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REVIEWS

Single-port laparoscopic surgery: an overview

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As innovation continues to move 21st century surgery forward, one of the emerging concepts is single-port or single-incision laparoscopic surgery. The fundamental idea is to have all of the laparoscopic working ports entering the abdominal wall through the same incision. The major drawback to such a surgical approach is that the concept of "triangulation" to which laparoscopic surgeons have grown accustomed in terms of both the instruments and scope is lacking. This, however, seems to be overshadowed by the increasing acceptability of in-line viewing, with the reemphasis on surgeons performing flexible endoscopy and on newer ideas such as natural orifice translumenal endoscopic surgery (NOTES).

This very paradigm shift has energized both surgeons and industry to research important issues and develop new technology to make concepts such as single-port laparoscopic surgery become a reality.

As part of the effort put forth by the technology committee of the Society of Gastrointestinal and Endoscopic Surgeons (SAGES) to inform surgeons about cutting edge technology, this article is published both to clarify understanding of the single-port laparoscopic surgery concept and to categorize the currently available tools and techniques.

Nomenclature

Unlike NOTES, to date, no consensus name exists for this developing technique of minimally invasive surgery. Many names seemingly centered on the type of acronym they will create have been used rather than a description of the access technique and exposure methods. One of the early names to gain popularity is single-port access (SPA) surgery, trademarked by Drexel University.

Industry has begun to adopt and trademark nomenclature of its own. Covidien Inc., has been calling this new technique single-incision laparoscopic surgery (SILS), whereas Ethicon EndoSurgery, Inc. has proposed the name single-site laparoscopy (SSL).

Some proposed names involve the umbilicus, such as one-port umbilical surgery (OPUS) [1] or transumbilical endoscopic surgery (TUES) [2, 3], embryonic NOTES (eNOTES) [4–6], and natural orifice transumbilical surgery (NOTUS) [7], with the embryonic notation referring to the umbilical opening in utero. Other names suggested include single laparoscopic port procedure (SLAPP) [8], single-port laparoscopic surgery (SPLS) [9], single-port laparoscopy (SPL) [10], and single laparoscopic incision transabdominal (SLIT) surgery [11].

A recent symposium convened to arrive at a consensus regarding the single-port concept has suggested the name laparoendoscopic single-site (LESS) surgery [12]. Another clever name that implies facility with the technique is single-instrument port laparoscopic surgery (SIMPL) [13]. Regardless of the final name that emerges, the current lack of consistent nomenclature has led both industry and individuals to trademark names that will apparently be used for economic gain in the future. Perhaps it is too late for the notion of controlling a disruptive technology before it is disseminated, as was done with Natural Orifice Surgery Consortium for Assessment and Research (NOSCAR), but one can still hope that in the near future, a name will be selected and standardized by NOSCAR group.

Interestingly, some of the early potential names do not accurately portray the technique being used. Some of the

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early concepts do in fact involve a single incision. Multiple ports are placed through the incision adjacent to one another, making the term single-port access a relative misnomer. Although SILS may be more accurate as an acronym, the term fails to recognize devices that allow multiple instruments through the same device.

Devices

TriPort

The TriPort (Advanced Surgical Concepts, Wicklow, Ireland) (Fig. 1), also known as the R-port, is a device designed to be deployed through a single incision, typically at the umbilicus. This device is Food and Drug Administration (FDA) approved and available in the United States. It requires a fascial incision approximately 1.5–2 cm long. A sheath is placed through the fascial opening, and the peritoneal surface of this sheath has a self-expanding ring, allowing the TriPort to remain inside the peritoneum. Because the sheath is adjustable in size, the outer component of the port can be placed snugly against the skin regardless of the abdominal wall thickness.

The TriPort is introduced into the abdomen through the fascial defect via an introducer device. The outer component of the TriPort has three ports: two 5-mm ports and one 12-mm port. To maintain pneumoperitoneum, the ports contain the same gelatin material as the GelPort (Advanced Surgical Concepts) used for hand-assisted laparoscopic surgery (HALS). Instruments require lubrication to pass through the ports without unnecessary drag. Iodine solution works well because it lubricates but does not coat the laparoscope with material such as a viscous lubricant that obscures the view. In addition, the TriPort contains an insufflation port, allowing regulated gas insufflation without the additional need for a Veress needle.

Fig. 1 TriPort

Case reports on the TriPort are beginning to emerge. Much of the experience has been confined to urologic procedures [1, 4, 14], although we have recently reported our initial experience using this device for cholecystectomy [15].

Another recently published study details experience with 20 laparoscopic cholecystectomies [16]. In addition, anecdotal reports describe TriPort cholecystectomies in India, Ireland, and the United States. To date, no data exist that compare the results of TriPort procedures with those for standard laparoscopic operations.

The TriPort has multiple advantages. First, multiple instruments can pass through different access points without loss of pneumoperitoneum. Moreover, the different ports allow instruments of variable sizes. Second, the TriPort is fairly simple to introduce into the abdomen and can even be replaced if it is removed, for example, for organ extirpation. Third, it can accommodate variable thicknesses of the abdominal wall. Fourth, each of the ports affords significant angles of distraction, allowing instruments to be located at wider distances away from one another inside the abdomen.

The disadvantages of the TriPort include the relative need for umbilical placement. It may be difficult to pass the introducer through a fascial defect not located at the umbilicus because cephalad distraction of the umbilical stalk allows a 45° angle of approach. This also can be limiting because the target tissue may be too far away for roticulating instruments. Also, in our experience with the device, we found it easy to cause dislodgment of the device, causing loss of pneumoperitoneum. The sheath can easily be torn, which may result in a need to replace the device.

A second version of the TriPort, tentatively called QuadPort, will have four hubs for instruments: one 12-mm and two 10-mm ports and one 5-mm port. Although no published case reports of its use exist to date, anecdotal reports have emerged about its clinical use for laparoscopic nephrectomy. At this writing, the new version of the device is not FDA approved.

AirSeal

An access port called AirSeal (SurgiQuest, Orange, CT, USA) involves a technology disruptive to the typical trocar

concept. All traditional laparoscopic ports use a mechanical barrier to maintain pneumoperitoneum while allowing instrument passage and limited specimen extraction through their lumen. Commercially available ports are round, with an inner diameter ranging from 2- to 15-mm.

AirSeal ports do not use a mechanical barrier but rather a pressure barrier that well exceeds the pneumoperitoneum (Fig. 2). This pressure barrier can be conceptualized as similar to the air curtain blowing down from the ceiling at the entrance of many operating suites. The barrier is created by gas pumped through openings within the housing of the port, creating turbulence that can be regulated and exceeding the pressure of the pneumoperitoneum, thus preventing gas loss, even when instruments and specimens are passed through its lumen. It uses a combination air pump and specialized tubing, with a filter serving to recirculate and filter the carbon dioxide used to create the pneumoperitoneum (Fig. 3).

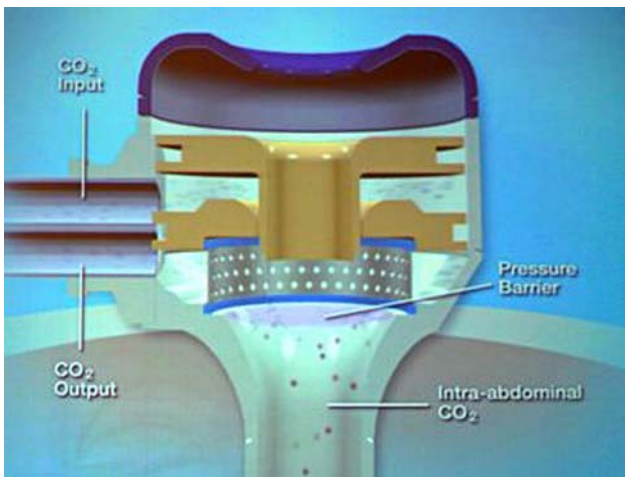

Fig. 2 AirSeal with pressure barrier

Fig. 3 AirSeal with air pump

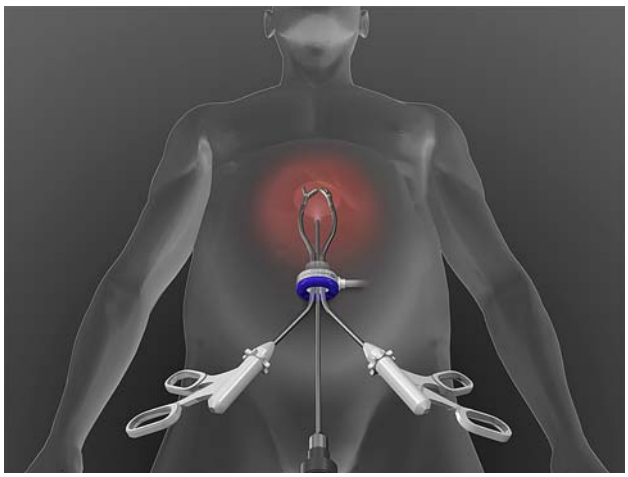

Fig. 4 Future design of AirSeal in nonround shape

AirSeal allows for the passage of multiple or odd-shaped instruments, extracorporeal knot tying without gas loss, and enhanced specimen extraction. The pressure barrier also reduces friction, particularly noticeable with laparoscopic stapling devices. Additionally, it is capable of maintaining operative exposure during suctioning and provides automatic smoke evacuation and filtration. The lack of a mechanical barrier makes it possible to have ports of different shapes and sizes and has the potential for inclusion with overtubes to maintain regulated insufflation for endoscopic procedures.

A 12-mm AirSeal port is FDA approved and currently available on a limited basis in the United States. Our experience with this device for single-port cholecystectomy has been reasonable, although the 12-mm port has a relatively long fulcrum, which limits instrument excursion, a problem that should be solved with newer designs (Fig. 4). One downside of the AirSeal port is the noise associated with the pressure barrier, which is comparable with opening the valve of a standard laparoscopy port.

SILS procedure kit and access devices

Covidien, Inc. (Norwalk, CT) currently is marketing roticulating disposable instruments packaged together with low-profile 5- and 12-mm Dexide ports (Covidien, Inc., Norwalk, CT) designed to be used through a single 15- to 25-mm periumbilical incision. Covidien also has a new access device, the SILS port (Fig. 5), expected to be available for clinical use in 2009. The device, made from an elastic polymer, is slightly hourglass shaped and can be deployed through a 2-cm fascial incision. It contains four openings: one for insufflation via a right-angled tube and three that can accommodate trocars 5 to 12 mm in size. The compressibility of the elastic polymer allows for the

Fig. 5 Single-incision laparoscopic surgery (SILS) port

Fig. 6 Uni-X image. Courtesy of Dr. Gregory Piskun

access ports to expand and form fit the space in which it resides as well the ports passed through the working channels. Performance data for this device are not yet available.

The Uni-X single-port laparoscopic device, recently acquired from Pnavel Systems (Morganville, NJ, USA), is a system designed to allow the simultaneous use of three 5-mm laparoscopic instruments through a single fascial incision (Fig. 6). The device is funnel shaped, which allows for a wide range of motion because the length of the tunnel through which an instrument can pass is shorter than a standard laparoscopic trocar. The Uni-X system also has a port to allow abdominal insufflation. Fascial fixation sutures are necessary to maintain the device in its position, and accompanying curved laparoscopic instruments are available that may be helpful when multiple instruments are operated through a single incision. Multiple case reports describe the use of the Uni-X system, primarily in the urologic arena [10, 17–19].

Single-incision with multiple trocars

Another technique involves placing multiple, commercially available, standard laparoscopic ports though a single periumbilical incision. Choosing ports that have a lower external or internal profile allows for a wider range of instrument motion. The AnchorPort (SurgiQuest) has an elastomeric shaft that recoils for automatic adjustment of its height to the thickness of the abdominal wall and holds it in place within the abdominal wall by having the intraperitoneal end flare out when it is deployed.

Another port useful with this technique is the Hunt Cannula/Trocar (Apple Medical, Marlborough, MA, USA) that accommodates 5-mm instrumentation, is relatively low profile and not adjustable, and has a threaded cannula to keep it in place. The best combination of ports depends on the procedure being performed, but it typically includes three or four ports, each 5-mm or smaller. Obviously, if a 12-mm port is chosen, the clinician can choose from a greater variety of instrumentation. The placement of each port through a separate fascial puncture raises concerns regarding an increase in incisional hernia rates, even with 5-mm ports, because the effect of multiple fascial punctures in close proximity is unknown.

Yet another idea is to combine a HALS device with standard laparoscopic surgery instrumentation. Merchant et al. [20] describe multiple operations performed with the aid of the GelPort (Applied Medical, Rancho Santa Margarita, CA) such as cholecystectomy, hemicolectomy, adjustable gastric banding, sleeve gastrectomy, and esophagectomy. Another recent report details the use of the same product to perform cholecystectomy [21].

Human experience

General and gynecologic surgery

Similar to standard laparoscopic surgery, the early adopters of single-incision techniques were in the gynecology world. Wheeless [22] is credited with performing the first single-incision tubal ligation, in 1969. Large series were later reported, with the number of cases well exceeding 1,000 [23, 24]. Laparoscopic total abdominal hysterectomy with bilateral salpingo-oophorectomy using only a single incision was reported by Pelosi and Pelosi [25] in 1992. The same authors reported single-port laparoscopic appendectomy for 25 patients, again in 1992 [26]. All these procedures were performed using an operative laparoscope that, interestingly, never gained popularity in the general surgery arena.

In 1998, Esposito [27] reported a technique for performing one-trocar appendectomy in a series of pediatric patients. In this report, an operating telescope was used. A grasper passed through the telescope was used to grasp and exteriorize the appendix so that an "open" appendectomy could be performed. A more recent report of laparoscopic appendectomy with a single trocar in the pediatric population was published in 2001 by D'Alessio et al. [28].

The first reported cases of single-incision laparoscopic cholecystectomy were published in 1997, when Navarra et al. [29] described a series of 30 cases performed with two 10-mm trocars placed via a single umbilical incision. The gallbladder was retracted using three traction sutures through the abdominal wall. Even cholangiography was achieved successfully in eight cases. Piskun and Rajpal [30] used the same concept of multiple trocars deployed via a single umbilical incision in 1999 but used two 5-mm ports. These authors also used traction sutures to retract the gallbladder. Bresadola et al. [31] also reported a similar technique, using 2-0 Dermalon sutures. Their report compared this approach with standard laparoscopic cholecystectomy and demonstrated lower pain scores in the single-port group.

A recent publication from Cuesta et al. [32] describes a procedure that uses two transumbilical 5-mm trocars and a 1-mm Kirschner wire instead of sutures for gallbladder retraction. Our group reported a single-port cholecystectomy using the TriPort [15] for instrumentation and transabdominal sutures placed with a Keith needle for retraction. Five subsequent cases have been managed, one of which was converted to a "standard" multiport laparoscopy because of inability to achieve adequate exposure.

Our group also has performed three single-port cholecystectomies using the 12-mm AirSeal port [33]. Suture retraction was used for the gallbladder but in a slightly different manner. The infundibulum stitch was placed with a standard curved needle and tied extracorporeally, leaving two long tails. The one tail was pulled from the abdominal wall with a looped spinal needle near the xiphoid, whereas the other was pulled out near the right anterior axillary line along the costal margin. This allowed for manipulation of the infundibulum that mimicked multiport laparoscopy.

Curcillo and King at Drexel University have reported more than 175 general surgery and gynecologic operations using a technique with multiple ports placed through a single periumbilical incision (personal communication) but have yet to publish their data except in abstracts detailing the technique in cholecystectomy and Heller myotomy [34, 35]. A published report from the same university details laparoscopic adrenalectomy with a similar technique [36]. For this procedure, three 5-mm trocars were used via a single 2-cm supraumbilical incision. Organ extraction was accomplished by upsizing one 5-mm port to 12 mm to allow the placement of an endoscopic retrieval bag.

Urology

Kaouk et al. [10] recently reported a series of four patients who underwent single-port laparoscopic radical prostatectomy via the Uni-X device. These authors were able to accomplish the urethrovesical anastomosis using extracorporeal knot-tying techniques. Garg et al. [13] reported a series of 26 children who underwent single-port nephrectomy requiring a mean operating time of less than 1 h. Desai et al. [14] recently reported transvesical placement of the TriPort to perform a single-port prostatectomy for three patients with large-volume benign prostatic hyperplasia. Kaouk et al. [17] also recently reported a series of 10 procedures performed with the Uni-X including renal cryotherapy for four patients, wedge kidney biopsy for one patient, radical nephrectomy for one patient, and abdominal sacrocolpopexy for four patients. Interestingly, some of this work was performed solely in the retroperitoneum, with the access device placed at the tip of the 12th rib rather than at the umbilicus. None of these procedures required conversion to standard laparoscopy. Other reports from the same group reported their first six renal cryoablation cases [18] and three varicocelectomies for adolescent patients [19].

Other investigators have described single-incision laparoscopic nephrectomy and pyeloplasty. Raman and colleagues compared the single incision with multiport laparoscopic nephrectomy in a retrospective review and found no differences in median operative time, postoperative hemoglobin change, tumor size, length of hospital stay, or analgesic use. There was less blood loss with the single-incision technique, a difference that reached statistical significance, but this was not clinically relevant [37–40].

Colorectal surgery

A recent case report by Remzi et al. [9] describes a right hemicolectomy performed using the Uni-X system. In this case, a single, 3.5-cm incision was made vertically at the site of the umbilicus. Hemostasis was achieved using the LigaSure (Covidien Ltd., Norwalk, CT, USA). The ileocolic anastomosis was performed after exteriorization of the bowel via this incision. The operative time was 114 min, and no complications occurred.

Two other case reports of single-port colorectal surgery also have emerged. Bucher et al. [41] also described a single-port right hemicolectomy for malignancy and found that the oncologic yield was appropriate. Leroy et al. [42] detailed the novel use of intralumenal magnets to assist with single-port sigmoidectomy in a porcine model.

Bariatric surgery

Obesity was once considered a contraindication to laparoscopic surgery, but single-port laparoscopy currently is being performed for weight loss procedures. Saber et al. [43] used the Uni-X, whereas Reavis et al. [44] used multiple ports through a single periumbilical incision. The devices in both cases were used to perform a sleeve gastrectomy. Nguyen et al. [11] also reported gastric banding via a single-port laparoscopic approach. Concerns of incisional hernia with multiple adjacent 5-mm ports are especially prevalent in the obese population.

Articulating instruments

Covidien, Inc. (Norwalk, CT, USA) has a line of instruments that can be articulated and rotated. Their Roticulator line includes a dissector, grasper, and scissors. All three instruments have 0° to 80° articulation at the distal end of the shaft. They function by extending the distal part of the instrument shaft beyond its outer sheath. The extended portion is bent, and the more it is extended, the closer it is to 80° articulation. This creates difficulty in performing tasks that require fine motor control, particularly at full articulation. The instruments also have integrated monopolar electrocautery connectors.

Novare Surgical Systems, Inc. (Cupertino, CA, USA) manufactures the RealHand instrument line. These instruments articulate similar to a human wrist. The surgeon articulates the handle against the fulcrum of the port, and the distal shaft of the instrument articulates in a mirror image fashion using cables that connect the handle to the distal shaft. The multiple degrees of freedom make fine dissection and cutting more feasible than with the Covidien articulating instruments.

The RealHand instrument line also is quite broad, including 11 different types of instrument tips. One of these tips is shaped like a curved dissector but also is capable of cutting and sealing tissue. The Thermaseal 5-mm instrument (Novare Surgical Systems, Inc., Cupertino, CA, USA) uses a separate energy source and heats tissue by increasing temperature without an electrical current, using a process the manufacturer terms "thermal ligation."

Cambridge Endo (Framingham, MA, USA) manufactures instruments similar to those in the Novare instrument line. There are four different types of tips including a needledriver, dissector, scissors, and a monopolar hook. A tissue grasper should be available in the near future. Although some features are different, the basic premise is the same in that the surgeon's hand articulates the distal shaft using the port as a fulcrum.

All the articulating instruments are currently available in the United States, and all are disposable. The fully articulating instruments are undergoing continued design improvements.

Technical challenges

One early principle of laparoscopic surgery as it rapidly developed was the concept of triangulation. Triangulation, still a widely accepted concept, is included in the SAGES and American College of Surgeons (ACS) joint program called Fundamentals of Laparoscopic Surgery (FLS). This was necessary for appropriate operative exposure while an ergonomically favorable position was maintained for the surgeon and assistants. Thus, the umbilicus has emerged as a central location for many laparoscopic procedures. If one wonders why single-port surgery did not develop sooner, it can be argued that this dogmatic principle would have been a limiting factor for many who considered adopting this conceptual idea into their surgical armamentarium.

As familiarity with angled telescopes took root in advanced laparoscopic surgical procedures, surgeons began to experiment with placement of the camera so that it no longer rested between the operating surgeon's hands. Currently, it is commonplace for a camera to be positioned lateral to both of the surgeon's working ports to maintain the best possible ergonomic positions for the surgeon and the assistant holding the scope.

Furthermore, with the recent interest in endolumenal procedures and natural orifice techniques, in-line viewing has become not only acceptable but also fashionable. We believe it is this change in perspective together with a drive to make NOTES feasible that has interested surgeons, industry, and the investment community in the adoption of single-port techniques.

The inherent technical challenge that arises from in-line viewing, however, is that of a partially compromised view.

It must be remembered that with in-line viewing, a move of the camera often results in an inadvertent move of an adjacent instrument. This can increase difficulty in performing relatively simple tasks that require looking at two sides of a structure, such as the placement of a clip on the cystic duct during a laparoscopic cholecystectomy. Although angled or flexible scopes can minimize this problem to some extent, there remains the issue of the limitations in external working space. Put simply, the multiple instruments and laparoscopes required for a procedure are competing for the same space at the fulcrum of the entry port, causing hand collisions externally and difficulty with instrument tip manipulation internally. Instruments of differing lengths can ameliorate some of this, but some learning on the part of the surgeon still is required.

With single-port surgery, the external area within which the surgeons' hands are located is much smaller than in standard laparoscopic surgery through multiple ports. In fact, we have found that a significant component of the learning curve for single-port surgery is related to the physical placement of the operator's hands within a relatively small space. In standard laparoscopic surgery, obstructions to the view are met with a change in location of the scope to a different port, angling of the scope, or moving of the scope externally away from the obstruction (limited by the amount of freedom of motion externally). In single-port surgery, no other port exists for placement of the scope, and the ability to move the scope significantly is limited by the other instruments. These aspects threaten to obscure the operative exposure, and hence the safety of the operation, making it critical to develop and disseminate the enabling instrumentation.

This problem can be solved in a number of different ways. First, articulation of instruments can allow work in the operative field without a straight approach from the access port. Second, instruments with handles that can be articulated away from the access port will clear space externally. The current design of articulating instruments requires angling of the handle toward the access port for some motions. Third, instruments of variable lengths allow manipulation of instruments externally such that they are operated in different planes, thus avoiding collisions. This is especially helpful when a bulky camera head with an attached light cord is used. A long laparoscope will move the camera head out of the way externally but decrease the amount of light returned to the image capture chip. Fourth, using a laparoscopic camera–scope combination with an in-line light cord and a low-profile camera head will cause less tangling externally and yield more working space.

One such laparoscope, the Olympus EndoEye (Olympus America, Center Valley, PA, USA), differs from many commercially available scopes in that the image capture chip is at the distal tip of the scope. Also, the insufflation tubing needs to be placed in a position such that it does not interfere with the other instruments. This will require a connection different from the currently used stopcock and Luer-lock system.

Although these concepts may seem mundane, inattention to these details can lead to poor operative exposure and instrument manipulation that prolong the operation and potentially compromise safety. Flexible-tip laparoscopes can be positioned favorably out of the field of view by deflection of the tip such that the external portion of the laparoscope is in a different plane than the working instruments. Finally, Teixeira (personal communication) has used currently available flexible endoscopes to facilitate the working environment for single-port laparoscopy.

Another concept unique to single-port laparoscopic surgery is the idea of cross-handed instrumentation. Currently, both the Novare RealHand HD and Cambridge Endo instruments articulate inside the abdomen by bending of the handles. The problem, however, is that when the tips of the instruments are bent in toward the target tissue, the operator's hands tend to collide, and the handles externally move toward one another (Fig. 7). The problem can be solved by crossing the instruments. The handles then are articulated away from each other, giving more working space outside the abdominal wall (Fig. 8). Although this is indeed helpful, the ergonomics with a cross-handed approach are awkward at best.

To avoid crossing of the hands with this technique, the surgeon's left hand must operate the instrument on the right, and vice versa, which can be uncomfortable. In addition, with the crossing of instruments internally, both instruments may compete for the same space in a vertical plane, as such, allowing the motion of the other to be limited. This creates additional difficulty in safe dissection of the target tissues.

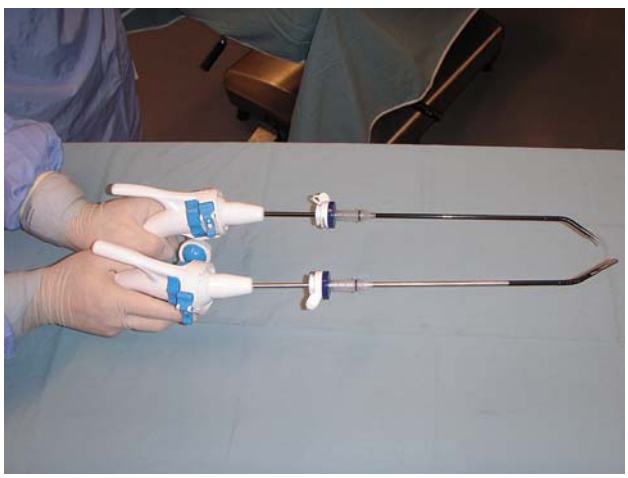

Fig. 7 Cambridge Endo instruments with handles articulated inward

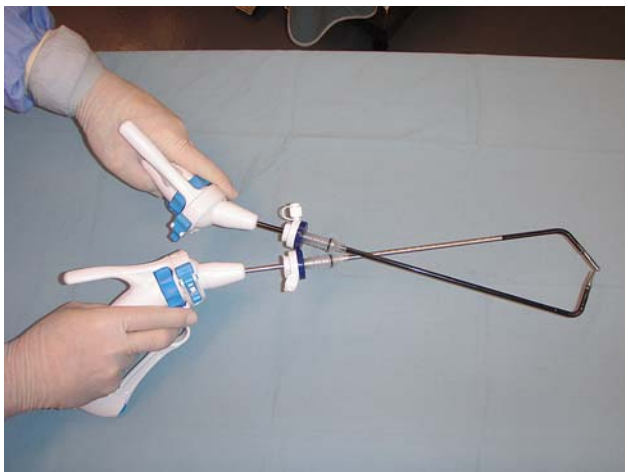

Fig. 8 Cambridge Endo instruments, crossed with handles articulated away from one another

Another potential solution to this problem is to use the daVinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA). With daVinci, by switching of the right- and left-handed instruments on the control panel, the crossed instruments can be manipulated at the console as they would be if they were not crossed. What this does to case cost and outcomes however remains to be seen.

Conclusion

The concept of performing laparoscopic surgery via a single incision regardless of the technique is gaining traction rapidly among patients, surgeons, industry, and investors. It is likely that the public will demand this even less invasive surgical approach much in the same way that it forced the explosion of laparoscopic surgery two decades ago. However, as surgeons, we should not advocate for slightly improved cosmetic value over safety. Although one retrospective study showed an improved pain benefit [31], more robust studies to show that there is indeed a difference without a significant compromise of safety would be helpful. Studies that examine the efficacy of the multiple new devices on the market and those under development may help to simplify the confusing landscape of new and novel products designed for this purpose. Conceptual development will occur as human experience grows, and techniques may be described to simplify maneuvers that currently seem complicated and more difficult than standard laparoscopic surgery. The significant amount of research and development in this growing field may even lead to a change in our operating platform whereby new access devices emerge that are completely different from the tools we use currently.

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