1).

In this review, we aim to discuss the early experience and evolution, research status, and prospects of SIRAS. We conducted a literature search using four English databases (PubMed, the Cochrane Library, Embase, and Web of Science) for relevant articles from 2005 to 2023. The search terms 'single incision', 'single port', 'single site', 'single access', and Medical Subject Heading (MeSH) terms 'robotic surgical procedure', were used in various combinations. After screening the abstract of the selected literature, and duplicates removed, a thorough full-text examination was carried out independently (Supplemental Fig. 1, Supplemental Digital Content 1, http://links.lww.com/JS9/B362).

The early experience of SIRAS and technological evolutions

In 2008, Desai *et al*[19] first successfully performed SIRAS for radical prostatectomy (RP) via a trans-vesical approach on newly thawed cadavers, which paved the road for standard robotic platform setup for surgeons to further explore the novel operation. Based on this previous experience, Kaouk *et al*[20] completed the first SIRAS radical nephrectomy, prostatectomy, and pyeloplasty via intraperitoneal approach successively 1 year later,

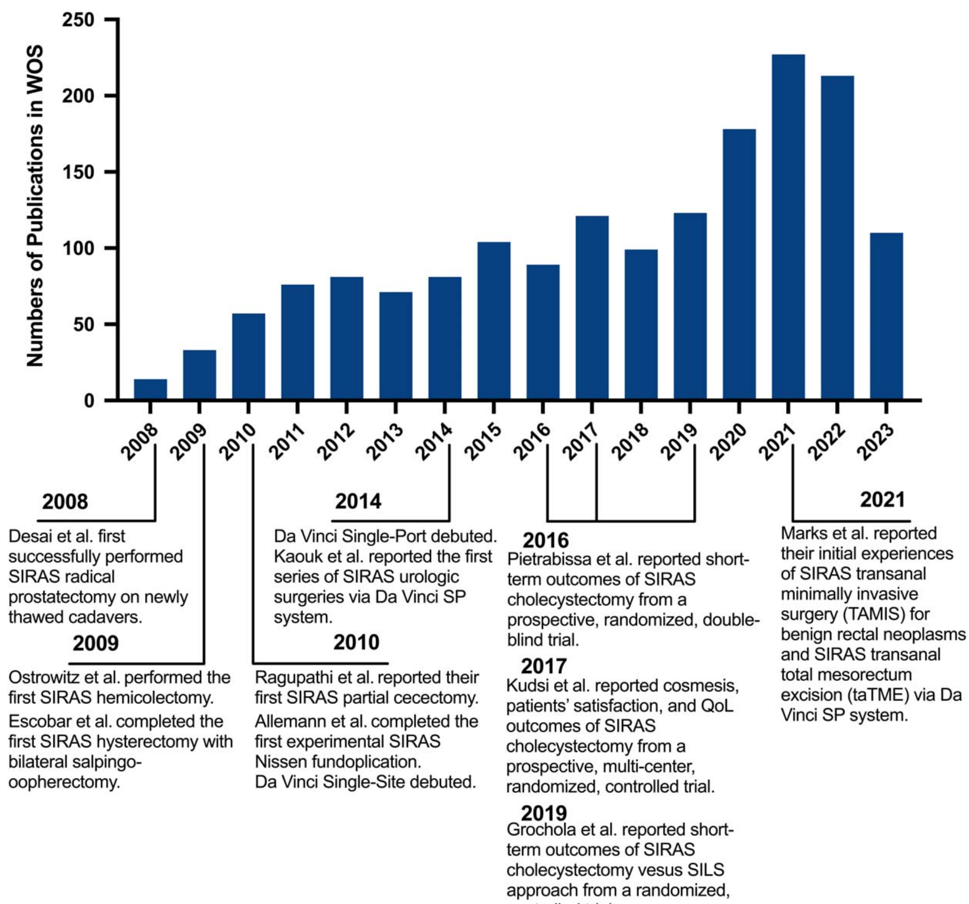

Figure 1. The emerging trend in literature reviews of single-incision robotic-assisted surgery (SIRAS).

in which SIRAS started to manifest its improved instrument triangulation, flexible camera relocalization, and organ retraction, igniting surgeons' interest to further investigation in this field.

Since then, attempts on SIRAS have flourished through various surgical specialties (Fig. 2). In 2009, Ostrowitz *et al*[21] performed the first SIRAS hemicolectomy while Escobar *et al*[22] completed the first SIRAS hysterectomy with bilateral salpingo-oophorectomy. In quick succession, Ragupathi *et al*[23] reported their first SIRAS partial cecectomy in 2010, and Allemann *et al*[24] completed the first experimental SIRAS Nissen fundoplication. These pioneering explorations were mostly based on the Da Vinci S or Si robotic surgical platform, through the accesses of GelPort/GelPoint access, SILS port, or homemade glove-port. Encouragingly, there were several serendipities reported, such as optic magnification of 3D surgical fields, improved ergonomic instrument maneuverability and stability, and enhanced operative precision[25]. Nevertheless, noticeable drawbacks still existed as serious obstacles to further applications of SIRAS, such as collision of instruments, loss of triangulation, and technical barriers of intracorporeal suturing, which were mainly related to parallel instruments inserting through the confined single-incision port.

To surmount the obstacles presented by the coaxial instrument arrangement, Joseph *et al*[26] reported a chopstick technique, which defined an intersection of robotic arms beneath the abdominal wall to obtain interspace between the tips of instruments. While acquiring spatial surgical fields and restoring triangulation, this technique generated another technically demanding situation, which is the converse feedback[27] of counter-intuitive control between manual manipulation and visualized screenage.

Labelled as a milestone in the evolution of SIRAS, a novel robotic surgical platform established by Intuitive Surgical Inc. in 2010, the Da Vinci Single-Site surgical platform (Intuitive Surgical Inc., USA), marked a significant step forward on the road of the widespread application of SIRAS. The prominent innovation of the Da Vinci Single-Site platform were two curved trocars within the single-site access port, which were customized for re-establishing triangulation of operative instruments in the surgical fields and avoiding extracorporeal instruments collision, in addition to the computer interactive software allowing surgeons to control the instruments in visualized left-right order. Soon after Escobar *et al*[22] reported their initial experience of the first SIRAS-modified radical hysterectomy via Da Vinci Single-Site platform on a cadaver, a certain branch of studies addressing SIRAS, mainly based on Da Vinci Si, Xi, or Single-Site platform, were published within a short period, which emphasized the further ergonomic refinement and reflected a more accessible tendency of SIRAS via this novel approach.

To further overcome the inconsistency between the single-port (SP) access and instruments and the multiport–based surgical platform, as well as between the instinct move and the visually reversed operation, the Da Vinci SP system (Intuitive Surgical Inc.)[28] was developed specifically for single-port surgery within a refined surgical field. Instead of independent trocars placed in different anatomical locations, the SP allows the surgery to be performed with a single trocar that houses three instruments and one flexible scope. It features in the 360 degrees of

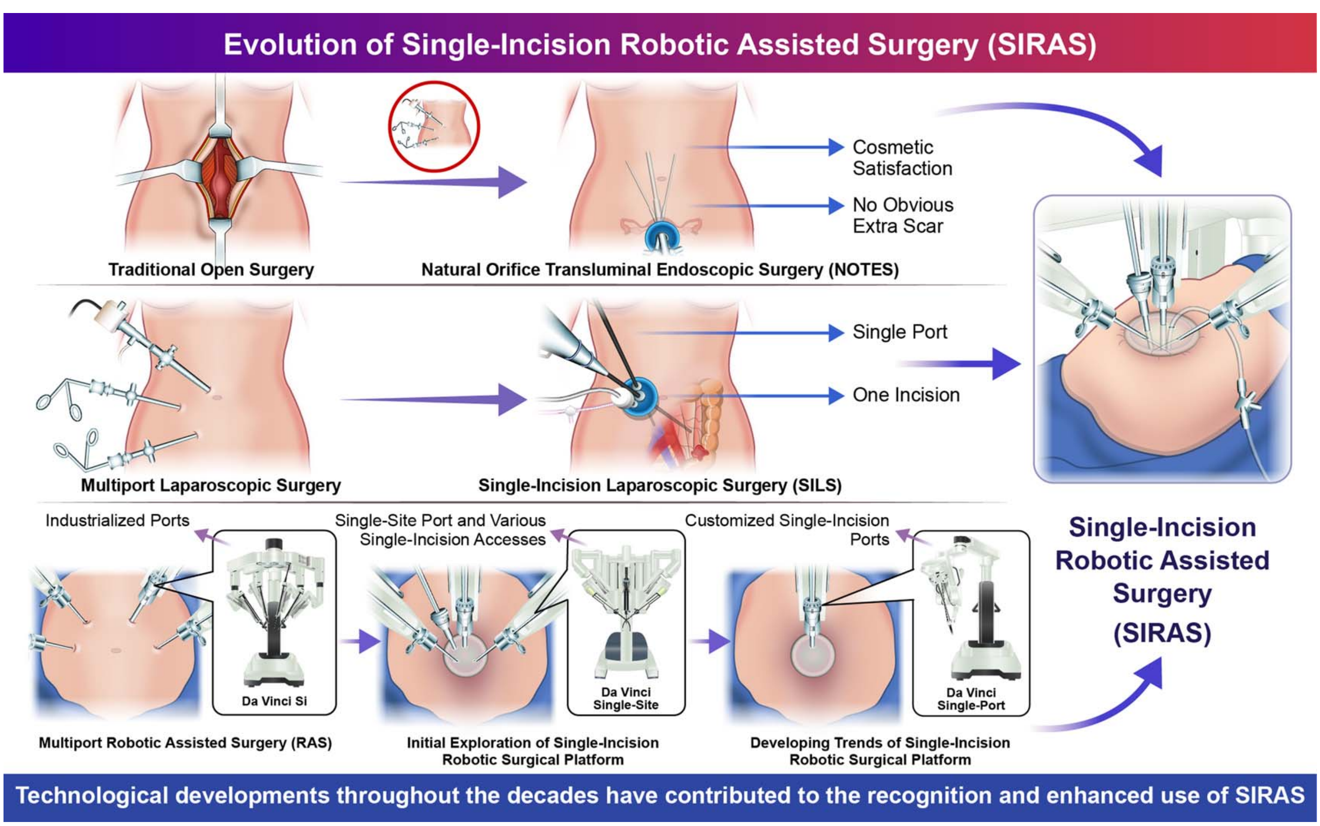

Figure 2. The evolution of single-incision robotic-assisted surgery in general surgery.

anatomical access, a cobra-like articulating 3D high-definition endoscope, and three wristed instruments installed through a SP with its unique patient cart design, instruments optimized for SP surgery, and advanced vision, empowering the surgeons to perform procedures with a range of complexity. Since the introduction of Da Vinci SP, an emerging amount of clinical evidence shows that surgeons are harnessing its unique attributes to move surgery forward, again.

The research status of SIRAS

The clinical status in gallbladder surgery

The advent of single-incision laparoscopic cholecystectomy (SILC) represented a notable advancement in MIS, bringing into question the long-held position of conventional multiport laparoscopic cholecystectomy (CMLC) as the gold standard treatment for benign gallbladder diseases. Concurrently, there was an emergence of interest in the field towards the investigation of single-incision robotic cholecystectomy (SIRC), in the hope of addressing the limitations of SILC such as unreasonable ergonomics and considerable workload imposed on the operators (Table 1)[29–69]. Coinciding with the refinement of surgical robotic technology, 2011 witnessed a succession of trailblazing implementations of SIRC, facilitated by the deployment of the Da Vinci Single-Site instruments (Intuitive Surgical, Sunnyvale, CA) in concert with the Da Vinci Si system[29–31]. In addition, the purposefully designed variant, the Da Vinci SP system, was initially utilized in cholecystectomy procedures by Cruz *et al*[60] in 2019, bringing minimally invasive gallbladder surgery into the next level.

Plenty of published literature had focused on the short-term and long-term outcomes of SIRC to evaluate the feasibility and safety of this novel procedure. In comparison with CMLC and SILC, SIRC had noninferior intraoperative and postoperative outcomes with similar perioperative complication rate, conversion rate, and estimated blood loss, as well as comparable hospital stay and readmission rate[70–72]. The total operative time was significantly longer for SIRC, specifically the preoperative time. This was probably related with inherent instrumental interference and lack of triangulation, as well as the prolonged docking time and surgeons' lack of experience. With time, as surgeons become more familiar with the devices and dedicated robot-compatible operating rooms, it is likely that the set-up times will decrease to an acceptable level. Also, the easier acquisition of critical vision of safety during SIRC can effectively prevent biliary injury[68] and help in improving operative safety and reducing operative time. Among others, the prevalence of postoperative incisional hernia (PIH) in SIRC was given the most attention. While there were some established literature reporting a higher incidence of PIH in SIRC[71,73], Abel *et al*[67] yielded the conclusion that advancing age and increasing body mass index were both statistically significant risk factors for PIH in a retrospective cohort study, where they argued that the perception of higher PIH prevalence in SIRC might be biased due to imbalanced patient characteristics, such as lower body mass index, inadequate duration of follow-ups of less than 90 days in most researches, and less stringent diagnosis of PIH without reviewing asymptomatic patients' imaging. Fascia closure technique and incisional infection also played a crucial role in PIH.[74] Therefore, more investigation on the long-term outcomes of SIRC should be conducted with more detailed stratification.

Apart from the initial discussion of validation, potential clinical advantages, and further application of SIRC were explored in the hope of addressing the limitations of existing paradigms. Better cosmesis outcome was the highlight of MIS while SIRC was reported to outscore CMLC in body image perception and cosmesis satisfaction.[43] Another advantage of SIRC involved reducing postoperative pain and additional use of analgesics compared with SILC and CMLC, as was reported by Lee *et al*[69] in a retrospective cohort of 157 patients. They also mentioned that a controversial opinion raised by Pietrabissa *et al*[43], that no difference in postoperative pain was observed between SIRC and CMLC, was probably due to a large loss to follow-up. In terms of the learning curve (LC), Kudsi *et al*[75] reported in a retrospective cumulative sum analysis establishing the LC of SIRC through an assessment of operative times and clinical outcomes that a steady decrease in skin-to-skin time was observed during the completion of the first 91 consecutive cases, in which a single MIS-trained surgeon performed more than 250 consecutive SIRC procedures. However, in previous retrospective studies, the LC of SIRC was established at a smaller number of 40–48 cases, with the mean operative time ranging from 45 to 83 min[36,42,54]. This contradiction, as was discussed by Kudsi, was associated with the simplicity of the evaluation of LC through a single surgeon's experience and a single parameter of operative time. Thus, a larger-scale prospective study of establishing LC by comparing groups of surgeons with different education and experiences, and through more parameters, remains to be investigated.

With the continuous progression of surgical methodology and technology, novel techniques had been introduced to further enhance safety and facilitate convenience for surgeons. Among these advancements was the use of real-time near-infrared fluorescent cholangiography utilizing indocyanine green assisted by the build-in near-infrared camera of the Da Vinci Single-Site platform[35], which aids in the precise identification of the biliary tree. Moreover, the deployment of the 'reverse-port' technique[39] served to expand Calot's triangle, thus providing surgeons with improved vision and making the procedure less challenging.

The clinical status in colorectal surgery

After the first attempt of SIRAS right hemicolectomy by Ostrowitz *et al*[21] based on the Da Vinci S platform in 2009, there was a small-scale upsurge of SIRAS in the field of colorectal surgery (Table 2)[21,23,76–94]. Ragupathi *et al*[23] subsequently reported a SIRAS partial cecectomy via Da Vinci S platform for a tubulovillous polyp that could not be resected under coloscopy with no conversion or complication recorded. In 2011, another experience of SIRAS right hemicolectomy was safely conducted with no complications reported by Singh *et al*[76] based on the Da Vinci S platform. 'Chopstick technique' and the reversal arrangement of robotic arms were adopted during the operation. In 2013, the first case series of SIRAS anterior resection for sigmoid colon cancer were carried out by Lim *et al*[78] based on the Da Vinci Single-Site platform through an Alexis wound protector with a homemade glove-port. As reported, there was no conversion to multiport laparoscopic surgery or open surgery. Later that year, Jiménez-Rodriguez *et al*[77] reported their first attempt on SIRAS total mesorectal excision (TME) for 2 cases of rectal cancer based on the Da Vinci S platform. Although two

Table 1

Summary of the reported studies on single-incision robotic-assisted cholecystectomy.

Citation number	Author	Publication date	Surgery	Robotic system	Port number	Access port	Case load
[29]	Kroh *et al*	2011 Nov.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	13
[30]	Morel *et al*	2011 Dec.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	28
[31]	Wren *et al*	2011 Oct.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	10
[32]	Spinoglio *et al*	2012 Jun.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	25
[33]	Buzad *et al*	2013 Sep.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	10
[34]	Gonzalez *et al*	2013 Dec.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	166
[35]	Spinoglio *et al*	2013 Jun.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	45
[36]	Angus *et al*	2014 Jun.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	55
[37]	Ahn *et al*	2015 Dec.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	9
[38]	Chung *et al*	2015 Jul.	Cholecystectomy	Da Vinci	1	NR	70
[39]	Jung *et al*	2015 Oct.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	55
[40]	Lee *et al*	2015 Jan.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	5
[41]	Gustafson *et al*	2016 Jun.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	38
[42]	Kubat *et al*	2016 Mar.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	150
[43]	Pietrabissa *et al*	2016 Jul.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	30
[44]	van der Linden *et al*	2016 Nov.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	27
[45]	Balachandran *et al*	2017 May	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	415
[46]	Balaphas *et al*	2017 Oct.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	48
[47]	Ege and Gulen	2017 Aug.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	10
[48]	Kudsi *et al*	2017 Aug.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	83
[49]	Lee *et al*	2017 Sep.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Glove port (NELIS, Bucheon, South Korea)	30
[50]	Lim *et al*	2017 Sep.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	37
[51]	Rosales-Velderrain *et al*	2017 Apr.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	14
[52]	Su *et al*	2016 May	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	51
[53]	Ayabe *et al*	2018 Apr.	Cholecystectomy	Da Vinci Si	NR	NR	98
[54]	Dughayli *et al*	2018 Jun.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	117
[55]	Hagen *et al*	2018 Mar.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	99
[56]	Kim *et al*	2018 Dec.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Glove port (NELIS, Bucheon, South Korea)	55
[57]	Ko *et al*	2018 Sep.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA) and Glove port (NELIS, Bucheon, Korea)	100
[58]	Mattei	2018 May	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	20
[59]	Nolan and Glen	2018 Jun.	Cholecystectomy	NR	1	NR	10
[60]	Cruz *et al*	2019 Oct.	Cholecystectomy	Da Vinci Single-Port (SP)	1	Pure single incision with Single-Port trocar	1
[61]	Grochola *et al*	2019 May	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	30
[62]	Jang *et al*	2019 Apr.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	39
[63]	Lee *et al*	2019 Feb.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	61
[64]	Schertz *et al*	2019 Aug.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	104
[65]	Han *et al*	2020 Jun.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	104
[66]	Lee and Lim	2021 Feb.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Glove Port	197
[67]	Abel *et al*	2022 Apr.	Cholecystectomy	NR	NR	NR	296
[68]	Lee *et al*	2022 Jan.	Cholecystectomy	Da Vinci Single-Site (Si)	1	Glove Port A (Meditech, Seoul, South Korea)	50
[69]	Lee *et al*	2023 May	Cholecystectomy	Da Vinci Xi	1	Glove port (NELIS, Bucheon-si, Gyeonggi-do, Korea)	39

NR indicates not reported

Table 2

Summary of the reported studies on single-incision robotic assisted colorectal surgery.

Citation number	Author	Publication date	Surgery	Robotic system	Port number	Access port	Case load
[21]	Ostrowitz *et al*	2009 Dec.	Right colectomy	Da Vinci S	1	SILS Port (Covidien, Norwalk, CT, USA)	1
			Right colectomy	Da Vinci S	0	Pure single incision with 3 trocars	1
			Right colectomy	Da Vinci S	0	3 trocars with purse-string suture	1
[23]	Ragupathi *et al*	2010 Sep.	Partial cecectomy	Da Vinci S	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	1
[76]	Singh *et al*	2011 Jun.	Colon resection for cecal cancer	Da Vinci S	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	1
[77]	Jiménez-Rodriguez *et al*	2013 Aug.	Total mesorectal excision	Da Vinci S	2	SILS Port (Covidien, Norwalk, CT, USA) + additional laparoscopic trocar	1
			Total mesorectal excision	Da Vinci S	1	SILS Port (Covidien, Norwalk, CT, USA)	1
[78]	Lim *et al*	2013 Mar.	Anterior resection for sigmoid cancer	Da Vinci S	1	Homemade port with Alexis wound retractor and surgical glove for 5 trocars	22
[79]	Morelli *et al*	2013 Sep.	Right colectomy	Da Vinci Single-Site (Si)	1	da Vinci Single-Site port (Intuitive, USA)	1
[80]	Juo *et al*	2015 Jul.	Right hemicolectomy	Da Vinci S	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	31
			Sigmoid colectomy	Da Vinci S	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	20
			Left hemicolectomy	Da Vinci S	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	5
			Low anterior resection	Da Vinci S	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	2
			Total colectomy	Da Vinci S	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	1
[81]	Spinoglio *et al*	2015 Jun.	Right colectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	3
[82]	Byrn *et al*	2016 Jun.	Right hemicolectomy	NR	1	SILS Port (NR)	17
			Left hemicolectomy	NR	1	SILS Port (NR)	12
[83]	Marks *et al*	2020 Aug.	Right colectomy	Da Vinci Single-Port (SP)	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	1
[84]	Chang *et al*	2020 Feb.	Right hemicolectomy	Da Vinci Si	1	Glove port (NELIS, Bucheon City, Korea)	6
			Left hemicolectomy	Da Vinci Si	1	Glove port (NELIS, Bucheon City, Korea)	1
			Sigmoid colectomy	Da Vinci Si	1	Glove port (NELIS, Bucheon City, Korea)	13
[85]	Marks *et al*	2020 Jan.	Left hemicolectomy	Da Vinci Single-Port (SP)	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	2
[86]	Bae *et al*	2021 Jun.	Right colectomy	Da Vinci Single-Site (Si or Xi)	2	Nonspecific single port + additional laparoscopic trocar	7
[87]	Chang *et al*	2021 May	Right hemicolectomy	Da Vinci Si	1	Glove port (NELIS, Bucheon City, Korea)	7
			Left hemicolectomy	Da Vinci Si	1	Glove port (NELIS, Bucheon City, Korea)	1
			Anterior resection	Da Vinci Si	1	Glove port (NELIS, Bucheon City, Korea)	13
[88]	Marks *et al*	2021 Aug.	Transanal minimally invasive surgery	Da Vinci Single-Port (SP)	1	GelPOINT Path Transanal Access Platform (Applied Medical, Rancho Santa Margarita, CA)	26
[89]	Marks *et al*	2021 Jun.	Transanal total mesorectal excision	Da Vinci Single-Port (SP)	1	GelPOINT Path Transanal Access Platform (Applied Medical, Rancho Santa Margarita, CA)	2
[90]	Bae *et al*	2022 Mar.	Tumor-specific mesorectal excision	Da Vinci Single-Site (Si)	2	Da Vinci Single-Site port (Intuitive, USA) and Glove port (NELIS, Bucheon City Korea) + additional laparoscopic trocar	36
[91]	Piozzi *et al*	2022 Jun.	Intersphincteric resection	Da Vinci Single-Port (SP)	1	Uniport system (Daelim Medical, Seoul, Republic of Korea) or da Vinci SP Access Port	7

			Right colectomy	Da Vinci Single-Port (SP)	1	Uniport system (Daelim Medical, Seoul, Republic of Korea) or da Vinci SP Access Port	5
			Transverse colectomy	Da Vinci Single-Port (SP)	1	Uniport system (Daelim Medical, Seoul, Republic of Korea) or da Vinci SP Access Port	1
[92]	Piozzi *et al*	2022 Aug.	Transverse colectomy	Da Vinci Single-Port (SP)	1	Uniport system (Daelim Medical, Seoul, Republic of Korea)	1
[93]	Lim *et al*	2023 Jun.	Right hemicolectomy	Da Vinci Single-Port (SP)	1	Homemade port with Care retractor (S-Medics Solution, Seoul, Korea) and glove for 5 trocars	41
[94]	Guo *et al*	2023 Aug.	Sigmoid colectomy/low anterior resection	SHURUI Endoscopic Sugrical Robotic System (SR-ENS-600)	1	Customized single-incision port (Beijing Surgerii Technology Co., Ltd.)	3
			Right hemicolectomy	SHURUI Endoscopic Sugrical Robotic System (SR-ENS-600)	1	Customized single-incision port (Beijing Surgerii Technology Co., Ltd)	4

additional trocars in the left-inferior abdomen and one additional trocar in the right-inferior abdomen were introduced in both operations due to coaxial instrument arrangement limited by single incision and poor exposure in the narrow pelvis, their initial explorations laid a foundation for subsequent research on SIRAS TME. In 2015, Juo *et al*[80] reported their first experience of five left colectomies and one total colectomy along with a case series of 55 colectomy procedures based on the Da Vinci S platform with acceptable postoperative complication rate and length of stay.

Initial explorations of the SIRAS colorectal surgery preliminarily verified its safety and feasibility in colorectal surgery with noninferior short-term surgical outcomes compared with SILS[87] and multiport robotic surgery[84]. Besides, the oncologic safety of SIRAS colorectal surgery was evaluated in a case series, in which all 16 cases that underwent surgery for colon cancer had negative surgical margins and the average harvested lymph nodes was 27 (range 17–53)[80]. Some reviews echoed this perception with an appreciation of its enhanced instrument articulation and range of motion, tremor reduction and motion scaling, 10-fold magnification, 3D visualization, depth perception, a stable camera platform, and improved ergonomics for the surgeon[82,95]. However, the inconsistency between the SP access and instruments and the multiport–based surgical platform, as well as between the instinct move and the visually reversed operation, posed an obstacle for surgeons to uptake the gist of SIRAS colorectal surgery. To overcome these shortcomings, Bae and colleagues developed the single plus one-port robotic surgery for right-sided and left-sided colon cancer and reported the safety and feasibility of this technique with reduced collisions between robotic instruments and the camera, ease of creating triangulation, cosmetic benefits, sharp dissection with the EndoWrist, and ergonomic comfort, while retrieving acceptable proximal resection margins of 19.7($\pm$7.4) cm, distal resection margins of 29.3($\pm$13.5) cm, and number of harvested lymph nodes of 27.2($\pm$11.9)[86,90], emphasizing the potential application of this amended method.

In response to the requirement of SIRAS, with wristed articulation and flexible elbows, console-controlled camera, its own dedicated instruments, and a holographic instrument positioning monitor, the advent of the SP Da Vinci robot platform (Intuitive Surgical, Inc.) marked a significant advancement in the field of minimally invasive colorectal surgery. In addition, the platform's boom could rotate 360° inside and outside the port's remote center, making it possible for the performance of multiquadrant surgeries such as colorectal surgery without redocking. Marks *et al*[83] took the lead and reported their first experience with the Da Vinci SP system in right colectomy, left colectomy[85], transanal MIS for local excision of benign rectal neoplasms[96], and transanal TME[89], presenting a satisfactory intraoperative performance and postoperative outcome. In addition, Piozzi *et al*[92] successfully conducted the first robotic transverse colectomy based on the Da Vinci SP system for mid-transverse colon cancer, and discussed their SP indications including right-sided colon cancer, ultralow-lying rectal cancer requiring intersphincteric resection, and small or down-sized/down-staged tumors after preoperative chemoradiation[91]. The SP platform addresses many of the limitations of SP transabdominal and transanal surgeries. If the instruments dedicated in the SP system are further developed and the robotic movement is improved, it is expected that the indications for SP will be expanded and it will become an ideal platform for SP surgery.

Several retrospective studies showed that SIRAS colorectal surgery was a safe and feasible surgical technique and has an advantage in the time to first bowel movement over SILS with no other complications[93]. As shown in a retrospective study of 141 cases, SIRAS colorectal surgery was capable of obtaining similar short-term oncologic outcomes, such as tumor size (4.46 ± 2.83 vs. 4.32 ± 2.59; $P = 0.769$), shortest surgical margins [6.50 (1.5–20.5) vs. 6.65 (2.0–17.0); $P = 0.98$],and harvested lymph nodes [27 (12–79) vs. 23 (12–72); $P = 0.148$] as SILS[93]. SIRAS can reduce the total incision length and surgical cost relative to multiport robotic-assisted colectomy, reduce surgical instrument collision, and improve the nonergonomic surgical operating environment faced by surgeons performing SILS during surgery.

Despite the rapid development of SIRAS colorectal surgery, most of the relevant literature was initial experiences and case series. There was still a lack of high-quality evidence to support its safety, feasibility, and clinical benefits in comparison with conventional multiport robotic surgery and SP laparoscopic surgery. Thus, larger-scale comparative and prospective studies of short-term and long-term outcomes of SIRAS colorectal surgery are expected in future investigation.

The clinical status in thyroid surgery

While the two-incision approach was widely adopted in the field of thyroid endoscopic and robotic surgery, Ryu *et al*[97] reported 281 cases of single-incision transaxillary robotic thyroidectomy (START) through a nonpneumatic approach between October 2007 and December 2009 based on the Da Vinci S platform in 2010. These operations were performed via four robotic trocars arranged in the single incision, with one 12 mm trocar for 30-degree dual-camera endoscope, one 8 mm trocar for grasper, and two 5 mm trocars for energy device and dissector, respectively. According to previous studies (Table 3)[97–112], the main advantages of START are ease of console stage, ease of detecting the recurrent laryngeal nerve, ability to perform total thyroidectomy with central and lateral neck dissections for advanced cancer[104,106,113,114], and more favorable postoperative swallowing function than conventional open thyroidectomy[98,113–115], as well as recognized safety and feasibility[105,110]. Especially for oncologic outcomes, Kim *et al*[112] summarized their experience of 5000 cases of START from October 2007 to May 2016 in a retrospective study, and reported no disease-specific mortality and a median recurrence-free survival of 52.5 ± 27.1 months. However, major drawbacks of START consist of possible risks of anterior chest paresthesia and brachial plexus injury[116]. Since the initial exploration of START, new approaches to robotic thyroidectomy have been developed, including the retroauricular approach, or often referred to as 'facelift,' first described by Terris *et al*[99] to avoid the complications that are associated with START. It brings the benefit of reduced risk of injury to the great vessels, the esophagus or the anterior chest sensory nerves, significantly reduced field of dissection when compared to START, which was associated with a faster recovery and decreased postoperative discomfort with similar cometic satisfaction, and ease of operation on obese patients.[100] Also, complications of injury to greater auricular and marginal mandibular nerves should be taken into consideration when applying this approach. With the recent introduction of the Da Vinci SP system, the adoption of this novel surgical system into thyroidectomy was first made by Kim *et al*[109], specifically through a 3–4 cm axillary incision with a two-step retraction method. They further performed 200 cases START using the Da Vinci SP system with the gasless method and verified the safety and feasibility of this procedure while retrieving better cosmesis and functional benefits and recusing surgeons' workload[111].

The clinical status in breast surgery

As the focus of treatment for early breast cancer shifted to de-escalated surgery due to early diagnosis and the use of neoadjuvant chemotherapy for down-staging in reconstruction, the robotic nipple-sparing mastectomy (RNSM) was first introduced by Toesca *et al*[117] through a single 2.5-cm-long extramammary axillary incision based on a multiport Da Vinci Single-Site (Intuitive Surgical Inc.) robotic platform in 2015, improving patient quality of life and satisfaction with better cosmetic outcomes. An international multicenter pooled data analysis involving 755 cases of RNSM in 2022 by Park *et al*[118] further demonstrated its oncologic safety, in terms of events of survival such as local recurrence, regional lymph node recurrence, and distant recurrence, compared with conventional NSM with a median follow-up of 18 months both before ($P = 0.28$) and after ($P = 0.29$) propensity-score matching. However, the universal obstacles, such as instrument collision and prolonged docking time, came along with the cumbersome multi-port surgical platform inserted and working in the narrow space during the gradual adoption of SIRAS in mastectomy (Table 4)[117–121]. To address these hurdles, Park *et al*[119] applied the Da Vinci SP system into RNSM with immediate reconstruction in 2018 with the advantage of detailed movement of instrument arms, enhanced vision provided by cobra-like camera, and ergonomic improvement. They furthermore reported 81 cases (70 patients) of RNSM using the SP system between 2018 and 2021 in a retrospective study[121]. Complications requiring intervention occurred in six cases (7.5%) among which occurred one case (2.5%) of nipple-areolar complex necrosis, comparatively lower than multiport RNSM, and no cases of conversion to open mastectomy were reported, indicating its safety and feasibility. RNSM using the Da Vinci SP system with an axillary minimal incision of 20–55 mm proved to have a lower working load for surgeons and better cosmetic outcomes than conventional RNSM through the inframammary fold incision, especially with small-to-medium-sized breasts without ptosis, and probably a preferable alternative for risk-reducing mastectomy for BRCA carriers. In the promising future, prospective studies, such as Mastectomy with Reconstruction Including Robotic Endoscopic Surgery (MARRES) initiated by the Korea-BSG and Korean Breast Cancer Study Group[122], will provide a higher level of evidence about the surgical and oncologic safety and outcome of RNSM compared with conventional NSM.

The clinical status in inguinal hernia surgery

In 2011, Tran[123] reported the initial attempt in SIRAS inguinal hernia repair in a total extraperitoneal (TEP) manner, based on a robotic Freehand camera controller (Prosurgics, Blacknell, UK) worn on surgeons' forehead as a replacement for camera assistants. Despite this initial attempt and encouraging finding of lower number of times of the scope cleaning, this prototype of robotic device did not draw much attention for SIRAS inguinal hernia repair due to its technical limitation of interfering instrument triangulation when switched to the left side. It was not until 2015 did

Table 3

Summary of the reported studies on single-incision robotic-assisted thyroid surgery.

Citation number	Author	Publication date	Surgery	Robotic system	Port number	Access port	Case load
[97]	Ryu *et al*	2010 Sep.	Thyroidectomy	Da Vinci S	1	Pure single incision with 3 robotic arms inserted directly	281
[98]	Lee *et al*	2010 Dec.	Thyroidectomy	Da Vinci S or Si	2	Pure single incision with 3 robotic arms inserted directly + additional laterosternal robotic trocar	41
[99]	Terris *et al*	2011 Aug.	Thyroidectomy	Da Vinci S	1	Pure single incision with 3 robotic arms inserted directly	17
[100]	Terris *et al*	2011 Aug.	Thyroidectomy	Da Vinci S	1	Pure single incision with 3 robotic arms inserted directly	18
[101]	Ciabatti *et al*	2012 Dec.	Thyroidectomy	Da Vinci S	1	Pure single incision with 3 robotic arms inserted directly	29
[102]	Terris and Singer	2012 Jul.	Thyroidectomy	Da Vinci S	2	Pure single incision with 3 robotic arms inserted directly + additional laterosternal robotic trocar	15
[103]	Aliyev *et al*	2013 May	Thyroidectomy	Da Vinci S	1	Pure single incision with 3 robotic arms inserted directly	30
[104]	Axente *et al*	2013 Aug.	Thyroidectomy	Da Vinci Si	2	Pure single incision with 3 robotic arms inserted directly + additional laterosternal robotic trocar	50
[105]	Lee *et al*	2013 Jan.	Thyroidectomy	Da Vinci S	1	Pure single incision with 4 robotic arms inserted directly	352
[106]	Ban *et al*	2014 Sep.	Thyroidectomy	Da Vinci S or Si	1–2	Pure single incision with 3 robotic arms inserted directly (+ additional anterior chest wall robotic trocar)	3000
[107]	Kandil *et al*	2015 Mar.	Thyroidectomy	Da Vinci Si	1	Pure single incision with 3 robotic arms inserted directly	12
[108]	Byeon *et al*	2016 Aug.	Thyroidectomy	Da Vinci Si	1	Pure single incision with 3 robotic arms inserted directly	87
[109]	Kim *et al*	2020 Jun.	Thyroidectomy	Da Vinci Single-Port (SP)	1	Pure single incision with Single-Port (SP) trocar	6
[110]	Kang *et al*	2022 Oct.	Thyroidectomy	Da Vinci Single-Port (SP)	1	Single cannula	100
			Thyroidectomy	Da Vinci Single-Port (SP)	2	Gelport (Applied Medical, Rancho Santa Margarita, CA) + additional trocar beside the main incision	4
[111]	Kim *et al*	2022 Apr.	Thyroidectomy	Da Vinci Single-Port (SP)	1	Pure single incision with 3 robotic arms inserted directly	200
[112]	Kim *et al*	2017 Sep.	Thyroidectomy	Da Vinci	1–2	Pure single incision with 3 robotic arms inserted directly (+ additional anterior chest wall robotic trocar)	5000

Engan *et al*[124] pick up SIRAS transabdominal preperitoneal (TAPP) inguinal hernia repair through a single 25 mm midline epigastric incision based on the Da Vinci Si system. Later on, based on the Da Vinci Single-Site platform, Bosi *et al*[125] described their experience of the first SIRAS TAPP bilateral inguinal hernia repair in Brazil in 2016, while Cestari *et al*[126] demonstrated the first SIRAS TEP inguinal hernia repair in 2017. Meanwhile, there were voices against SIRAS inguinal hernia repair due to concerns about the unnecessary large incision for single-site trocar that was very likely to develop incisional hernia, and the prolonged and complicated procedure for such simple operation[127]. A retrospective study by Cuccurullo *et al*[128] of 44 cases of SIRAS TAPP in 32 patients between Feburary 2016 and July 2018 reported no recurrence and PIH at 12-month follow-up, and only one case of temporary postoperative pain of 4 months, but the small sample size was a major limitation. With the introduction of the cutting-edge Da Vinci SP system, Kim and Lee[129] and Lee *et al*[130], respectively, described the detail of the technically challenging procedure of SIRAS TEP inguinal hernia repair utilizing this novel surgical platform in 2022. As practices of SIRAS inguinal hernia repair cumulate (Table 5)[123–126,128–131], this approach has been proved safe and feasible with improved cosmesis, similar short-term postoperative morbitiy, higher same-day discharge rate and quicker postoperative recovery, as well as an estimated pooled prevalence of hernia recurrence rate of 0.18%, PIH (2.3% vs. 1.1%; $P=0.31$) and chronic postoperative pain (0.0% vs. 0.4%; $P=1$)[131,132]. These surgical outcomes of SIRAS inguinal hernia repair are yet to be further evaluated through more larger-scale and well-structured studies with longer follow-up.

The clinical status in urology

Urology has witnessed the origination, development and gradual maturity of SIRAS, standing at the forefront of the innovation and revolution of MIS (Table 6)[20,133–150]. Past experiences with

Table 4

Summary of the reported studies on single-incision robotic-assisted breast surgery.

Citation number	Author	Publication date	Surgery	Robotic system	Port number	Access port	Case load
[117]	Toesca *et al*	2017 Aug.	NSM and IBR	Da Vinci S	1	Single Port (Access Transformer OCTO, Seoul, Korea)	1
[118]	Park *et al*	2022 May	NSM and IBR	Da Vinci Si or Xi	1	Single Port (Lapsingle, Sejong Medical Inc., Korea)	237
[119]	Park *et al*	2019 Oct.	NSM and IBR	Da Vinci Si or Xi	1	Single Port (Lapsingle, Sejong Medical Inc., Korea)	2
			NSM and IBR	Da Vinci Si or Xi	1	Pure single incision with 3 robotic arms inserted directly	10
[120]	Park *et al*	2019 Nov.	NSM and IBR	Da Vinci Single-Port (SP)	1	GelPoint attached to Alexis O wound protector	1
[121]	Go *et al*	2022 Sep.	NSM and IBR	Da Vinci Single-Port (SP)	1	GelPoint attached to Alexis O wound protector	81

NSM indicates nipple-sparing mastectomy, IBR, immediate breast reconstruction.

Table 5

Summary of the reported studies on single-incision robotic-assisted inguinal hernia surgery.

Citation number	Author	Publication date	Surgery	Robotic system	Port number	Access port	Case load
[123]	Tran	2011 Jul.	TEP	Freehand (Prosurgics, Blacknell, UK)	1	Tri-port (Olympus Winter & Ibe GmbH, Hamburg, Germany)	16
[124]	Engan *et al*	2015 Jun.	TAPP	Da Vinci Si	1	Single-site port (NR)	45
[125]	Bosi *et al*	2016 Apr.	TAPP	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	1
[126]	Cestari *et al*	2017 Jun.	TEP	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	3
[128]	Cuccurullo *et al*	2020 Oct.	TAPP	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	44
[129]	Kim *et al*	2022 Oct.	TEP	Da Vinci Single-Port (SP)	1	Da Vinci SP access port kit (Intuitive, USA)	1
[130]	Lee *et al*	2023 May	TEP	Da Vinci Single-Port (SP)	1	Glove port (NELIS, Bucheon, South Korea)	1
[131]	Dreifuss *et al*	2023 Mar.	TAPP	Da Vinci Single-Port (SP)	1	Da Vinci SP access port kit (Intuitive, USA)	87

TAPP indicates transabdominal preperitoneal; TEP, totally extraperitoneal.

SILS have provided abundant nourishment and fertile ground for the evolution and application of SP robotic surgery in urology. Ever since Kaouk *et al*[20] performed the first series of SP robotic surgeries in 2008 using a custom designed R-Port through a 2 cm umbilical Incision, a new era of MIS has begun, throughout which was the self-perpetuating cycle of technological innovations and clinical feedbacks. Early attempts for SIRAS urologic surgery based on the Da Vinci Si or Xi platform spanned from upper urinary tract surgery, such as radical nephrectomy, partial nephrectomy, pyeloplasty, and donor nephrectomy and renal transplant, to lower urinary tract surgery, such as RP, simple prostatectomy, radical cystectomy, and lower ureteral reconstruction[133–137,143,149,153]. Multiple studies demonstrated the outstanding benefit of SIRAS urologic surgery in noninferior oncologic outcomes, satisfactory cosmetic effect, reduced postoperative pain and opioid use, shorter hospital stay and fast postoperative recovery[20,133,138–140,142,144,147,148]. With the most recent Da Vinci SP system, there are significant improvements in imaging and technical capabilities. It provided versatility with an independent instrument clutch and pivot controls that allow positioning of instruments around the robot's remote center. No significant differences between SIRAS and laparoscopy were reported in terms of oncologic outcomes such as positive surgical margin rates (24% vs. 37.3%; $P=0.08$) and biochemical recurrence rates ($P=0.472$) in RP[145,151], and trifecta achievement (11/14, 79%) and disease recurrence (0/14, 0%) in partial nephrecto[152]. Safety and feasibility of SIRAS urologic surgeries based on the Da Vinci SP system underwent further evaluation and were verified across various types of urologic surgeries[141,145,146,148,150,154].

The clinical status in gynecology

Gynecology was among the first surgical fields to adopt SIRAS (Table 7)[22,155–169], as early as in 2009 when Escobar *et al*[22] reported their experience with SIRAS hysterectomy based on the Da Vinci Single-Site system. Since then, the SIRAS approach had been applied to a wide range of gynecological procedures for treating both benign and malignant indications, such as myomectomy, hysterectomy, pelvic floor reconstructive surgery, endometriosis and ovarian cyst, and endometrial cancer[155,156,158,159,162–165]. A retrospective study of 44 cases of SIRAS radical hysterectomy for early cervical cancer by Song *et al*[169] reported a 5-year disease-free survival of 90.9%, and four cases (9.1%) of recurrence with mean recurrence times of 16.9 months. Manifesting advantages of comparable surgical outcomes, excellent cosmetic effects, and potential for reducing postoperative pain and improving ergonomics, several retrospective and comparative studies supported the safety and feasibility of SIRAS in patients with gynecological diseases[157,160,161,166–168], emphasizing on the stringent criteria for patient selection to maximize the benefits[169].

The prospects and limitations of SIRAS

After the introduction of MIS in various surgical specialties, surgeons' pursing for invasiveness minimization of surgical interventions has never been impeded. Combining robotic technology with single-incision endoscopic surgery, the novel SIRAS approach provides a new solution to the awkward dilemma of balancing invasiveness and surgical benefits. Associated with better cosmesis, minimal postoperative pain, faster recovery and declined port-related complications, SIRAS is being explored and validated for feasibility, safety, and surgical oncology by randomized controlled trials in several operations of urology and gallbladder surgery. Provided by robotic surgical platform, magnified vision, ergonomics enhancement, instrument dexterity and stability, surgical precision, as well as convenient relocation, counteract the technical obstacles of SILS, such as instrument collision, triangulation loss, poor exposure, and retraction, multisite dissection of technological demanding operations.

However, there are still several difficulties we might encounter when performing SIRAS in practice. First, in the narrow pelvis during SIRAS anterior resection, the conventional trans or periumbilical single-incision does not provide an ideal angulation for intracorporeal stapler dissection that usually required an extra trocar in inferior abdomen. Although there was a small-scale study reported their initial attempts in pure SIRAS natural orifice transluminal endoscopic surgery transanal TME, extensive and long-term explorations are still demanded. The issue is also a public concern in the fields of SIRAS total colectomy, SIRAS pancreatic surgery and the further application of SIRAS in stomach surgery. Second, the learning curve of SIRAS in technical demanding surgery has not been determined. This novel approach was reported to be easily handled in skilled surgeons and there was no significant difference found in the uptake of SIRAS between the inexperienced and experienced in relatively simpler operations, such as cholecystectomy and inguinal hernia repair. However, evidence is too scarce to form a robust conclusion under the circumstance that most of the current studies

Table 6

Summary of the reported studies on single-incision robotic-assisted urologic surgery.

Citation number	Author	Publication date	Surgery	Robotic system	Port number	Access port	Case load
[20]	Kaouk *et al*	2009 Feb.	Radical prostatectomy	Da Vinci S	1	R-port (Advanced Surgical Concepts, Dublin, Ireland)	3
[133]	Arkoncel *et al*	2011 Sep.	Partial nephrectomy	Da Vinci S	2	Homemade port with Alexis wound retractor and surgical glove for 5 trocars	35
[134]	White *et al*	2011 May	Radical nephrectomy	Da Vinci S or Si	1	The SILS port (Covidien, Mansfield, MA, USA) and the GelPort or GelPOINT port (Applied Medical, Rancho Santa Margarita, CA, USA)	10
[135]	Komninos *et al*	2014 Sep.	Partial nephrectomy	NR	1	Homemade port with Alexis wound retractor and surgical glove for 5 trocars	78
[136]	Mathieu *et al*	2014 Feb.	Radical nephrectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	6
[137]	Shin *et al*	2014 Oct.	Partial nephrectomy	Da Vinci S	1–2	Homemade port with Alexis wound retractor and surgical glove for 5 trocars (+ additional assistant trocar)	79
[138]	Kaouk *et al*	2019 Apr.	Ureteric reimplantation	Da Vinci Single-Port (SP)	1–2	GelPOINT™ Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA) (+ additional assistant trocar)	3
[139]	Lenfant *et al*	2020 Sep.	Pyeloplasty	Da Vinci Single-Port (SP)	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	9
			Pyeloplasty	Da Vinci Single-Port (SP)	2	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA) + additional assistant trocar	1
[140]	Steinburg *et al*	2020 Aug.	Simple prostatectomy	Da Vinci Single-Port (SP)	1	GelPOINT mini system (Applied Medical, Rancho Santa Margerita, CA, USA)	10
[141]	Zhang *et al*	2020 Apr.	Radical cystectomy	Da Vinci Single-Port (SP)	2	GelPOINT mini system (Applied Medical, Rancho Santa Margerita, CA, USA) + additional assistant trocar	4
[142]	Gross *et al*	2021 Aug.	Radical cystectomy	Da Vinci Single-Port (SP)	2	Pure single incision with SP trocar + 12-mm AirSeal assistant port	12
[143]	Ju *et al*	2021 Nov.	Radical prostatectomy	Da Vinci Si	1	An 8-cm quadri-channel laparoscopic port (Lagis Inc., Taichung, China)	30
[144]	Kaouk *et al*	2021 Sep.	Kidney transplantation	Da Vinci Single-Port (SP)	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	6
			Kidney autotransplantation	Da Vinci Single-Port (SP)	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	3
[145]	Lenfant *et al*	2021 Sep.	Radical prostatectomy	Da Vinci Single-Port (SP)	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	100
[146]	Abou Zeinab *et al*	2022 Aug.	Simple prostatectomy	Da Vinci Single-Port (SP)	1	Da Vinci SP access port kit (Intuitive, USA)	42
[147]	Beksac *et al*	2022 Feb.	Pyeloplasty	Da Vinci Single-Port (SP)	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	11
[148]	Francavilla *et al*	2022 Feb.	Radical prostatectomy	Da Vinci Single-Port (SP)	2	Homemade port with Alexis wound retractor and surgical glove for 5 trocars + additional 5-mm AirSeal (ConMed Corp., Utica, NY, USA) port for assistant	40
[149]	Kaviani *et al*	2022 Sep.	Kidney transplantation	Da Vinci Single-Port (SP)	1	GelPOINT access platform (Applied Medical Resources Corp, Rancho Santa Margarita, CA, USA)	12
[150]	Harrison *et al*	2023 Feb.	Partial nephrectomy	Da Vinci Single-Port (SP)	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	48
[151]	Wei *et al*	2023 Mar.	Radical prostatectomy	Da Vinci Xi	1	NR	124
[152]	Francavilla *et al*	2022 Feb.	Partial nephrectomy	Da Vinci Single-Port (SP)	1	A dedicated 25-mm multichannel port	14

Table 7

Summary of the reported studies on single-incision robotic-assisted gynecologic surgery.

Citation number	Author	Publication date	Surgery	Robotic system	Port number	Access port	Case load
[22]	Escobar *et al*	2009 Sep.	Hysterectomy and salpingo-oophorectomy	Da Vinci S	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	1
[155]	Kane and Stepp	2010 Jan.	Hysterectomy	The ViKY System 'Vision Control for endoscopY' (Endocontrol Medical, La Tronche, France)	1	SILS Port (Covidien, Mansfield, MA)	1
[156]	Fagotti *et al*	2013 Jul.	Hysterectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	19
[157]	Akdemir *et al*	2015 Jan.	Hysterectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	24
[158]	Gargiulo *et al*	2015 Dec.	Ovarian endometrioma excision	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	1
[159]	Guan *et al*	2016 Jan.	Endometriosis resection	Da Vinci Si	1	NR	1
[160]	Lopez *et al*	2016 Jan.	Hysterectomy	Da Vinci Single-Site (Si)	1	NR	50
[161]	Paek *et al*	2016 Mar.	Hysterectomy	Da Vinci Single-Site (Si)	1	Homemade port with Alexis wound retractor and surgical glove for 5 trocars	25
[162]	Choi *et al*	2017 May	Myomectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	61
[163]	Gargiulo *et al*	2017 Mar.	Myomectomy	Da Vinci Si	1	GelPOINT Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA)	21
[164]	Giannini *et al*	2017 Jun.	Apical lateral suspension	Da Vinci Si	1	Da Vinci Single-Site port (Intuitive, USA)	1
[165]	Matanes *et al*	2017 May	Sacrocolpopexy	Da Vinci (NR)	1	Single-port (NR)	25
[166]	Moukarzel *et al*	2017 Sep.	Hysterectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	14
[167]	Choi *et al*	2022 Dec.	Myomectomy	Da Vinci Single-Site (Xi)	1	Glove port (NELIS, Bucheon, South Korea)	13
			Myomectomy	Da Vinci Single-Site (Xi)	1	Da Vinci Single-Site port (Intuitive, USA)	131
[168]	Gardella *et al*	2023 Jan.	Hysterectomy	Da Vinci Single-Site (Si)	1	Da Vinci Single-Site port (Intuitive, USA)	122
[169]	Song *et al*	2023 Apr.	Hysterectomy	Da Vinci Si or X	1	Da Vinci Single-Site port (Intuitive, USA)	44

remain to be small-scale case reports for feasibility and safety examination. In addition, for complex surgeries, systematic and generalized training programs, standardized guidelines, refined protocols, and customized instruments for each specialty are expected to be improved. Third, the cost effect of SIRAS cannot be omitted. The investment of purchasing the latest robotic surgical platform compatible with SIRAS, such as Da Vinci Single-Site or SP, was no easy decision for medical institutions of any level, as it could cost millions of dollars along with all the axcessory and annual maintenance fee, just for starters[33]. This considerably hindered the availability and widespread adoption of SIRAS. Other than that, even in 'robot-existing' model, the cost benefit of SIRAS varied in different types of surgery[170]. The discordance is probably related to the balance of operative time and hospital stay, among a large number of other possible variables. Therefore, further investigations about this aspect is needed to allow an exact estimate on this issue. Finally, surgeons are never satisfied with current surgical plans and are always striving perfection in the ongoing loop of technological innovation and application. Further modification and adaption of the Da Vinci robotic system should be investigated to both alleviate workload and bend the steep learning curve for inexperienced surgeons in commonly adopted surgeries and facilitate better performance for technically challenging procedures.

In terms of long-term follow-up of patients who underwent SIRAS, current literature exhibits a scarcity of outcomes from large-volume prospective study and well-designed randomized controlled trial and cannot finalize the controversies and concerns accompanied with the debut of novel surgical approach. To protect the rights of participants, oncologic safety and post-operative quality of life should not be sacrificed at any situation, which are the priority in carrying out clinical research of SIRAS. Other aspects that affect the choice of SIRAS for surgeons and patients should be given more attention, such as the general cost for SIRAS and its economic effect possibly causing bias in patient enrollment, and discussion for appropriate indications and contraindications of SIRAS to reduce the misuse of this novel approach.

Conclusions

In conclusion, SIRAS proves to be safe and feasible with remarkable advantages in noninferior clinical outcomes and better cosmetic effect in the limited range of surgery among the strictly selected patients, providing surgeons with more instinctive surgical experiences. In the promising future, SIRAS has the potential to become the dominant surgical option for MIS after the verifications from a wide range of large randomized controlled trials and high level evidence.

Ethical approval

The study procedures were approved by the ethics committee of Shanghai Ruijin Hospital affiliated with Shanghai Jiao Tong University School of Medicine.

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Author contribution

X.C.: data curation, formal analysis, methodology, visualization, writing-original draft, writing-review and editing, funding acquisition. C.H.: data curation, formal analysis, methodology, visualization, writing-original draft. W.J. and Z.G.: data curation, formal analysis, methodology, visualization, writing-original draft, writing-review and editing. Y.S., Z.S., and H.H.: data curation, formal analysis, methodology. S.X. and H.L.: data curation, formal analysis, visualization. S.W. and Y.Z.: data curation, methodology, visualization. T.Z.: conceptualization, data curation, methodology, supervision, writing-review and editing, funding acquisition. K.L.: writing-review and editing, visualization, data curation, supervision, methodology, funding acquisition. X.J.: conceptualization, supervision, methodology. R.Z.: conceptualization, formal analysis, funding acquisition, methodology, supervision, writing-review and editing.

Conflict of interest disclosure

The authors declare no conflict of interest.

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Guarantor

Ren Zhao, Xiaopin Ji, Xi Cheng, and Kun Liu.

Data statement

The data that support the study findings are available upon reasonable request from the corresponding authors (Ren Zhao, Xiaopin Ji, Xi Cheng, and Kun Liu).

Meeting presentation

None.

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