Introduction: From Multiport Laparoscopic Surgery to Single-Port Laparoscopic Surgery

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1.1 General Considerations

Minimally invasive laparoscopic surgery reduces abdominal parietal trauma while strictly respecting the surgical principles of open surgery. Due to sound and scientifically proven benefits, the laparoscopic approach has become the gold standard for specific interventions such as cholecystectomy, antireflux procedures, and bariatric surgeries, with a worldwide penetration. For more complex procedures, such as colorectal resections, mainly for cancer, the penetration rate among the surgical community is still surprisingly low, reaching barely 40 % in the best cases [1–7]. Lack of adequate training of surgeons, as these are complex and challenging operations with a long learning curve [8], and concerns about oncological safety of the procedure [9] have accounted for this slow uptake. Since Jacobs first described a laparoscopic colectomy in 1991 [10], it has taken a relatively long time and four major clinical trials published between 2002 and 2004 [11–14] to firmly convince skeptical surgeons of the overwhelming advantages of laparoscopy over open surgery in the colorectal field.

Reduction of postoperative pain and of wound complications, reduced formation of intra-abdominal adhesions, shorter hospital stays with reduced medical costs, earlier return to professional activities, and improved cosmetic outcomes are the benefits of the standard multiport approach over conventional large laparotomy incisions.

The achievement of multiport laparoscopic surgery and the continued technological effort to facilitate the spread of this creed have opened further horizons towards even less invasive approaches.

The obvious rationale to persevere in this quest lies in that each abdominal incision carries the risks of morbidity originating from bleeding, hernia, and internal

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G. Pignata et al. (eds.), *Single-Access Laparoscopic Surgery*,
DOI 10.1007/978-3-319-06929-6_1,

organ injury and exponentially affects cosmetic outcome. In a nutshell, the size and number of incisions matter [15].

This novel surgeon-incision relationship culminated with the concept of natural orifice transluminal endoscopic surgery (NOTES). In NOTES, endoscopes, flexible or rigid, and operating instruments are introduced into the abdominal cavity through natural orifices (stomach, vagina, rectum, or bladder) communicating with the external environment, without any trauma to the abdominal wall. Again in France, 20 years after Mouret's first laparoscopic cholecystectomy, the first transvaginal scarless cholecystectomy was performed in Strasbourg [16] and gave birth to the NOTES era.

This "surgery without scars" may potentially offer reduced, if not inexistent, postoperative pain that could well accelerate the patient's return to daily activities and produce optimal cosmetic results. However, the penetration of NOTES is still very limited, as was laparoscopy in its infancy. Although substantial improvements have been made, the multiple challenges of the technique, namely, the inability to obtain an effective surgical triangulation and to achieve good exposure of the surgical field, have limited patient recruitment. To push the concept forward, further refinements of surgical endoscopic platforms and possibly the integration of robotic assistance are required [17]. The most commonly used current strategy to attempt NOTES without compromising surgical safety is a "hybrid" approach associating a natural orifice access with some transparietal assistance [18–21].

The global brainstorming generated in the attempt to solve the challenges of NOTES has rekindled interest in a probably less disrupting, but certainly more realistic, concept: single-incision surgery or surgery with fewer scars.

Laparoendoscopic single-site surgery (LESS) falls within the same quest to reshape the surgery-incision axiom: a single surgical abdominal access is created through which multiple instruments are inserted simultaneously via a large-caliber single-port device or via small adjacent ports placed into one or multiple fascial incisions [15, 22]. Single-incision surgery has been given a wide range of acronyms and names, including single-incision laparoscopic surgery (SILS), single-access laparoscopic surgery (SALS), single-port access (SPA) surgery, single laparoscopic incision transabdominal (SLIT) surgery, one-port umbilical surgery (OPUS), natural orifice transumbilical surgery (NOTUS), and embryonic natural orifice transumbilical endoscopic surgery (E-NOTES). A recent consortium of experts has finally agreed on the acronym of laparoendoscopic single-site surgery (LESS) [23].

The first descriptions of single-incision laparoscopic digestive surgery date back to more than 10 years [24–26]. However, the approach initially failed to gain popularity due to technical limitations with conventional instrumentation and due to a general lack of advanced laparoscopic skills. Again the same refrain: LESS poses unique difficulties that dramatically hinder the fundamental principle of laparoscopy surgery, i.e., "triangulation," and compromise ergonomics with limited surgical maneuvers and repeated conflicts between instruments, impaired vision, wider umbilical incisions, and a subsequent risk of parietal complications [27]. LESS is another instance that surgical progresses can be made only through a systematic approach to surgical technology innovation and bio-design, where engineers and surgeons create the interface to design specific solutions to deal with specific

challenges. We have recently reviewed the current technology armamentarium to cope with LESS [28], which will be further developed in the present book, in a dedicated chapter. LESS has been applied to a variety of procedures, including complex surgeries such as bariatric [29] and colorectal [30].

As per cholecystectomy, which is often the sounding board to test new technologies, there is limited evidence of improved outcomes of LESS when compared to conventional laparoscopic approaches. In a recently published prospective randomized clinical trial comparing LESS vs. standard multiport cholecystectomy [31], including 200 patients with 12 months of follow-up, the LESS group presented higher pain scores ($p=0.028$) and greater wound complication rates ($p=0.047$) when compared to standard four-port cholecystectomy. In addition, operative time was statistically significantly longer in LESS (57 vs. 45 min, $p=0.0001$). Safety profile was similar between the two techniques. The only favorable point for LESS was improved cosmesis score ($p=0.002$).

A recent systematic review and meta-analysis by Markar et al. [32] pooled information from seven randomized trials comparing clinical outcomes between "conventional" multiport vs. LESS cholecystectomy for uncomplicated biliary disease. It showed no statistical difference between both techniques for primary outcomes such as postoperative complications and postoperative pain nor secondary outcomes such as hospital stay. The only statistically significant difference was operative time, which was higher in LESS cholecystectomy.

It has to be pointed out that cholecystectomy is probably not the killer application for LESS, at least with current technology, since it is difficult to perform better than a laparoscopic multiport approach, without increasing operative risks or complexity.

Quite different considerations can be made for LESS in colorectal surgery. There are at least two situations in which a LESS approach can maximize outcomes: the first one is when a protective ileostomy is planned and the future ileostomy site is used as the single access to perform the procedure and to extract the specimen offering a virtual zero scar procedure [30]. The second situation is when a natural orifice specimen extraction (NOSE) is performed to avoid port-site incision enlargement or to perform a mini-laparotomy for surgical specimen extraction and/or to perform the anastomosis [20, 21, 33, 34]. However, efforts are still required to teach and standardize such quite advanced procedures. The next advance in LESS in the colorectal field lies in the optimized use of the Transanal Endoscopic Operation (TEO™) platform, which is basically a single-port device that can allow for pure transanal total mesorectal excision (TME), as could be demonstrated in the experimental [35–37] and clinical setting [38].

1.2 Robotic Assistance and LESS

Robotic research has provided specific technology to facilitate single-incision surgery ruling out the difficulty to achieve surgical triangulation with instruments entering the body from a single surgical access [39]. As outlined by the recent transdisciplinary review by Balaphas et al. [40], the majority of clinical applications of

robotic LESS belong to urology and gynecology with only minor experiences in digestive surgery.

The initial experiences with robotic LESS have been performed using the da Vinci® Surgical System robot by Intuitive Surgical, Inc. (the only available surgical robotic platform) in combination with various clinically approved single-port devices (SILS™, GelPort™, and GelPoint™) or through multiple fascial incisions. Ostrowitz successfully completed three right hemicolectomies using a SILS™ port and a single or multiple fascia incisions alternatively [41]. The author experienced some troubles with robotic arms through the SILS™ with cluttering of instruments within the port and a range of motion restriction as well as elevated torque force transferred onto the abdominal wall. To carry on the procedure, an additional port was placed in the umbilicus outside the SILS™ port. Similarly, Romanelli et al. [42] attempted a robotic LESS cholecystectomy through a single skin incision and multiple fascial entries, but the robotic procedure was aborted due to high torque forces resulting in loss of pneumoperitoneum and pursued with hand-held single-incision laparoscopic cholecystectomy. The geometry of the GelPort™ and GelPoint™ used by Singh [43] and Ragupathi [44], respectively, allowed for a greater freedom of movement, and the procedure was completed smoothly.

Recently, Intuitive Surgical, Inc. introduced a specifically designed Robotic Single-Site (VeSPA®) instrumentation. So far only cholecystectomies have been performed in the clinical setting [45–51] using this new platform. The general feeling with these preliminary cases is that robotics simplifies LESS cholecystectomy [50], but still remains more difficult than standard multiport surgery. In the largest series available from a multicenter trial, a 2 % conversion rate to open surgery and only minor intraoperative complications (gallbladder ruptures and minor bleeding) have been reported. In a case-matched study comparing robotic LESS with standard multiport cholecystectomy, Wren et al. [51] reported no difference in total operative time. On the other hand, Spinoglio et al. [50] reported a statistically significant operative time reduction in the robotic LESS group when compared to the "manual" LESS cholecystectomy group ($p<0.006$). Globally, the da Vinci® Surgical System is an impressive concentrate of technology, accounting for the high costs. Considering the mild benefits for patients demonstrated so far, these costs are prohibitive today. The improvement of robotics should go through changes in the shape of surgical telemanipulators and miniaturization.

1.3 Perspectives for LESS: Miniature Robots and Surgical Endoscopic Platforms

Robotic surgery encounters enthusiastic favors and sarcastic criticisms. It is our personal belief that robotics- and computer-assisted surgery will bring surgery to the next era. However, at least for the digestive tract, new generations of robotic platforms are required. Some promising prototypes are being developed such as the miniature dexterous robot conceived at the Nebraska Medical Center, which can be assembled directly in the abdominal cavity and can perform complex surgical tasks

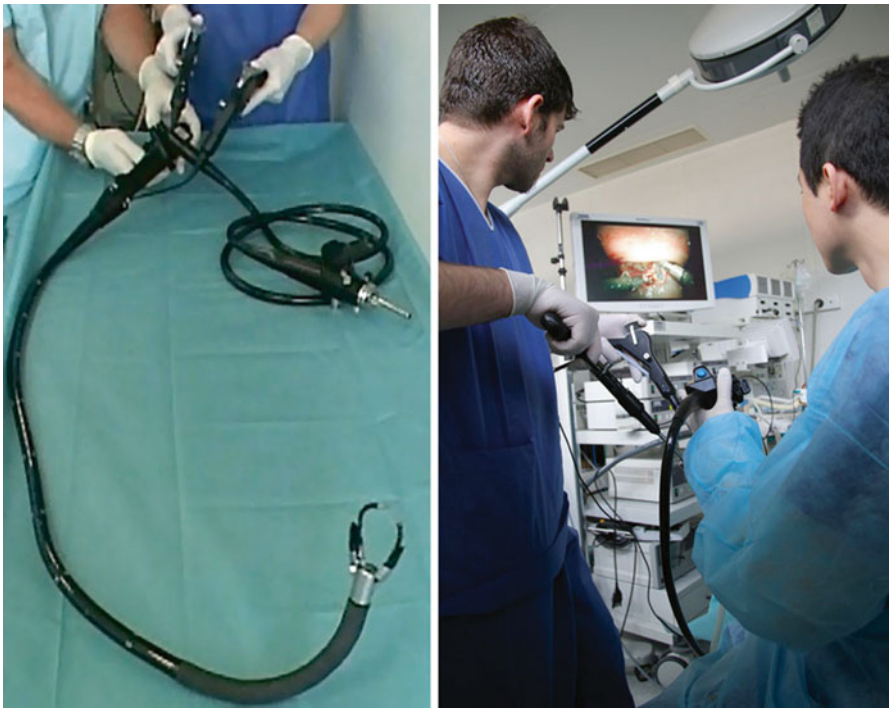

Fig. 1.1 The ANUBISCOPE® (Courtesy of Karl Storz, Tuttlingen, Germany) is a flexible surgical endoscopic platform adapted to Laparo-Endoscopic Single-Site Surgery and to natural orifice transluminal endoscopic surgery. The shaft houses two 4.3-mm and one 3.2-mm working channels to insert operating instruments. The tip opens up like a clam shell to space instruments and offers surgical triangulation. Instruments have an articulated tip, allow for 5° of freedom, and are manipulated by two intuitive handles

[52]. Similarly, the SPRINT (single-port laparoscopy bimanual robot) is a teleoperated mini-robotic system that shows promising results [53] and some snake-like robotic platforms, specifically conceived for single-port surgery [54]. At the IRCAD Institute, we have developed a new surgical endoscopic flexible robotic system that originates from a mechanical hand-held platform, the ANUBISCOPE® (Karl Storz, Tuttlingen, Germany). This platform is composed of a flexible shaft that houses two 4.3-mm and one 3.2-mm working channels. The shaft's tip opens up like a clam shell to space instruments and offers surgical triangulation. Instruments have an articulated tip and allow for 5° of freedom and are manipulated by two intuitive handles (Fig. 1.1). The mechanical device has been used to perform a series of experimental hybrid NOTES procedures [55] and endoluminal procedures such as colonic endoscopic submucosal dissection (ESD) [17]. A shorter version of the ANUBISCOPE®, the ISISSCOPE®, 55 cm in length and 1.8 cm in diameter, has been successfully used in the clinical setting to perform single-port cholecystectomy [56]. The robotic version is telemanipulated through an intuitive haptic interface that allows for very smooth and controlled micromovements (Fig. 1.2). It has

Fig. 1.2 The robotic version of the ISISSCOPE® (Courtesy of Karl Storz, Tuttlingen, Germany) is telemanipulated through an intuitive haptic interface that allows for very smooth and controlled micromovements

so far been used to perform ex vivo tests such as endoscopic submucosal dissections in porcine stomachs and colons, showing a high agility as well as the ability to transfer a sufficient amount of force for traction, suturing, knot tying, and dissection.

Conclusions

LESS has the potential to positively influence incision-related morbidity, cosmetic outcome, and overall perioperative morbidity in selected procedures. Specifically applied to the colorectal field, LESS may offer enhanced recovery, particularly when coupled with natural orifice specimen extraction or when the site of a planned stoma is used as the access point. However, the uptake of LESS will depend on further technological developments as well as on the creation and implementation of new generations of miniature robotic platforms.

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