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REVIEW

Evolution and advances in laparoscopic ventral and incisional hernia repair

Alan L Vorst, Christodoulos Kaoutzanis, Alfredo M Carbonell, Michael G Franz

Alan L Vorst, Christodoulos Kaoutzanis, Michael G Franz, Department of Surgery, Saint Joseph Mercy Health System, Ann Arbor, MI 48106, United States

Alfredo M Carbonell, Department of Surgery, Greenville Health System, University of South Carolina School of Medicine - Greenville, Greenville, SC 29605, United States

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Correspondence to: Christodoulos Kaoutzanis, MD, Department of Surgery, Saint Joseph Mercy Health System, 5333 McAuley Drive, Reichert Health Building, Suite R-2111, Ann Arbor, MI 48106, United States. ckaoutzanis@gmail.com
Telephone: +1-734-8340597
Fax: +1-734-7122809

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Abstract

Primary ventral hernias and ventral incisional hernias have been a challenge for surgeons throughout the ages. In the current era, incisional hernias have increased in prevalence due to the very high number of laparotomies performed in the 20th century. Even though minimally invasive surgery and hernia repair have evolved rapidly, general surgeons have yet to develop the ideal, standardized method that adequately decreases common postoperative complications, such as wound failure, hernia recurrence and pain. The evolution of laparoscopy and ventral hernia repair will be reviewed, from the rectoscopy of the 4th century to the advent of laparoscopy, from suture repair to the evolution of mesh reinforcement. The nuances of minimally invasive ventral and incisional hernia repair will be summarized, from preoperative considerations to variations in intraoperative practice. New techniques have become increasingly popular, such as primary defect closure, retrorectus mesh placement, and concomitant component separation. The advent of robotics has made some of these repairs more feasible, but only time and well-designed clinical studies will tell if this will be a durable modality for ventral and incisional hernia repair.

Key words: Evolution; Advances; Laparoscopic ventral hernia repair; Laparoscopic incisional hernia repair; Laparoscopic ventral incisional hernia repair; Ventral hernia repair; Incisional hernia repair; Ventral hernia; Incisional hernia

Core tip: This manuscript reviews the evolution and advances of laparoscopic ventral and incisional hernia repair. We discuss preoperative considerations,

intraoperative factors including the type of mesh in conjunction with placement and fixation of the mesh, as well as postoperative issues such as complications, recurrence and quality of life. New evolving techniques such as minimally invasive components separation and robotic surgery are reviewed. In addition, some of the future directions of this exciting and rapidly developing field are explored. We hope you find this review helpful in summarizing the past advances in hopes that it may illuminate new avenues of research in minimally invasive ventral and incisional hernia repair.

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BRIEF HISTORY ON THE EVOLUTION OF LAPAROSCOPY

The concept of minimally invasive surgery has been present for millennia, and started with the advent of endoscopy of the rectum, vagina, ear, and nose. Hippocrates first described a rectoscope in the 4th century[1]. Later in the 10th century, Albukasim, an Arab physician, developed methods of speculum illumination with candlelight and mirrors. In the early 19th century, Phillipp Bozzini utilized the centrally bored mirror for his cystoscope. In 1879, Maximilian Nitze improved the cystoscope, adding a platinum wire electric light source and developing the first endoscopic photographs[2].

In 1901, the German surgeon George Kelling insufflated a dog's abdomen and viewed the viscera with the Nitze style cystoscope. A Swedish surgeon, Hans Christian Jacobaeus, performed the same procedure that year and coined the term laparoscopy. The new procedure of diagnostic laparoscopy then spread around the world. Innovations were rapidly added, such as needle induced pneumoperitoneum, 45-degree laparoscopes, trocar insertion, and insufflation machines. In 1933, Heinz Kalk, a German gastroenterologist, pioneered many of these techniques. He developed a dual trocar technique and a wide-angle scope to obtain biopsies. Visualization improved remarkably in the 1950's with the Hopkins lens and fiberoptic cold illumination; however, interest in these techniques waned for several decades. Gynecologists began experimenting again in the 1970's with tubal ligation, oocyte harvesting, and tumor biopsies[3]. In 1971, Harrith Hasson developed a technique to safely enter the abdomen with his new trocar. Kurt Semm performed the first laparoscopic appendectomy in 1983, and went on to perform a total of 20000 procedures. The German surgeon Erich Muhe performed the first laparoscopic cholecystectomy in 1985, but was not initially received well by his peers. This was followed by an explosion of laparoscopic procedures, including the first laparoscopic ventral hernia repair done by LeBlanc and Booth[4] in 1993.

TRANSLATION TO HERNIA REPAIR

While the incidence of primary ventral hernias has been relatively static, the incidence of incisional ventral hernias has increased as abdominal surgery has become more prevalent. In the United States, 4 to 5 million laparotomies are performed each year, and it is estimated that three to as high as fifty percent of these patients develop incisional hernias, although the exact incidence is unknown[5-8].

Prior to 1993, all ventral and incisional hernias were repaired with open exposure. Primary suture repair remains one of the oldest techniques, but it has been shown to have a high recurrence rate with wide variability, ranging from 8% to 63%[8-10]. The invention of prosthetics has revolutionized ventral hernia repair, leading to a significant reduction in the recurrence rates, ranging as low as 1% to 14% in some studies[8,9]. In the best prospective, randomized controlled trial of mesh based ventral incisional hernia repair, the recurrence rate was 24% with an appropriate follow-up period of 3 years[10]. The gold standard repair widely reinforces or bridges the defect, with mesh placed posterior to the fascia either in a retrorectus, preperitoneal, or intraperitoneal anatomic space. This takes advantage of LaPlace's Law, distributing intra-abdominal pressure across the overlapping mesh instead of only at the hernia defect[7]. However, the need for an extensive dissection, which was associated with postoperative wound-related complications, has driven surgeons to search for new techniques. This was translated to laparoscopic surgery in hopes of decreasing the morbidity of open surgery, including wound complications, postoperative pain, hernia recurrence, and delayed return to normal function[7,11]. Nowadays, about 20% to 27% of repairs are performed laparoscopically[11,12]. One challenge for the minimally invasive approach has been creating a more anatomic, physiologic abdominal wall reconstruction.

The general steps in laparoscopic ventral and incisional hernia repair include safe entry into the peritoneum, insufflation, careful lysis of intra-abdominal adhesions, reduction of the hernia contents, wide, typically intraperitoneal mesh coverage of the defect, and mesh fixation[8,11]. Primary defect closure or concomitant component separation can be performed in selected patients[13,14]. There is wide surgeon variability in preoperative selection of patients for open *vs* laparoscopic repair. These clinical decisions are based on patient factors such as obesity, previous operative history, and size and location of the hernia defect. Furthermore, there are surgeon specific variations in mesh fixation techniques, and differences in the type and size of mesh used[8,11].

PREOPERATIVE CONSIDERATIONS

Any given patient with a ventral or incisional hernia must be evaluated for open *vs* laparoscopic repair. Past data has pooled primary ventral hernias with ventral incisional hernias; however, the behavior of these two types of hernias is most likely different, and should not be overlooked during preoperative assessment. For example, Stirler *et al*[15] showed that laparoscopic repair of incisional hernias on average results in more adhesiolysis, a higher conversion to open, longer operative times, and a higher recurrence rate when compared to primary ventral hernias.

For the majority of surgical specialties, it is well established that patients' preoperative health status can significantly impact postoperative outcomes. Laparoscopic ventral and incisional hernia repairs are not an exception to this principle. Known risk factors for incisional hernia include male sex, advanced age, obesity, tobacco use, chronic obstructive pulmonary disease, immunosuppression, diabetes mellitus, and history of an emergent operation[7,8,16]. All these factors should be addressed during preoperative counseling. Postoperative wound-related complications have also been identified as a major risk factor for recurrence after laparoscopic ventral hernia repairs[7]. Wound infections may increase the incidence of incisional hernias up to 80%[10,17]. Our institution has previously identified predictive factors for postoperative wound infections after ventral and incisional hernia repairs using the American College of surgeons national surgical quality improvement program (NSQIP) database[18]. We found several risk factors for postoperative wound infections after ventral/incisional hernia repair including high body mass index (*i.e.*, greater than 30 kg/m^2), tobacco use, high American Society of anesthesiologists class (*i.e.*, 3 or 4), open surgical approach, prolonged operative times, recurrent hernias, and inpatient status. In addition, with the widespread use of smartphones, other investigators created a smartphone application, which uses an externally validated formula to calculate the risk of wound related complications and the associated cost of care after ventral hernia repairs[19]. These novel methods of patient education may provide motivation to modify these risk factors.

Martindale and Deveney[20] provide an extensive review of perioperative interventions aimed at decreasing wound infection and recurrence. Smoking cessation, blood glucose control, and obesity are again reviewed. Smoking cessation for 4 wk is associated with a decrease in complication rate from 41% to 21%. Preoperative blood glucose control with hemoglobin A1c less than 7% is desired, and perioperative blood glucose should be between 140-160 mg/dL. Obesity is more difficult to control; however, body mass index correlates strongly with recurrence. Many surgeons will not electively repair ventral hernias in patients with a body mass index over 50. In this setting, it has been suggested that aggressive attempts at weight loss including weight loss surgery should precede a futile attempt at ventral hernia repair. Other interventions include preoperative antibiotics and optimizing nutrition. Ríos *et al*[21] showed prophylactic antibiotics decrease wound infection rates in incisional hernia repair from 26.3% to 13.6%. Nutrition is a vital part of healing, and preoperative nutrition may decrease recurrence. Arginine and fatty acid mixtures have been shown to decrease perioperative complications, infection related morbidity, and length of hospital stay[20].

INTRAOPERATIVE CONSIDERATIONS

Selection of mesh

An ideal mesh has sufficient strength, is chemically stable, is easily sterilized, resists infection, is non-carcinogenic, limits inflammatory foreign body reactions, and incorporates (heals) well into the abdominal wall[22]. The latter point is important as many ventral hernia recurrences occur at the interface of the mesh and the wounded abdominal wall, a form of acute wound failure[23,24]. Materials fitting these prerequisites were not developed until the 1900s. Silver was used first, followed by stainless steel and other metals[22]. Polypropylene mesh was not created until 1959. Since then, several categories have been produced: Non-absorbable synthetic meshes, composite meshes, absorbable meshes and tissue-based biologic implants.

Permanent meshes, such as polypropylene and polyester, were use when laparoscopic hernia repairs were first started. However, uncoated meshes were soon abandoned due to the large number of visceral adhesion related complications, such as fistula, bowel obstruction, and complications during re-operative adhesiolysis[24]. Table 1 summarizes some of the main advantages and disadvantages of these meshes.

Composite meshes were developed for laparoscopic intraperitoneal onlay placement, and are the ones usually used for laparoscopic hernia repair[24]. They combine the strength of permanent mesh with a bowel-protective anti-adhesion barrier. The parietal peritoneum side is composed of permanent mesh, usually polypropylene or polyester, which provides structural strength and promotes tissue inflammation and ingrowth. The visceral facing side of the mesh requires an anti-adhesion barrier. Most of these barriers are absorbable, with the exception of expanded polytetrafluoroethylene[25]. Table 2 provides a general overview of the most common composite meshes used for laparoscopic ventral and incisional hernia repair and relevant research. Unfortunately, there is a lack of high-level clinical evidence to direct surgeons and patients as to the safest and most effective material.

New meshes are being developed for potential use in laparoscopic ventral and incisional hernia repair (Table 3). Recently, absorbable synthetic meshes were developed to have a better infection resistance profile, but risk recurrence by weakening during the resorption process[37]. To date, at least 3 new, slow resorbing meshes have been developed, including

Table 1 Advantages and disadvantages of permanent synthetic mesh materials (polyester and polypropylene)

Advantages	Disadvantages
Permanent synthetic mesh, either woven or knit	Risk contraction, chronic inflammation, stiff abdominal wall, chronic pain especially with heavy weight PP
Provides strength by stimulating inflammation and abdominal wall ingrowth	PE with possible higher infection and recurrence *vs* PP
PE has less contraction than PP	Should not be placed in contact with bowel as inflammatory response increases adhesions to viscera
Lightweight PP has less foreign body response, more pliable, more ingrowth[25]	Increased risk of fistula, bowel obstruction, and re-operative complications[26]
Sometimes able to salvage lightweight mesh after infection due to improved antibiotic penetration[25]	Enterotomy and/or bowel resection upon re-operation are almost four times greater with prior use of mesh, with most of these being uncoated mesh[27]

PE: Polyester; PP: Polypropylene.

Table 2 Advantages and disadvantages of commonly used composite meshes

Mesh	Abdominal wall side/visceral side	Advantages	Disadvantages
Composite meshes[24]	Permanent mesh/anti-adhesion barrier	Permanent mesh for inflammation, fibrosis, and abdominal wall ingrowth and strength Visceral side designed to prevent adhesion related complications	No level I evidence of the superiority of one mesh over another. Some differences have been noted in animal models, although adhesion prevention is similar for most[28]. A multi-center, human study is underway to better determine the characteristics of these composite meshes (NCT01355939)[29]
Dualmesh[25]	Micropore ePTFE/Macropore ePTFE	Minimal inflammatory reaction[22] Adhesions less tenacious than all other meshes[24,30] Less adhesiolysis time/mesh surface area compared to composix[24]	PTFE has higher rates of bacterial adherence and less resistant to colonization[31,32] Higher risk of explantation in open cases (14.2%), but not laparoscopic cases (4.6%)[32] Limited fibrous tissue ingrowth and incorporation[22]
Composix™[25]	PP/ePTFE	PP thought to promote better ingrowth and inflammation	Adhesions predominately found due to mesh eversion at periphery[24] Possible increased infection risk (8% in one series)[33]
Parietex[30]	PET/type I collagen, polyethylene glycol, and glycerol	United States evaluation showed adhesions in 18% of patients, *vs* 77% when uncoated PE was used	Collagen film absorbed quickly (20 d)[34]
Proceed[30]	PP encapsulated by PDS/oxidized regenerated cellulose	Lightweight, macro-porous mesh[34]	Incomplete peritoneal mesothelialization over graft Induced dense adhesions in rabbit models[35]
C-QUR[30]	PP/omega 3 fatty acid gel	Less contracture in rabbit model[30]	Poor incorporation strength in rat model[28]
Sepramesh[25]	PP/sodium haluronate and carboxy - methylcellulose	Low adhesion coverage and good incorporation[28]	Inflammation induces breakdown of the coating, resulting in delayed adhesion formation[28]

ePTFE: Expanded polytetrafluoroethylene; PDS: Polydioxanone; PE: Polyester; PET: Polyethylene terephthalate; PP: Polypropylene.

BioA® tissue reinforcement by Gore®, TIGR® Matrix by Novus Scientific[38], and Phasix™ mesh by Bard[39]. These meshes might be used for laparoscopic repair in contaminated fields, including parastomal hernia repair.

Titanized mesh might help reduce inflammatory, foreign body reactions and reduce pain after laparoscopic repair, although results have yet to be confirmed in randomized or comparative studies[42]. A third kind of mesh helps prevent migration and reduces the amount of mesh fixation needed. Covidien created a new, self-gripping mesh currently being used in laparoscopic inguinal, as well as open ventral and incisional hernia repairs. ProGrip™ is a polyethylene mesh that includes small absorbable "hooks" designed to promote abdominal wall adhesion, prevent migration, and decrease the number of fixation points needed. One study asserts less postoperative pain after inguinal hernia repair, but this has not been observed in other studies[43,44]. This mesh might be used in order to decrease the number of tacks and sutures needed for fixation.

Placement and fixation of mesh

Laparoscopic lysis of adhesions is performed prior to mesh placement. Multiple instruments exist for this application, including newly developed ultrasonic shears and bipolar devices. However, there is currently no level I data on the superiority of one over the other. Intraperitoneal mesh is placed once the hernia defect is identified and prepared, and there are many variations

Table 3 Advantages and disadvantages of newly developed meshes

Name	Materials	Properties	Current research
BioA® Tissue Reinforcement by Gore®[36,37]	3D matrix copolymer of polyglycolic acid and trimethyl carbonate	Absorbed in 6 mo	Prospective, observational study (NCT01325792) to evaluate single-staged open ventral incisional hernia repair with midline reinforcement in clean contaminated and contaminated wounds. Early one-year results demonstrated a hernia recurrence rate of 14% and an 18% infection rate[36]
TIGR® Matrix by Novus Scientific[38]	Knit mesh of fast absorbing and slow absorbing glycolide, lactide, and trimethylene carbonate fibers	First fiber retains strength for 1-2 wk Second fiber retains strength for 6-9 mo Stimulates neovascularization and a high level of type I collagen ingrowth Absorbed in 3 yr	One case report of onlay use for open ventral hernia repair[38] Currently three-year safety and performance study showing use for inguinal hernia repairs in humans[40]
Phasix™ mesh by Bard[39]	Monofilament, knit mesh of poly-4-hydroxybutyrate	Minimal absorption in 12-26 wk Porcine model shows 18% strength than natural abdominal wall at 48 wk Manufacturer claims hernia repair support for 12-18 mo	Launched in 2013 and currently there are no published results in human subjects
Titanized mesh[41]	PP mesh with relatively inert titanium coating	Retains strength of PP mesh Titanium retards inflammation and decreases foreign body reaction[42]	Lower analgesic use (1.6 d *vs* 6.1 d, $P < 0.001$) and a quicker return to baseline activity (6.9 d *vs* 9.7 d, $P < 0.001$) when compared to parietex mesh. Also less postoperative pain at 1 mo, but no difference at 6 mo
Progrip by Covidien[43]	Self gripping PP mesh with small, absorbable hooks	Promotes abdominal wall adhesion, prevents migration, and decreases the number of tack or sutures fixation points	Has been used in laparoscopic inguinal, ventral, and incisional hernia repairs One study asserts less postoperative pain after laparoscopic inguinal hernia repair, but another shows no difference with open repair[43,44] Operative times may be less

PP: Polyethylene.

in the fixation of that mesh. Most surgeons cover the hernia defect with a 3 to 5 cm overlap circumferentially, and then secure the mesh in place with transfascial sutures and/or intra-abdominal peritoneal tacking[8,11]. Little is known about the physiologic movement of mesh *in vivo* during physiologic stress, however, the ideal technique would prevent migration and folding of the mesh[45].

Over the years, surgeons have varied greatly in the number of tacks, the number of sutures, as well as the materials of tacks and sutures used for fixation[46]. The goal has been to balance adequate fixation to prevent recurrence against excessive fixation that can lead to unnecessary pain. It is also important to minimize the amount of permanent component of mesh without sacrificing overlap, because large meshes require multiple, potentially painful fixation points, and have an increased risk of chronic pain from foreign body reaction[47]. The use of transfascial sutures may allow the surgeon to limit overlap to only 3 cm, whereas the use of tacks requires at least 5 cm of overlap[48]. An intuitive understanding of biomechanical forces suggests that transfascial sutures provide better fixation, as they are secured to the strong anterior fascia. Unfortunately, transfascial sutures risk abdominal wall nerve entrapment and muscle strangulation, which is thought to contribute to the significant postoperative pain[46]. Tacks provide a 3.8 to 6.8 mm posterior to anterior purchase of the abdominal wall and do not capture the anterior fascia[49]. The tensile strength of sutures was 2.5 times greater than that of tacks in a pig cadaver model; however, a laparoscopic pig model showed no signs of migration or recurrence, and no additional fixation strength at 4 wk when only tacks were used[46]. More tacks are used than suture, and increasing the number of tacks theoretically cause more pain. Schoenmaeckers *et al*[50] demonstrated that decreasing the average number of tacks to 20 from 40 significantly decreases their visual pain analog scale at 3 mo from 5.8 to 1.8 out of 100 ($P = 0.002$), which is not likely to be clinically significant. Of note, this study did not control for the type of mesh.

Recently absorbable tacks have been developed, with the objective of reducing pain, foreign body reactions, and adhesion formation. One porcine model proved similar tensile fixation strength between a 4.1 mm poly (glycolide-co-L-lactide) tacks and a control titanium tacks at 6 mo and less tensile strength with 6.8 mm poly (D,L)-lactide tacks[49].

Many studies compare sutures *vs* spiral tackers; however, many of these studies do not adequately control for patient demographics, hernia size, technical variations, suture type, and mesh size and type, to name a few. Multiple reviews largely showed no optimal technique to prevent recurrence and reduce pain. A recent systematic review by Reynvoet *et al*[46] grouped 25 prospective and retrospective studies from 1999 to 2011 into suture only repair, tack only repair, and

both sutures and tacks. Other reviews included many of the same studies, however, this study used the DerSimonian-Laird random effects model to assign relative weights in relation to study sample size. The hernia recurrence rate for the suture only group (0.9%CI: 0%-1.7%) was less than the tacks only group (3.4%CI: 2.4%-4.5%) and the combination of suture and tack group (2.5%CI: 1.3%-3.7%). As the CIs were overlapping, there was no significant difference in recurrence rate between the three fixation techniques. This is consistent with other past reviews[46,48,51].

The review by Reynvoet *et al*[46] was unable to statistically analyze the outcome of pain following hernia repair, as there was not a standardized way between studies to report pain outcomes. Chronic pain was defined as pain anywhere from 4 wk to 6 mo. Narcotic use, pain analog scales, and quality of life surveys measured pain threshold. Despite these methodological variations between individual studies, Reynvoet *et al*[46] concluded that literature currently shows no significant difference in postoperative pain between suture and tack repairs.

In contrast, the WoW trial (with or without sutures), a randomized controlled trial from Belgium, showed significantly more pain with "sutures and tackers" *vs* a "double crown" tack arrangement[52]. Patients were asked to draw a line representing postoperative pain; significant pain was defined as a visual analog scale score greater than 1 cm. There was a significant difference at 4 h when coughing, and 3 mo at rest (31.4% *vs* 8.3%, $P = 0.036$). Secondary outcomes were reported, showing less operative time in the tacks only group and similar hernia recurrence at 24 mo. However, the main limitation was the somewhat arbitrary 1 cm visual analog scale for pain (VAS) cutoff for significant. A similar study by Wassenaar *et al*[53] used VAS mean scores instead of the 1 cm cutoff. It showed no difference between double crown tackers, absorbable suture and tackers, and non-absorbable suture and tackers.

New less invasive, less painful alternatives for mesh fixation have been developed for hernia repair. Fibrin sealant initially was used for inguinal hernia repair; however, it has also been studied for laparoscopic incisional repair[54]. In 2011, a randomized prospective study was performed comparing the use of fibrin sealant only to the use of titanium tacks only after laparoscopic umbilical hernia repair[55]. At 4 wk follow-up, there was significantly less acute postoperative pain both at rest and during activity, as well as shorter convalescence (median 7 d *vs* 18 d, $P = 0.027$) with use of fibrin sealant. At 1-year follow-up, these differences were not significant, and the hernia recurrence rate was predictably higher in the fibrin only group, though statistically insignificant (26% *vs* 6%, $P = 0.18$). Another study used fibrin sealant in the hernia sac after laparoscopic hernia reduction[56]. This showed a significant reduction in the incidence of seromas at 1 mo (72% control *vs* 28% with sealant, $P = 0.002$). Although promising for some limited applications, the current data does not show an advantage to routine use of fibrin sealant, and shows a trend toward increased recurrence rates if it is used alone for mesh fixation.

EVOLVING TECHNIQUES

Primary defect closure

Once the hernia contents are reduced, the defect is measured and prepared for mesh placement[11]. Traditionally, a tension free repair is created by placing mesh over the defect and securing it in place. Some surgeons prefer to close the hernia defect primarily prior to this step. Three main laparoscopic approaches have been described: (1) interrupted percutaneous closure with suture passer; (2) intra-corporeal suturing; or (3) Endo Stitch™ suturing with a knot pusher[13]. Barbed suture can be used for defect closure or mesh fixation in order to decrease the tension needed when placing each suture. Lyons *et al*[57] used a porcine model to show that barbed suture requires the application of 75% less force than conventional suture, while maintaining adequate mesh fixation strength.

There are many proposed advantages of performing primary defect closure before applying the mesh[13,58]. Re-approximating the abdominal fascia is thought to be a more physiologic repair, and thus stronger. Additionally, it provides a greater surface area of abdominal wall for the mesh to be in contact with. Furthermore, it prevents postoperative bulging of the mesh into the defect. Bulging is not ideal for cosmesis, and may allow mesh to come closer to the skin surface, which can increase the risk of mesh infection and erosion. Conversely, closing the defect increases tension, which may be counterproductive. Also, placement of extra suture in the abdominal wall increases the risk of postoperative pain. Many surgeons have yet to adopt this technique, most likely due to the technical difficulty, and the current lack of evidence suggesting its superiority when compared to mesh placement alone.

Current literature lacks randomized control trials examining the effectiveness of concomitant primary defect closure during laparoscopic ventral and incisional hernia repair. Nguyen *et al*[58] performed a systematic review of 11 studies, including case series and retrospective reviews. Recurrence rate ranged from 0% to 7.7%, and seroma rates were 0% to 11.4%. Three of the retrospective reviews included compared laparoscopic hernia repairs with and without primary defect closure. Clapp *et al*[59] was the only risk adjusted study and followed 72 cases for an average of 24 mo. Hernia recurrence was 16.7% in the group without primary defect closure, whereas no recurrences were seen in the group with primary defect closure. Bulging in this study was decreased from 69.4% in the non-closure group to 8.3% in the closure group. In addition, superficial wound infections were decreased from 13.9% to 8.3%, and the incidence of seroma was decreased from 27.8% to 5.6%. Another retrospective comparative review of 128 patients also reported low recurrence rates after concomitant primary defect closure (6.25%), but

this was not significantly different when compared to the group without primary defect closure[13]. Interestingly, the incidence of seroma formation was higher in the group with primary defect closure than the group without primary defect closure (11.4% *vs* 4.3%).

Component separation

The separation of components technique includes various methods of dissecting the abdominal wall layers in order to advance facial edges and decrease physiologic tension. In 1990, Ramirez *et al*[60] first described releasing the external oblique aponeurosis alone, which allows approximately 5 cm of unilateral fascia advancement at the umbilicus, and 3 cm inferiorly and superiorly. The drawback is that it weakens the abdominal wall, especially laterally at the semilunar line[61]. In 2000, Lowe *et al*[62] combined an open technique with balloon dissection endoscopy. A few years later, Rosen *et al*[63] began separating the external and internal oblique muscles laparoscopically, followed by release of the external oblique aponeurosis. In the morbidly obese population, the presence of thick subcutaneous tissue can make this last technique challenging. After laparoscopic myofascial release, the overlying attached subcutaneous tissue limits movement of that fascia toward the midline[64]. This restricts the advancement to 86% of that of the open release[63].

Although minimally invasive separation of components provides less myofascial release, it avoids creating large skin flaps and spares vital perforating vessels[61,64]. On the other hand, open technique allows excision of dystrophic and tissue expanded skin in conjunction with the hernia sac. One could assume that subsequent advancement of normal skin into the wound may lead to better wound healing and cosmetic result. However, recent studies note a decrease in wound complications with the minimally invasive approach, without significantly affecting recurrence rates[64]. A systematic review comparing minimally invasive component separation with open component separation included 7 non-randomized controlled studies and 56 case series with a total of 3055 patients[61]. Minimally invasive component separation as compared to open component separation resulted in lower rates of total complications (20.6% *vs* 34.6%), superficial wound infection (3.5% *vs* 8.9%), necrosis (2.1% *vs* 6.8%), and hematoma/seroma (4.6 % *vs* 7.4%). Open component separation had a lower rate of recurrence (11.1% *vs* 15.1%), possibly due to a higher rate of simultaneous midline mesh repair in this group. They went on to perform a meta-analysis of the 7 non-randomized controlled studies, which included 387 patients. This showed a significant decrease in skin dehiscence (OR = 3.18) favoring minimally invasive component separation.

Most studies use variations of the Rosen anterior release technique. Posterior component release techniques have also been described, most notably the transversus abdominis muscle release[65]. This involves dissection in the retrorectus space to the semilunar line. The transversus abdominis muscle is then divided vertically that allows entry to the preperitoneal space below, dissection is carried laterally, and a mesh is placed as a sublay. This dissection is tedious and theoretically carries higher risk with a wider learning curve due to the presence of neurovascular structures. It is therefore rarely performed laparoscopically. However, the added dexterity of robotics make the minimally invasive technique feasible.

Multiple concomitant procedures

Ventral and incisional hernias are relatively common in patients requiring other procedures, such as cholecystectomy and bariatric procedures. Previous studies have shown a high recurrence rate and complications rate with ventral and umbilical hernia repair during bariatric procedures[66]. However, a recent retrospective review of 54 patients reported a favorable experience with laparoscopic mesh repair after gastric banding, sleeve gastrectomy, and Roux-en-y gastric bypass[67]. There were no mesh infections and only one hernia recurrence after 12 mo of follow-up. Eleven percent of patients had complications including leak, abdominal wall hematoma, and pulmonary embolism. This was consistent with expected outcomes for bariatric surgery.

Similar results were not obtained when ventral hernia repair was performed with cholecystectomy. Orr *et al*[68] queried the NSQIP database and found 357 cases of simultaneous cholecystectomy and ventral hernia repair. Stepwise multi-variable logistic regression analysis was performed for over 50 risk factors in the NSQIP database, comparing these to 74019 cases of cholecystectomy alone. This model determined that patients undergoing the combination procedure were 2.4 times more likely to have a wound complication, 3.1 times more likely to have sepsis or septic shock, and 2.8 times more likely to have pulmonary complications. The study was limited as it was only able to analyze 30-d outcomes. Also, it was not able to separate out which patients had mesh repair or suture repair. Nevertheless, this study gives great pause to surgeons promoting laparoscopic hernia repair during cholecystectomy.

Avoiding port site hernia

The rate of incisional hernias due to previous laparoscopic port placement is 1% to 22%, which has stimulated interest in more advanced minimally invasive options[69]. Bucher *et al*[69] also reported a case series of 52 patients undergoing single port ventral and incisional hernia repair through one 10-mm endoscope with a working channel. There were no conversions to open and no morbidity, with exception of two seromas. No recurrences were noted at 16 mo. Other surgeons seek to avoid 10-mm ports altogether. Agarwal *et al*[70] described a technique of introducing the mesh through a port placed in the hernia defect. This obviated the

need for a 10-mm port in the flank.

Natural orifice transluminal endoscopic surgery

Natural orifice transluminal endoscopic surgery (NOTES) continues to be explored as a future option for general surgery. One case report describes repairing an umbilical port site hernia through a 2 cm incision in the posterior vaginal fornix[71]. Panait *et al*[72] reported a series of 107 patients undergoing transvaginal appendectomy, cholecystectomy, and ventral hernia repair. Proponents of this approach claim a potential benefit in cosmesis, decreased pain, early return to work, decreased port site complications, and specific advantages in the obese population. Most agree that NOTES operations for hernia repair increase the risk of a major complication, and these techniques should strongly be considered as experimental for now and performed under institutional research protocols.

Robotic surgery

The use of the da Vinci robot has expanded since its approval by the Food and Drug Administration in 2000[73]. Initially applied for hysterectomy and prostatectomy, it has recently been used for an increasing number of general surgery procedures, including Nissen fundoplication, single site cholecystectomy, colectomy, and ventral or incisional hernia repair. The magnified, three-dimensional high-definition view, computer-aided elimination of tremor, and seven degrees of freedom at the distal ends of the instruments with superior maneuverability, have led to its increasing adoption by several prominent surgeons[74]. In fact, LeBlanc *et al*[75] presented his early experiences with robotic approach at a recent American college of surgeons meeting, asserting its role in replicating open technique with minimally invasive methods.

Many surgeons are currently utilizing the robot simply to facilitate their ability to suture the hernia defect closed, and thus place the mesh as an intraperitoneal onlay. Gonzalez *et al*[76] compared a standard laparoscopic intraperitoneal mesh placement technique without defect closure, to a similar technique, which utilized the robot to close the hernia defect. They found an increased operative time for the robot with no difference in wound complications or recurrence. In our practice (AC-Greenville), we have developed a robotic approach to replicate the open Rives-Stoppa retromuscular incisional hernia repair technique. We are able to perform a retrorectus dissection, with or without the addition of a transversus abdominis release, or posterior component separation. We then suture the posterior rectus sheaths closed in the midline, followed by uncoated polypropylene mesh placement in the retrorectus space, and closure of the abdominal wall defect. A case controlled retrospective cohort study comparing our robotic Rives-Stoppa to the open technique favored the robotic approach with less blood loss and a shorter length of stay with no difference in operative time or direct hospital cost. Surgical site infection was 9.5% in the open group and 0% in the robotic group (P = 0.48)[77]. The sample size was small, which increased the likelihood of type Ⅱ statistical error. Like any new operation, there is a steep learning curve. On the other hand, the ergonomic nature of the robotic system may allow a novice user to rapidly progress. Initially, the robotic retrorectus mesh repair with simultaneous posterior component release was taking upwards of 6 h to perform. With some technique modifications and experience, we have been able to decrease operative times into the 2.5-4 h range depending upon the degree of intraperitoneal adhesions. Interestingly, the initial cost analysis suggests that this repair is equal to open repair. Decreased cost with robotic use is not unprecedented. In fact, one study in the United States showed decreased costs with robotic single site cholecystectomy *vs* laparoscopic cholecystectomy ($1319 *vs* $1710, P = 0.001), mostly due to decreased use of supplies[78].

POSTOPERATIVE CONSIDERATIONS: COMPLICATIONS, RECURRENCE, AND QUALITY OF LIFE

The patient centered outcome reporting initiative is a nonprofit organization in the United States authorized by congress in the patient protection and affordable care act. It is charged to "improve the quality and relevance of evidence available" on healthcare topics such as this[79]. They noted that a lack of convincing trials makes it difficult to develop and validate an ideal, standardized approach to laparoscopic ventral and incisional hernia repair. However, it is generally accepted that decreased risk of postoperative infection is the primary advantage, especially in the obese population[80-82].

Recently, there has been a movement to separate primary ventral and secondary incisional hernias into two different categories. Stirler *et al*[15] showed that laparoscopic repair of incisional hernias on average results in more adhesiolysis, a higher conversion to open, a longer procedure, and a higher recurrence rate when compared to primary ventral hernias. In 2014, Awaiz *et al*[83] performed a meta-analysis with strict exclusion criteria in order to evaluate elective repair of incisional hernias. There was a statistical reduction in bowel related complications favoring open repair *vs* laparoscopic repair. However, "bowel injury" included an aggregate of enterotomies, serosal tears, and small bowel obstructions. There was no difference in other postoperative morbidities. Arita *et al*[84] reviewed ventral and incisional hernias separately, and found that superficial surgical site infection rates were higher in open repairs for both hernia types, but there was no difference in recurrence rates between open and laparoscopic approaches.

There has also been an attempt to correlate the acuity of hernia presentation with outcomes. Our group used NSQIP database to determine propensity score adjusted OR in 26766 subjects undergoing open *vs*

laparoscopic ventral and incisional hernia repair for reducible and incarcerated/strangulated hernias[85]. Laparoscopic repair was found to have a small but significant decrease of length of stay in both reducible (open = 2.79, 2.59-3.00; laparoscopic 2.39, 2.20-2.60; $P < 0.01$) and strangulated/incarcerated hernias (open = 2.64, 2.55-2.73; laparoscopic 2.17, 2.02-2.33; $P < 0.01$). Open repair of incarcerated/strangulated hernias increased the risk of superficial surgical site infection (OR = 3.1, $P < 0.01$), deep surgical site infection (OR = 8.0, $P < 0.01$), and wound disruption (OR = 9.3, $P < 0.01$) when compared to laparoscopic repair. Open repair had a lower risk of organ/space surgical site infection after repairing reducible hernias when compared to laparoscopic repair, but there was no increased risk of other infections.

Quality of life

As the incidence of recurrence decreases, there is an increasing focus on secondary patient reported outcomes that affect postoperative quality of life. Surrogates have been created because there is no consensus on how to measure pain, mobility, cosmesis, and length of convalescence. A 2011 Cochrane review found no significant differences in acute postoperative pain (mean difference 0.09, 95%CI: -0.45 to 0.62), and return to full activity (mean difference -0.70, 95%CI: -2.10 to 0.70)[81]. One study showed no difference in acute postoperative pain, but another study showed less chronic neuralgia in the laparoscopic group. Regarding return to full activities, Pring *et al*[86] revealed no difference between open and laparoscopic repairs. However, Itani *et al*[87] found a near significant advantage for laparoscopic repair (23 d *vs* 28.5 d, adjusted hazard ratio 0.54, 95%CI: 0.28-1.04; $P = 0.06$). The Cochrane review showed a significant difference in hospital stay (mean difference -4.63, 95%CI: -5.95 to -3.32); however, this was only if the open repair control group stayed longer than 5 d[81]. There was no significant difference in quality of life (mean difference 0.44, 95%CI: -0.24 to 1.11).

In 2014, Jensen *et al*[88] reviewed 26 articles for quality of life assessment methods. Fifty-four percent of these used the short-form 36 (SF-36), which is a non-surgery or hernia specific scoring of general physical and mental health. The physical component focuses on pain, energy/fatigue, and functional limitations. The mental health component focuses on social functioning, emotional wellbeing, and general perception of health. Two of the studies discussed found no difference when comparing open to laparoscopic repair[87-89]. On the contrary, some other authors showed better quality of life, and better short-term physical functioning with laparoscopic repair[90]. In addition, when tack and transfascial suture techniques were compared using the SF-36, no significant difference was noted between the two approaches[52,53,88].

Only two of the quality of life assessment methods are hernia specific. These include the Carolinas comfort scale and the hernia-related quality of life survey (HerQLes). The Carolinas comfort scale assesses pain, limitations in movement, and mesh sensation for eight daily activities. Colavita *et al*[91] assessed 710 patients and showed worse quality of life one month after laparoscopic repair when compared to open repair, but there was no long-term difference. Two other studies showed large hernia defects and the presence of preoperative pain to be strong predictors of a short-term decrease in quality of life, most likely due to pain[92,93]. The HerQLes is a newly developed assessment first reported by Krpata *et al*[94]. It associates hernia specific physical limitations with overall physical and mental effects on quality of life. It shows an advantage in laparoscopic repair at 4 wk, but no difference at 6 mo. Based on the available literature, it appears that there might be some improvement in short-term quality of life with the laparoscopic approach, but this benefit balances out in the long run.

FUTURE DIRECTIONS

Preoperative patient selection and risk modification

Most surgeons attempt to decrease modifiable risk factors through patient encouragement; however, there are very few multidisciplinary programs that actively and successfully accomplish this. Further research is required to validate methods to decrease known modifiable risk factors, such as obesity and smoking. Furthermore, only 20% to 27% of hernias are repaired laparoscopically, despite the benefits noted above[12,18].

Considering the plethora of procedural and equipment options, surgeons need criteria to develop a tailored surgical technique for each patient, including surgical approach, mesh material, fixation material, and fixation method. Several algorithms have been developed for operative planning, but no one method has become ubiquitous. Eid *et al*[95] developed an algorithm to stratify obese patients, taking into account body mass index, abdominal wall thickness, and presence of symptoms. Parker *et al*[96] proposed another algorithm to determine open *vs* laparoscopic component separation, and concomitant open *vs* laparoscopic ventral hernia repair. Further research is needed to create a reliable and validated algorithm for surgical selection.

Mesh selection

No one mesh has become dominant in intraperitoneal onlay repair. There is an ongoing study at Washington University determining the adhesion profile of these meshes[29]. Several other studies have attempted to stratify mesh characteristics, but the numbers are too small to draw definitive conclusions[24]. Mesh technology continues to develop ahead of validating research. Long-term absorbable meshes, self-gripping meshes, and titanium reinforced meshes are now available for

use. The robotic platform increases the ability to place mesh in the retrorectus space, which may obviate the need for different mesh materials. Surgeons and patients would benefit from more level 1 clinical studies scientifically comparing the risks and benefits of evolving mesh technologies.

New techniques

Non-standard laparoscopic techniques are being increasingly utilized, such as simultaneous primary hernia closure, retrorectus mesh placement, concomitant component release, and mesh fixation, in order to decrease wound complications, postoperative pain, and hernia recurrence. Surgeons are more likely to attempt laparoscopic repair of more complex hernias, such as incarcerated/strangulated ventral hernias, as their collective experience grows. In the same way, newer fixation methods might decrease postoperative pain, such as barbed suture or fibrin sealant, but may risk re-herniation if they do not provide adequate fixation. Simultaneous component release has gained popularity as it allows reconstruction of the midline. Considering the relatively low incidence of complications, mesh registries may be useful to increase the power of future studies.

The robotic platform

The ease of robotics may decrease the learning curve for surgeons, making a good laparoscopic surgeon better able to replicate the tenets of open repair. It permits relatively easy access to the anterior abdominal wall, allowing the surgeon to perform the ideal repair for that patient - including possible primary defect closure, retrorectus mesh placement, intracorporeal suturing, and concomitant posterior component release. It also might allow for standardization of surgical technique in order to develop a reliable approach to hernia repair that can be offered to an increasing number of patients. Further research is needed to determine the ability to decrease patient morbidity *vs* the increased cost of technology.

Patient reported outcome measures

Patient reported outcome measures (PROM) are standardized measures used to assess symptom status, physical function, mental health, social function, and wellbeing, with the goal of patient centered improvement of care. This system has been implemented in the United Kingdom and the National Health Service for many years with variable success[97]. Previously discussed studies have attempted to assess quality of life using similar standardized measures for ventral hernia repair, such as the SF-36, Carolinas comfort scale, and the HerQLes. Thus far, these studies have been experimental and have not been used to guide treatment. Further research might develop specific PROM that may be used to enable cost analysis, standardization of treatment, and quality improvement.

CONCLUSION

Laparoscopic ventral and incisional hernia repair has evolved significantly since its roots in the crude endoscopy of Hippocrates. The experience of the last 25 years has allowed us to significantly decrease the morbidity of post-laparotomy incisional hernia and *de novo* ventral hernias. Preoperative risk factor modification and a useful diagnostic algorithm have a significant role in preparing a patient for the right operation. New hernia repair techniques have the potential to continue to reduce the associated morbidity, and perhaps robotic surgery will be the tool to accomplish the ideal hernia repair in the appropriate setting. Despite the advances noted above, open surgical technique is many times necessary and should not be overlooked. Improved postoperative evaluation is necessary to effectively weigh the results of our innovations, and continue to evolve solutions to ventral and incisional hernias.

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