Single-Incision Laparoscopic Surgery (SILS) in Biliary and Pancreatic Diseases

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Abstract Laparoscopic cholecystectomy is the gold standard for gallbladder removal and the most common laparoscopic procedure worldwide. With the advent of laparoscopic surgery and its continuous development, the focus has shifted to ‘scarless’ surgery. In recent times, the innovative technique of single-incision laparoscopic surgery (SILS) has been applied in gallbladder removal and even more complex biliopancreatic procedures to further minimize the invasiveness of the surgery. Newer developments in laparoscopic equipments and instrumentation have helped to further evolve this field of minimally invasive surgery. Literature search was performed using the following online search engines: Google, Medline, PubMed, Cochrane, and the online Springer link library. The terms used for the search were as follows: SILS, LESS, single-incision laparoscopic surgery, single-port laparoscopic surgery, SILS cholecystectomy, and SILS pancreatic surgery. Articles that matched the search criteria were selected and extensively reviewed. Moreover, pertinent information on instrumentation and technology for SILS and LESS was obtained by accessing websites of manufacturers. Although SILS represents the search for an essentially scarless surgery, there is still not a widespread use and uniformity of this procedure. SILS is performed either by single- or multiple-port technique. In the present article, we present a review of the potential benefits, limitations, and risks of SILS in biliary and pancreatic diseases. There are many studies showing benefits in cholecystectomy. A few case

reports have also emerged about its feasibility in procedures such as cystogastrostomy and limited pancreatic resection. Further research and development of this technique is needed to arrive at a tangible conclusion about the perceived benefits of SILS. Randomized studies to compare SILS with traditional laparoscopy are essential.

Keywords Cholecystectomy · Single-incision laparoscopic surgery · SILS

Introduction

Over recent decades, the evolution of laparoscopic techniques has transformed much of the traditional surgery. Compared to an open approach, minimally invasive techniques have proven effective in reducing surgical trauma, thereby improving patient recovery and length of hospital stay [1, 2]. Benefits of improved postoperative pain and cosmesis are now well established for many operations [3–5].

However, the true birth of laparoscopy can be dated to over 100 years ago when George Kelling from Dresden, Germany, introduced a cystoscope into the peritoneal cavity of a living dog and insufflated air to enhance the view [3, 6]. Surgery of the gallbladder has tremendously evolved over the last century. Carl Langenbuch performed the first successful cholecystectomy on a 43-year-old man with symptomatic cholelithiasis in 1882 [7]. More than a century later (in 1985), German surgeon Eric Mühe [8] applied the technique of laparoscopy to remove a gallbladder using a modified laparoscope, called the galloscope. It was soon thereafter (1987) that the advent of the computer chip television camera allowed Phillipe Mouret to perform the first video-laparoscopic cholecystectomy [9].

Today, laparoscopic cholecystectomy is the gold standard for gallbladder removal and the most common

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laparoscopic surgical procedure in the world. Numerous reports have provided overwhelming evidence that laparoscopy provides better cosmetic results, less postoperative pain, and shorter recovery time when compared with open cholecystectomy [7]. However, the quest to develop even more minimally invasive surgical techniques in order to enhance the advantages of laparoscopy remains robust. This quest has led surgeons to seek to minimize the number and the size of incisions, or in the case of natural orifice transluminal endoscopic surgery (NOTES), eliminate skin incision(s) altogether. The hope of these more minimally invasive procedures is that they will also lead to minimal or no postprocedural pain while improving cost-effectiveness and patient safety.

Although totally incisionless surgery remains an impossible idea at present, NOTES, initially performed in animal models, [10] is now a clinically relevant idea with anecdotal procedures having been performed on human subjects worldwide. Reddy and Rao [11] are credited with performing the first transgastric appendectomy in a human without an external incision, and Marescaux et al. [12] performed the first cholecystectomy via a natural orifice. As a bridge between traditional laparoscopy and NOTES, recent focus has been on the development of single-incision laparoscopic surgery (SILS) to further minimize the invasiveness of laparoscopy by reducing the number of incisions, and hopefully the pain and complication(s) associated with them. SILS was described as early as 1992 by Pelosi and Pelosi [13] who performed a single-puncture laparoscopic appendectomy and in 1997 by Navarra et al. [14] who performed a laparoscopic cholecystectomy via two transumbilical trocars and three transabdominal gallbladder stay sutures. These innovations, either exclusively or in a hybridized fashion, have now been applied to a wide variety of surgical procedures.

Technological improvements have led to a progressive contraction in the size and number of operating ports; hence, reducing abdominal wall trauma and providing further benefits for the patients [15]. The switch from four to single incision has constantly shown better outcomes in terms of postoperative pain and cosmetic results [16–18], and may reduce the risk of trocar-site-related complications such as incision hernia or infections.

Single-port laparoscopic surgery is increasingly being performed today. It is deemed a safe and effective procedure, but has not yet passed the acid test because of operative difficulties, partly due to the lack of adapted instruments [19]. Since operating instruments come from a single port, there is a lack of triangulation with repeated conflicts between operating instruments as well as a lack of proprioception due to the crossing of instruments with difficult exposure of organs and structures [20]. Surgeons have to get used to these new surgical constraints and may be starting a new learning curve.

Nomenclature

Unlike NOTES, to date, no consensus terminology has emerged for this technique of minimally invasive surgery. Many terminologies, seemingly centered on the type of acronym they will create, have been used rather than a description of the access technique and exposure methods [21]. One of the early nomenclatures to gain popularity was single-port access (SPA) surgery.

Manufacturers of instruments have also adopted nomenclature of their own. Covidien Inc. has termed this new technique as single-incision laparoscopic surgery (SILS), whereas Ethicon EndoSurgery Inc. has proposed the nomenclature of single-site laparoscopy (SSL) [21].

Some of the nomenclature is based on the site of access such as one-port umbilical surgery (OPUS) or transumbilical endoscopic surgery (TUES), embryonic NOTES (eNOTES), and natural orifice transumbilical surgery (NOTUS). Other nomenclature suggested include single laparoscopic port procedure (SLAPP), single-port laparoscopic surgery (SPLS), single-port laparoscopy (SPL), single laparoscopic incision transabdominal (SLIT) surgery [21].

A recent symposium, convened to arrive at a consensus regarding the single-port concept, has suggested the name laparoendoscopic single-site surgery (LESS) [22]. Another nomenclature that implies facility with the technique is single-incision multiple-port laparoscopic surgery (SIMPLE). Regardless of the final nomenclature that emerges there is a current lack of consensus about the nomenclature for this evolving technique.

Single-incision laparoscopic surgery can be broadly classified into three types based on the method of access:

1. Single-incision single-port surgery
2. Single-incision multiple-port surgery
3. Single-incision direct access surgery

Equipment

Single-Incision Surgery Devices

Single-Incision Single-Port Devices

The use of a single port permits the entry of three or four instruments through a single opening in the umbilicus and leaves a fascial defect that is easy to close. There are a number of different access ports including GelPort® (Applied Medical, USA), the SILS® (Covidien, Norwalk, CT, USA), the R-Port® and TriPort® (Advanced Surgical Concepts, Wicklow, Ireland), the Uni-X® (Pnavel, New Jersey, USA), SSL® (Ethicon, USA), Air Seal® (Surgi Quest, Orange, CT, USA), X-Cone® and EndoCone® (Karl Storz, Germany).

R-Port® and TriPort® (Figs. 1 and 2)

The R-Port® was the first of these devices that had a single-gel interphase that can be perforated many times to get the instruments in. This led to the development of multivalve ports currently in use. The TriPort® system has two 5-mm and one 12-mm ports. In addition, it has an insufflation port and the retractor system that firmly grips the incision, ensuring a gas-tight seal.

AirSeal® access port (Fig. 3)

The AirSeal® access port uses a technology that is different to the typical laparoscopic ports. It uses a pressure barrier to maintain pneumoperitoneum rather than the traditional mechanical barrier use by other ports. AirSeal® re-circulates and filters peritoneal gas—instead of venting it into the room—providing for improved visibility and creating a safer work environment for the patient and the entire surgical staff. Since the system does not require valves or gaskets, the instruments move smoothly through its invisible barrier, without debris and tissue fragments adhering to the scope and obstructing vision.

One disadvantage with the AirSeal® is the noise associated with the pressure barrier similar to the opening of the valve of a standard laparoscopic port.

SILS® Port (Fig. 4)

The SILS® port device is hourglass shaped and is made from an elastic polymer. It can be deployed through a 2-cm fascial incision. It contains four openings; one for insufflation via a right-angled tube and three openings that can accommodate trocars 5–12 mm in size. The compressible elastic polymer allows the access ports to snugly fit in the incision.

X-Cone® and EndoCone® (Figs. 5 and 6)

The X-Cone® and EndoCone® devices are the first reusable devices developed for SILS. The design of X-Cone® offers high instrument mobility, stable guidance,

Fig. 1 R-Port®

Fig. 2 TriPort®

and comfortable introduction technique. Three working channels permit the introduction of instruments up to 12.5 mm in size (clip applicator, stapler). Special curved instruments permit adequate triangulation, a good overview of the site, and exact manipulation both inside and outside of the body. The use of a special, extended length telescope reduces the risk of instrument collision and creates the perfect conditions for optimal image quality, as it is compatible with high-resolution, true-color 3-chip HD cameras (IMAGE 1 HD).

The EndoCone® was designed to enable instrument triangulation, albeit reduced from the ideal 60–30°, because of the restricted space imposed by the access port. To achieve this, the shape of the port is complex and consists of a proximal section (cone), leading to a short cylindrical section for negotiation through the abdominal wall and having an outer diameter of 35 mm. This cylindrical section

Fig. 3 AirSeal®

Fig. 4 SILS Port®

has a protruding rim of sufficient width that aids insertion of the EndoCone® (by a clockwise movement) and ensures secure retention within the abdominal wall. The proximal conical section of the EndoCone® is capped with a separate seal cap (bulkhead) that houses 8 valved instrument seals: two large ones in the midline (for instruments up to 15 mm in diameter) and three on either side (for instruments up to 5 mm in diameter).

Single-Incision Multiple-Port Technique

The technique has also been described as SIMPLE by some authors. In single-site multiple-port access, all trocars (usually three or four) are inserted transumbilically. The trocars, which are low profile and short to minimize clashing of instruments, are inserted using a special technique. This results in good triangulation and minimization of visible scarring. Flexible trocar sleeves are used for curved instruments. The best combination of instruments required for SIMPLE typically includes three or four ports, each 5 mm or smaller in diameter. The placement of multiple ports through separate fascial incisions in close

Fig. 5 Xcone®

Fig. 6 EndoCone®

proximity raises concerns about incisional hernias during follow-up.

The AnchorPort® (SurgiQuest, Orange, CT, USA) (Fig. 7) is a trocar that anchors itself in the abdominal wall by using an integrated elastomeric, stretchable cannula system that goes in elongated and when the insertion gun is retracted, self adjusts to the abdominal wall thickness. The short trocar size made possible by this mechanism prevents the instruments from crisscrossing. The device can be inserted through a 1-inch skin incision through which three or more cannula ports can be inserted.

Another trocar useful with this technique is the Hunt Cannula/Trocar® (Apple Medical, USA) that anchors itself securely to patients by fascia threads that hold cannula securely in place, regardless of the number of instrument

Fig. 7 AnchorPort®

changes [21]. Its short, low internal/external profile design enhances instrument maneuverability and it accommodates 5-mm instruments.

Single-Incision Direct Access Surgery

In single-site direct access surgery, central telescope trocar is the only trocar necessary. The instruments are directly inserted through the abdominal wall just beside the telescope trocar (direct access). The DAPRI instruments designed by Karl Storz have optimal sheath curvature, which ensures that the handles do not enter the operating range of the laparoscope. This permits the surgeon to work in a comfortable, ergonomic position without the surgeon and the camera assistant interfering with one another.

Hand Instruments

Hand instruments come in two configurations—standard or articulating. Standard hand instruments are rigid in design and were developed over the last 30 years for use in laparoscopy. Articulation is designed to overcome one of the challenges inherent in SILS, i.e., decreased triangulation of instruments. A number of factors influence a surgeon's decision to use standard or articulating hand instruments including which access port they use, their own surgical skills, and cost, as articulating instruments are significantly more expensive than standard instruments.

The articulating instruments initially in use were the RealHand® (Novare Surgical, CA, USA) and Autonomy Laparo-Angle® articulating instruments (CambridgeEndo, Framingham, MA, USA). Newer instruments such as Roticulator instruments (Covidien) provide up to 80° of articulation and infinite freedom of tip placement. This enables optimum tissue manipulation and triangulation with hand-like access to difficult anatomy. These instruments give the maneuverability to perform SILS procedures through one access point. By facilitating a high level of surgical dexterity, precision, and control, roticulator instruments provide the same angle of approach to the target tissue through a single access point, as compared with traditional hand instruments used in multiple port laparoscopic surgery.

Video Equipment

Although standard 10-mm 30° scopes can be used, the recommended extralong 5-mm telescope or the ENDOCAMELEON® (Karl Storz, Germany) (Fig. 8) is reducing the risk of instrument collisions and create the perfect conditions for an optimal image quality and ergonomics. The EndoEye® (Olympus, Tokyo) (Fig. 9) has the 'chip on tip'

Fig. 8 ENDOCAMELEON®

technology with a single coaxial cable and a deflectable tip with a camera. The associated 90° light cable connector helps to reduce clashing between the operating instruments and the light cable. Although standard laparoscopic units might be used for SILS, the use of a high system is extremely helpful due to the brilliant image quality and the wide screen picture.

SILS in Biliary Disease

Laparoscopic Cholecystectomy

Cholecystectomy is the most common surgical procedure to which significant efforts have been applied toward the development of technique and equipment, for both NOTES and SILS. Navarra et al. [14] performed the first SILS cholecystectomy in 1997 using two 10-mm trocars and three transabdominal stay sutures to aid in gallbladder retraction. Piskun and Rajpal [23] described the use of two 5-mm trocars and two stay sutures in 1999. In both these methods, the two trocars were inserted through the

Fig. 9 EndoEye®

umbilicus, and were used for a camera and a working instrument, respectively. The two umbilical fascial incisions were united by cutting the bridge between them to allow retrieval of the gallbladder.

In place of sutures, Cuesta et al. [17] inserted a percutaneous Kirschner wire subcostally and modified it into a hook intraperitoneally. This wire hook was used to provide exposure of Calot's triangle. The authors used this technique to successfully treat ten female patients with cholelithiasis, with an average operative time of 70 min.

Gumbs et al. [24] used the same approach as performed by Cuesta et al. except that they were able to operate with a deflecting laparoscope, an articulating grasper, a straight dissector, and without suspension sutures. Rao et al. [25] utilized an R-Port® to perform 20 SILS cholecystectomies. The authors successfully performed cholecystectomy in 85% of the patients on whom it was attempted, with an average operative time of 40 min. In seven of the 17 cases completed, a stay suture in the right subcostal area was required to expose the Calot's triangle. Importantly, the authors noted the complexity of the procedure, despite careful selection of patients which excluded those with severe acute cholecystitis or history of pancreatitis, but nevertheless achieved a successful outcome in the vast majority of patients.

A similar technique, using a TriPort® system, has also been reported by Romanelli et al. [26] in the completion of their first case of SILS cholecystectomy. Merchant et al. [27] have reported the completion of 21 SILS cholecystectomies using a similar multichannel port termed as the Gelport® system. The operative times ranged from 45 to 90 min. All patients in the series studied by Merchant et al. had symptomatic cholelithiasis and one of the two, who had acute cholecystitis, required placement of an accessory port in the right upper quadrant to achieve safe dissection.

Zhu et al. [28] have performed a total of 40 different cases of transumbilical endoscopic surgery (TUES) using special instruments, including a trichannel umbilical trocar (15 mm in diameter), which allows for insertion of a flexible endoscope or a laparoscope through the 5-mm channel, and semirigid working instruments through each of the other two 2.8-mm channels. They performed six cholecystectomies using a trichannel trocar and another 20 using a double-trocar technique through the umbilicus. In all cholecystectomies, a 2-mm grasper, inserted through an extraincision in the right upper abdomen, was used to retract the gallbladder. They were able to successfully remove the gallbladder using this technique in all but one case, which required conversion to standard laparoscopic procedure for uncontrolled hemorrhage.

Palanivelu et al. [29] performed a study to assess the feasibility of a minimally invasive hybrid cholecystectomy technique. The procedure used a 2-mm Veress needle

placed transumbilically to create pneumoperitoneum with the subsequent placement of a 15-mm double-channel endoscope through which working instruments were introduced. Another 3-mm trocar was inserted in the left hypochondrium to retract the gallbladder. Ten well-selected cholelithiasis patients (four males, six females; average age 29.5 years), excluding those the authors thought may have complicated disease, underwent this hybrid procedure and 50% were completed successfully. Four of the ten cases were converted to conventional laparoscopic cholecystectomy due to uncontrollable hemorrhage from the cystic artery (two), and difficulty in dissection (two). One of the six patients who underwent the hybrid procedure was readmitted on the fourth postoperative day for a biliary leak (90 mL biloma) due to clip slippage from the cystic duct stump. This complication was treated with ERCP and bile duct stenting.

Chow et al. [30] have used a two-port technique using roticulating instruments through the umbilicus. They used two stay sutures to 'puppeteer' the gallbladder, thus, replicating the movements of traditional laparoscopic instruments. In their study, SILS cholecystectomy was done for 23 patients. All patients scheduled for laparoscopic cholecystectomy were considered for SILS cholecystectomy. There were no additional contraindications to SILS surgery beyond the standard contraindications to laparoscopic cholecystectomy.

The average operative time for these cases was 127 min (range, 60–276 min). The longest case required 276 min and involved a patient with acute cholecystitis. All patients were discharged within 48 h, with the majority going home in less than 23 h. The patient response to SILS cholecystectomy was positive, especially with regard to the cosmetic benefit. Their only postoperative complication was a biliary leak from an accessory duct of Lushka. The authors do not think this would have been avoided by the use of the standard laparoscopic technique.

Duron et al. [31] used a SILS® port to perform single-incision cholecystectomy. Their patient population consisted of 43 women (78%) and 12 men (22%) with a mean age of 44.2 years (range, 22–89 years). Their body mass index ranged from 16.1 to 46.8 kg/m² (mean 29.1 kg/m²). The mean operating room time was 66.5 min (range, 30–140 min). Of the 55 patients, 6 had acute cholecystitis, typically associated with more challenging dissections. One patient had gallstone pancreatitis. The first 19 cases were managed through a single incision, but with two fascial defects through which the ports were placed. The last 36 cases were managed through a single skin incision with a single fascial incision. Follow-up assessment was documented for 6 months to 2 years after surgery. No port-site hernias, wound infections, small bowel obstruction, or other postoperative complications were observed. There were no readmissions to the hospital.

Cholecystojejunostomy

Tian et al. [32] reported on transumbilical single-incision cholecystojejunostomy. Two 58-year-old patients (one male) underwent this procedure. The male and female patients were diagnosed with duodenal papillary carcinoma and pancreatic cancer, respectively. The hepatocystic junction was preoperatively confirmed to be patent in both patients. A 2-cm periumbilical incision was made for the placement of three trocars. Conventional rigid laparoscopic instruments were solely used throughout the procedure, and operative techniques were carried out in the same fashion as for conventional laparoscopic cholecystojejunostomy.

The procedures were completed uneventfully in 190 and 155 min, respectively, with no complications, and the estimated blood loss was 80 and 20 mL, respectively. Postoperative pain scores on postoperative day 1 were 4/10 and 3/10, respectively. The patients were discharged from the hospital on postoperative days 3 and 5 with resolving jaundice.

They concluded that transumbilical single-incision laparoscopic cholecystojejunostomy appears to be a technically feasible alternative to standard laparoscopic procedure and can be performed using conventional laparoscopic instruments.

SILS in Pancreatic Disease

Cystogastrostomy

Lutfi et al. [33] have reported a case of hand-sewn cystogastrostomy using the single-incision laparoscopy with a flexible-tip laparoscope. A 53-year-old patient of symptomatic pseudocyst in distal pancreas underwent single-incision transumbilical hand-sewn cystogastrostomy. The surgery was performed using a 1.5-cm umbilical fascial incision through which a Multichannel TriPort® was placed. A flexible 5-mm laparoscope and a 5-mm roticulating grasper were used. The stomach was retracted using percutaneous sutures. The procedure was successfully completed with no complications. The patient was discharged after 48 h and she was asymptomatic on 3 months follow-up. The authors concluded that even advanced procedures such as cystogastrostomy can be performed by single-incision laparoscopy.

Pancreatic Resection

Barbaros et al. [34] have reported the first transumbilical single-incision laparoscopic pancreatectomy in a patient who had renal cell cancer metastasis in her pancreatic corpus and tail. A 59-year-old female who had metastatic lesions on her pancreas underwent laparoscopic subtotal pancreatectomy through a 2-cm umbilical incision. Single-

incision pancreatectomy was performed with a special port (SILS® port) and articulating instruments. The procedure lasted 330 min. Estimated blood loss was 100 mL. No perioperative complications occurred. The patient was discharged on the seventh postoperative day with a low-volume (20 mL/day) pancreatic fistula that ceased spontaneously. Pathological examination of the specimen revealed renal cell cancer metastases. They concluded that transumbilical single-incision laparoscopic pancreatectomy is feasible and can be performed safely in well-experienced centers.

Future Perspectives

After more than two decades since the first laparoscopic cholecystectomy, new treatment methods such as NOTES and robotic surgery are gaining more and more interest. Newer camera systems are being developed to reduce the number of ports.

The initial robots created in the mid 1990s were used only for telescope holding and they were steered with voice. With the development of technology, precise machines were developed, which were able to carry out complicated procedures (fundoplication, gastrectomy, or colectomy), even across long distances. At present, two types of robots are being used in surgical practice: Da Vinci® (Intuitive Surgical, Sunnyvale, California, USA) and Zeus® (Intuitive Surgical). SILS has inherent difficulties in instrument manipulation and visibility when performed without robots. The Da Vinci Surgical System allows some of these ergonomic challenges to be obviated with potentially reduced instrument clash, reduced surgeon and assistant fatigue, and better precision with target tasking. It is envisioned that once satisfactory and acceptable surgical access is obtained with the various modalities of single-incision surgery, robotics will enhance and facilitate the ergonomics of the operative procedure.

Until specifically designed endoscopic tools are available for NOTES, the hybrid technique with ultrasonic dissection conducted through a 5-mm port is being tried in natural orifice cholecystectomy in order to shorten the duration of surgery and make this approach effective, safe, and reproducible [35]. The procedure is performed by using a combination of working tools inserted through the entry port for the minilaparoscopy and the video gastroscope, inserted into peritoneal cavity by transvaginal/transgastric approach. The gallbladder is removed transvaginally through the video gastroscope.

Concerning the vision system, a very promising approach to allow triangulation and to minimize both internal and external instrument collisions is represented by softly-tethered intra-abdominal cameras. Recently, a softly-tethered miniaturized camera robot has been developed that

has an internal magnetic mechanism allowing for highly precise tilt control [36]. Thanks to its reduced dimensions (12.7 mm diameter, 48 mm length), the proposed system can be introduced through a channel of a standard LESS multiport, thus maximizing the number of surgical tools that can be used at the same time. The camera allows a complete exploration through different points of view. Thanks to fine robotic tilting, the specific site of operation is always centered, thereby minimizing manual movements of the camera, and thus enhancing image stability.

Conclusion

SILS is a promising technique in the field of minimally invasive surgery and is emerging as a safe procedure for cholecystectomy in selected patients. A few case reports have also demonstrated its feasibility in more complex biliopancreatic surgeries. Moderate success rates and avoidable complications as reported in literature suggest need for further evolution of this technique. However, we are only at the beginning of a new minimally invasive procedure, and modifications in the technological aspects of SILS will likely yield better outcomes. Randomized studies comparing single-incision laparoscopy with traditional laparoscopy are necessary to evaluate the safety, efficacy, complication rates, and potential benefits, if any, that this innovative technique may provide.

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