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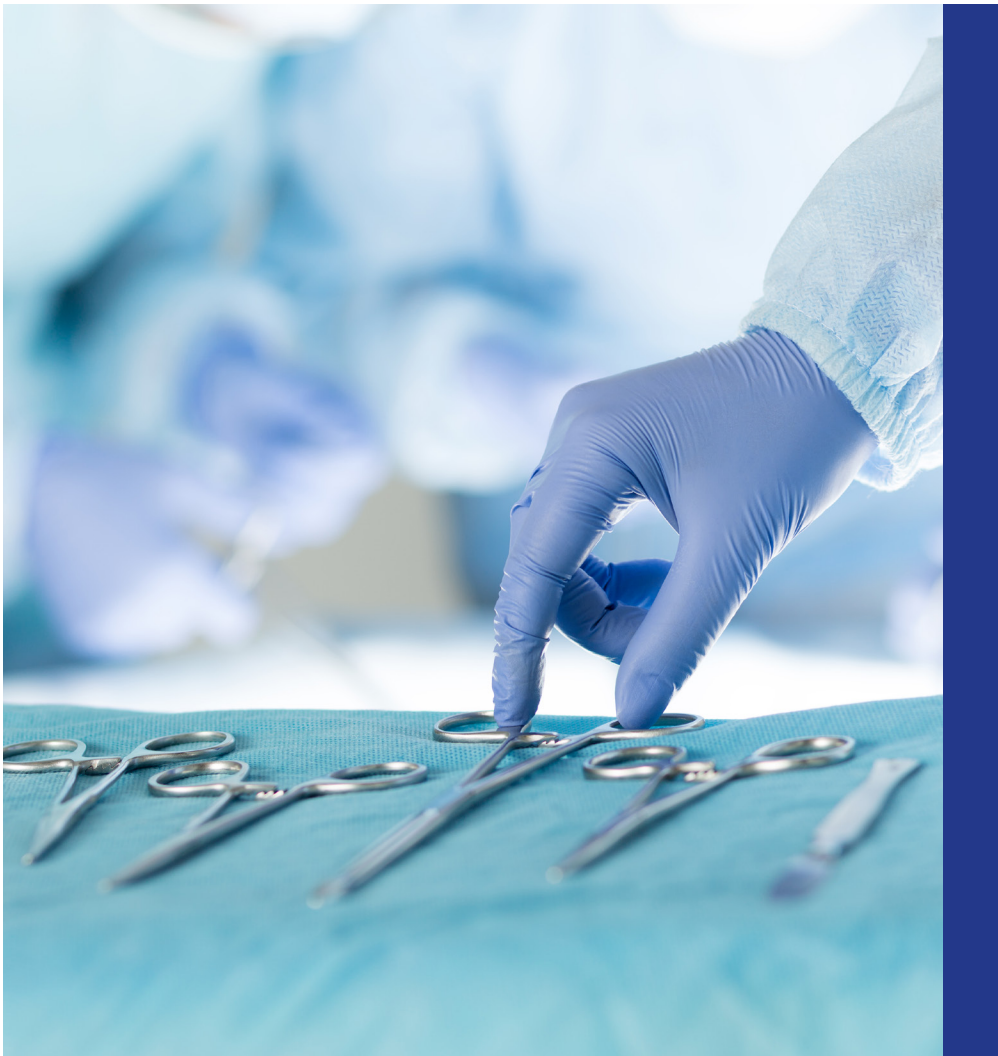
`JAWS in US´ offers an accessible synthesis of 12 articles published in the Journal of Abdominal Wall Surgery (JAWS) between 2023–2025 by a U.S. surgical group dedicated to abdominal wall care. The e-book provides a panoramic view of the group's contributions: standardization of techniques, clinical and functional outcomes, learning curves, perioperative safety, and adoption across different hospital environments.

This e-book inaugurates a `Country & Region Series´ that will invite teams worldwide to document local advances and stimulate international collaboration. Our goal is to bring curated, practice-ready evidence to residents, specialists, and decision-makers, building bridges across diverse surgical realities with a common language: outcomes that matter to patients.

It is a pleasure to introduce `JAWS in US´ at the AHS 2025 Annual Meeting. I am grateful to the authors for their rigor and for sharing data and insights with our community. I also invite teams from other countries and regions to contribute to future titles in our `Country & Region Series´ where we aim to translate it into better outcomes worldwide.



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ORIGINAL RESEARCH
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Patients With Systemic Reaction to Their Hernia Mesh: An Introduction to Mesh Implant Illness

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In our practice, we have noticed an increased number of patients requiring mesh removal due to a systemic reaction to their implant. We present our experience in diagnosing and treating a subpopulation of patients who require mesh removal due to a possible mesh implant illness (MII). All patients who underwent mesh removal for indication of mesh reaction were captured from a hernia database. Data extraction focused on the patients' predisposing medical conditions, presenting symptoms suggestive of mesh implant illness, types of implants to which reaction occurred, and postoperative outcome after mesh removal. Over almost 7 years, 165 patients had mesh removed. Indication for mesh removal was probable MII in 28 (17%). Most were in females (60%), average age was 46 years, with average pre-operative pain score 5.4/10. All patients underwent complete mesh removal. Sixteen (57%) required tissue repair of their hernia; 4 (14%) had hybrid mesh implanted. Nineteen (68%) had improvement and/or resolution of their MII symptoms within the first month after removal. We present insight into a unique but rising incidence of patients who suffer from systemic reaction following mesh implantation. Predisposing factors include female sex, history of autoimmune disorder, and multiple medical and environmental allergies and sensitivities. Presenting symptoms included spontaneous rashes, erythema and edema over the area of implant, arthralgia, headaches, and chronic fatigue. Long-term follow up after mesh removal confirmed resolution of symptoms after mesh removal. We hope this provides greater attention to patients who present with vague, non-specific but debilitating symptoms after mesh implantation.

Keywords: mesh, allergy, mesh reaction, mesh removal, mesh-ASIA, hernia mesh, mesh implant illness, Shoenfeld's syndrome

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INTRODUCTION

Mesh implantation for hernia repair has become standard practice for the majority of hernia repairs (1). Mesh-based hernia repairs have been shown to be a durable solution, however, postoperative complications, such as chronic postoperative pain, remain a concern. Chronic pain following mesh inguinal hernia repair is either neuropathic and/or nociceptive (2). In our practice, which specializes in the management of complications after herniorrhaphy, we have noticed an increasing incidence of a new cause of complications after mesh-based hernia repairs: a systemic reaction to the mesh material (3).

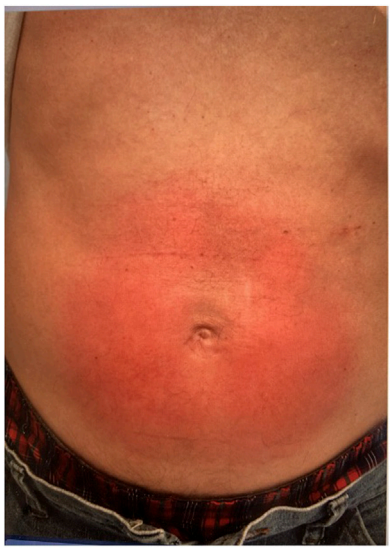

FIGURE 1 | Abdominal wall macular rash after open ventral hernia repair with 4.3 cm round onlay mesh. This is a direct dermatologic reaction to the mesh and not considered a systemic MII.

To date, there have been few investigations into the inflammatory response to mesh (4, 5). These show variability in patients' responses to mesh and suggest there is a group of patients who are "high responders." This subpopulation exhibits a significantly more virulent immunologic response to mesh in comparison to their peers (6). This inflammatory response to implant material has been termed "autoimmune/inflammatory syndrome induced by adjuvants (ASIA)" or "Shoenfeld's syndrome" after Dr. Yehuda Shoenfeld who first acknowledged this reaction (7).

ASIA/Shoenfeld's syndrome may occur as a reaction to any implant. Given that this syndrome is considered to occur only in a small subset of patients, there is limited *in vivo* data and even less description of the clinical consequences of these reactions. Only one study has described ASIA in a population of patients after mesh implantation, such as for hernia repair and pelvic organ prolapse surgery (8). Others have shown ASIA in patients after silicone breast implantation (9–14).

We have an interest to evaluate ASIA specifically among patients undergoing hernia repair surgery. We chose the term mesh implant illness (MII) to refer to the subset of patients with ASIA whose illness stems from a systemic reaction to their mesh implant. This terminology stems from the well established term, breast implant illness (BII), which refers to the subset of patients with reactions to breast implants. We reviewed MII patients' clinical findings and followed their outcomes after mesh removal, with the goal of developing a comprehensive plan of care for patients with MII.

MATERIALS AND METHODS

Records were reviewed from all patients who underwent implant removal following a hernia repair at a single surgeon center (ST) between August 2013 and June 2020. Data was extracted from a prospectively maintained hernia database.

A systemic mesh reaction captured as MII was defined as any post-herniorrhaphy illness that was not locally neuropathic or nociceptive. All attempts were made to rule out other causes of their illness, which typically included gastroenterologic, urologic, gynecologic, orthopedic, rheumatologic, allergic, immunogenic, dermatologic, neurologic, and/or infectious workups (**Figure 1**). Patients with suspected chronic mesh infection, who had findings of inflammation on preoperative imagine or abnormalities in blood testing suggestive of chronic infection (for example, abnormal CBC, differentials, ESR, other inflammatory markers) were not included in this population. Data collection included patient demographics, medical history, surgical history, allergy history, family history, presenting symptoms, hernia type, operative details, implant material removed, and postoperative outcomes. Patients were followed up in person and by phone. Short-term follow-up is defined as within 30 days after surgery.

Statistical analyses included Fisher's exact and Chi-square test.

RESULTS

Over a span of almost 7 years, 191 of 847 (23%) hernia-related operations involved implant removal. Of these, 165 (86%) patients had one or more meshes removed. Others involved suture and/or tack removal only and were excluded from our analysis. We divided our mesh removal population into two groups: Patients with MII and those without MII. Among patients who underwent mesh removal, 28 (17%) had mesh removed for the postoperative diagnosis of probable MII, while 137 (83%) had mesh removed for other reasons such as pain, meshoma, infection, neuralgia, and/or hernia recurrence (**Table 1**). Among the 28 patients with a likely MII, 16 (57%) were female, average age was 46 years (range 22–68), and average BMI was 24.8 kg/m^2 (range 17.64–32.80) (**Table 2**). Seven MII patients (25%) had their original hernia repair and mesh placement performed by us.

All of the patients with suspected MII had at least one of the following new symptoms as part of their syndrome: chronic fatigue (23, 82%), bloating with or without nausea (18, 64%), local swelling (16, 57%), joint pain (14, 50%), rash or erythema (13, 46%), headaches (12, 43%), fevers (9, 32%), and fibromyalgia (3, 11%) (**Table 3**). Of those with new and inexplicable rashes, 8 (62%) had a body rash distant from the area of mesh implant, e.g. along the neck, chest and back (**Figure 2A**). Symptoms began shortly after the mesh implant. Seven patients (25%) reported immediate start of symptoms, i.e., within days of their hernia surgery with mesh. Two patients (7%) reported symptoms within weeks, and 4 (14%) reported symptoms within 4 months postoperatively. The majority (23, 82%) of patients also complained of pain at the surgical site. The average pre-operative pain score was 5.4/10 (range 1–10).

Three patients with suspected MII (11%) had a known personal history of an autoimmune and/or inflammatory disorder prior to the mesh implantation. An additional

TABLE 1 | Operative details for patients that underwent mesh removal due to mesh implant illness (MII) or other reasons (non-MII).

	MII	Non-MII	*p*
	N = 28	N = 137	
Indication for removal, N (%)			
Pain	23 (82%)	101 (74%)	NS
Recurrence	8 (29%)	46 (34%)	NS
Neurectomy	6 (21%)	34 (25%)	NS
Neuralgia	5 (18%)	11 (8%)	NS
Meshoma	3 (11%)	54 (39%)	**0.003**
Numbness	2 (7%)	2 (1%)	NS
Infection	1 (4%)	25 (18%)	NS
Index Surgical Approach[a]			
Open	13 (47%)	82 (60%)	NS
Laparoscopic	13 (43%)	43 (31%)	NS
Robotic	3 (13%)	7 (5%)	NS
Time to Mesh Removal			
Average (range)	3.5 years (3 months - 26 years)	4 years (12 days - 27 years)	NS
Mesh Removal Approach[b]			
Robotic	14 (50%)	43 (31%)	NS
Open	10 (36%)	71 (52%)	NS
Laparoscopic	4 (14%)	21 (15%)	NS
Combination	0 (0%)	2 (1%)	NS

[a]*Some patients had multiple prior repairs.*
[b]*Some patients had multiple meshes removed.*

TABLE 2 | Demographics of patients that underwent mesh removal due to mesh implant illness (MII) or other reasons (non-MII).

	MII	Non-MII	*p*
	N = 28	N = 137	
Age, mean (range)	46 (22–69)	54 (21–81)	**0.005**
Sex, male (%)	12 (43%)	84 (61%)	NS
BMI, kg/m^2, mean (range)	24.8 (17.6–32.8)	26.8 (17.8–43.9)	NS
[a]History of Autoimmune, Yes (%)	3 (11%)	8 (6%)	NS

[a]*Some patients have multiple autoimmune disorders.*

3 patients (11%) had a family history of autoimmune and/or inflammatory disorder without themselves having known autoimmune and/or inflammatory disorder. Postoperatively, after initial mesh implantation, 12 more patients (43%) were diagnosed with autoimmune and/or inflammatory disorders, for a total of 15 (54%) with a personal history. These included: Hashimoto's thyroiditis (3), Chronic Fatigue Syndrome (5), Fibromyalgia (2), Lyme Disease (2), Ehlers-Danlos Syndrome (1), Autoimmune Urticaria (1), Mast Cell Activation Syndrome (1), Lupus Erythematosus (1), Common Variable Immunodeficiency (1), and Lichen Planus (1). Eleven (39%) had multiple allergies and sensitivities to medications, foods, implants and environmental pathogens. In the non-MII group, 8/137 (6%) patients had a known personal history or autoimmune and/or inflammatory diagnosis prior to their mesh removal. These included Sjögren's Syndrome (3), fibromyalgia (2), Lupus Erythematosus (1), Grave's Disease (1), Celiac Disease (1), Common Variable Immunodeficiency (1), Fibromyalgia (1), Ulcerative Colitis (1) and Crohn's Disease (1).

TABLE 3 | Symptoms prior to mesh removal in patients with suspected mesh implant illness (MII).

Symptoms, N (%)	MII
	N = 28
Fatigue	23 (82%)
Bloating	18 (64%)
Swelling	16 (57%)
Joint Pain	14 (50%)
Rash	13 (46%)
Full Body	8 (62%)
Localized	5 (38%)
Headache	12 (43%)
Fevers	9 (32%)
Fibromyalgia	3 (11%)

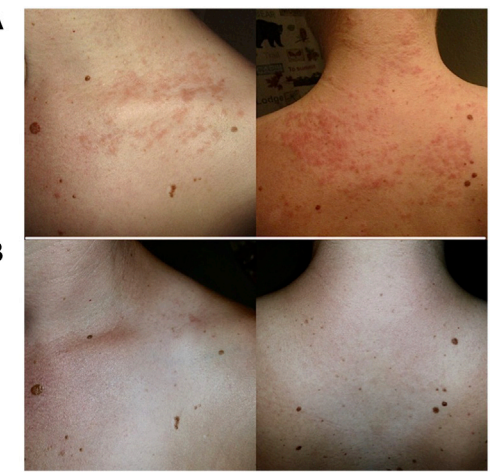

FIGURE 2 | Neck and back maculopapular rashes **(A)** after inguinal hernia repair with onlay mesh and **(B)** resolution after mesh removal.

All patients with suspected MII underwent extensive testing to help explain their new postoperative symptoms, including evaluations by gastroenterologists, neurologists, dermatologists, allergy/immunologists, orthopedic surgeons, urologists, and/or rheumatologists. This included blood testing to rule out disorders other than MII. All patients with MII had normal blood testing as it related to inflammatory and autoimmune markers. Seven patients underwent preoperative allergy and immunology evaluation, which included skin patch testing against various sutures and meshes.

All 28 patients with suspected MII had one or more mesh implants removed. The most common type of mesh material removed was polypropylene (20, 71%) (**Table 5**). All patients underwent complete mesh removal. This occurred on average 3.5 years after mesh implantation (range 3 months–26 years). Patients had mesh removed from the pelvis (20, 71%) and from the anterior abdominal wall (8, 29%) *via* robotic (14,

TABLE 4 | Post-operative outcomes of patients that underwent complete mesh removal due to mesh implant illness (MII).

	MII (N = 28)
Hospital Length of Stay, mean (range)	2.8 (2–5)
Complications	
Pain requiring intervention	2
Urinary retention	1
Seroma	1
Post-operative pain at short-term followup, average	4.4/10
Postoperative pain at long-term followup, average	3.4/10

50%), open (10, 36%) or laparoscopic (5, 14%) approach. In general, meshes placed as an onlay were removed *via* open technique and those placed as a sublay were removed *via* laparoscopic or robotic approach. Our techniques have been previously described (15, 16).

Sixteen (57%) of the mesh removals among patients with MII were performed as an outpatient. Most (21/28, 75%) operations were performed under general anesthesia. Nearly half (12/28, 43%) of the operations were performed as an inpatient with an average length of stay of 2.8 nights (range 2–5). Upon mesh removal, 16 (57%) patients underwent tissue-based hernia repair without mesh, 7 (25%) patients had complete mesh removal with no repair of their hernia, 4 (14%) patients had a hybrid mesh implanted, and 1 (4%) patient had their hernia repaired with a different material of synthetic mesh.

The average postoperative pain score upon initial short-term follow up was 4.4/10 (range 1–10). The average time to short-term follow up was 11 days (range 1 day–21 days). Pain score on long-term follow up was 3.4/10 (range 0–8) with an average follow-up time of 2.3 years (range 1.8 months–6.2 years) (**Table 4**). Four patients (14%) could not be reached for long-term follow up. No patients experienced bowel obstruction, deep venous thrombosis, pneumonia, peripheral nerve injury, sepsis, pulmonary embolism, urinary tract infection, surgical site infection, ileus, hematoma, or non-healing wound (**Table 4**).

After mesh removal, 19/28 (68%) patients had improvement and/or resolution of their systemic MII symptoms within the first month. **Figure 2B** shows resolution of rashes after mesh removal from an inguinal hernia repair. Upon long-term followup, 18/28 (64%) had resolution of their MII symptoms.

DISCUSSION

To date, mesh-related complications following inguinal hernia repair have been termed post-inguinal herniorrhaphy chronic pain, often due to mechanical complications, such as meshoma, mesh erosion, and nerve entrapment (17). We present a new subset of patients with mesh-related complications who present with a wide syndrome of non-mechanical systemic reactions to their mesh implant consistent with ASIA or Shoenfeld's syndrome (7, 8). We term this sub-population of ASIA as patients with mesh implant illness (MII).

It is unclear why a patient may develop MII. Some have categorized these systemic reactions to implants as mediated by a foreign body reaction to the implant, an upregulation in systemic inflammatory markers in response to the implant, a response to the *in vivo* degradation and absorption of the implant, and/or being a high responder to the implant (6, 18). Meanwhile, there is no objective proof that any of these mechanisms are the underlying causes of ASIA (18). *In vitro* trials by Schachtrupp et al., show markedly disparate responses in monocyte reaction to polypropylene mesh (6). While these trials did not extend to the *in vivo* or clinical setting, they propose a monocyte-macrophage response to be contributing to the variable response to implants. Studies on explanted hernia mesh have shown varying degrees of chemical degradation of the implant, suggesting that mesh is not an inert implant in all patients (19). Moreover, we have previously analyzed the clinical significance of explanted mesh pathology evaluation between mesh reaction and non-reaction groups and have found them to be similar (20). In both groups, commonly noted pathology findings included foreign-body reaction, fibrosis, and chronic inflammation (20). At this time, we do not have enough studies to define MII or ASIA to be due to any single or series of abnormalities. We recommend research into more detailed immunologic and inflammatory responses at the tissue level of explanted mesh in patients with suspected MII or ASIA.

In our practice, we see this variance in response to mesh implantation clinically. That is, though most patients have positive outcomes after their hernia repair with mesh, there is a subset of patients who exhibit severe systemic responses after hernia mesh implantation, such as fatigue, bloating, body swelling, joint pain, rash, headaches, fevers, and fibromyalgia (**Table 3**). In our study, we noted mesh reactions in patients with polypropylene (71%) as well as other materials, such as polyester (7%), cadaveric tissue (11%), and possibly ePTFE (11%) (**Table 5**). Meanwhile, the *in vitro* study looking at blood monocytes showed reactions primarily to polypropylene mesh (6).

While individual variability seems to be a determinant in MII, factors such as the size and/or number of implanted meshes, i.e., the load of implant on the body, may play a factor in MII and ASIA. In one study, the severity of oxidative stress and immunologic reaction to polypropylene were directly related to the amount of material implanted per cm^2 (21). This may explain why 5 (18%) of our patients expressed MII symptoms only after multiple mesh repairs were performed, a larger mesh was placed, and/or after exposure to other implants, such as breast implants and dental implants. This suggests that the amount of foreign body implants, as well as the quality and quantity of the implant, may contribute to an augmented inflammatory and/or immune response in certain patients.

The systemic inflammatory symptoms observed in our patients with MII are consistent with that described in the literature on silicone breast implants (22). Breast implants were introduced to the U.S. market in 1962. In 1980, there was a concern that silicone-based breast implants were responsible for systemic autoimmune disorders, including fibromyalgia, rheumatoid arthritis, lupus, and other connective tissue

TABLE 5 | Mesh material removed in patients that underwent mesh removal due to mesh implant illness (MII) or other reasons (non-MII) show no significant difference ($p < 0.05$).

Mesh material removed	MII	Non-MII	*p*
	N = 28	N = 137	
Polypropylene	20 (71%)	107 (78%)	NS
Polypropylene + ePTFE	3 (11%)	12 (9%)	NS
Polyester	2 (7%)	4 (3%)	NS
Hybrid	2 (7%)	3 (2%)	NS
Biologic	1 (4%)	3 (2%)	NS
Polypropylene + Hybrid	0 (0%)	1 (1%)	NS
ePTFE	0 (0%)	6 (4%)	NS
Unknown	0 (0%)	1 (1%)	NS

diseases (23). Due to these concerns, a moratorium on silicone implants was issued in 1992 (21). Further studies at the time failed to confirm a direct association between the silicone breast implants and these systemic symptoms. As a result, the moratorium was lifted in 1999, with the FDA approving two silicone-based implants. As of 2011, the FDA maintains the position that current evidence does not definitively support these systemic complications, lacking power and long-term data (23). More recently, a large population after-market study indeed showed higher risk of serious illness in patients with silicone-based breast implants (22). This has been termed by various groups as silicone implant incompatibility syndrome or, more simply, breast implant illness (BII). BII is now considered a subset of ASIA/Shoenfeld's syndrome (9–14). As of September 2022, the FDA has issued a safety statement confirming reports of squamous cell carcinoma and various lymphomas in the scar tissues (capsule) that forms around breast implants (24). Some suggest these underlying incidents are related to autoimmunity hyperstimulation by the implants (25, 26).

There is no consensus on the treatment of patients with MII. In our practice, we have taken several different approaches in regards to treating our population of patients with suspected MII. All patients underwent complete mesh removal. It is very important that the suspected implant is fully removed, as partial mesh removal, which may be appropriate for some patients with post-herniorrhaphy chronic pain, is an inadequate procedure for patients with suspected MII. The treatment plan should be carefully determined preoperatively. In our practice, we had 16 (57%) patients undergo a non-mesh tissue-based hernia repair, 7 (25%) required no repair of their hernia, and 4 (14%) patients had their hernia repaired using a hybrid mesh of biologic with a small percentage of permanent suture. We did have one patient who had their hernia repaired with polyester mesh after showing reaction to polypropylene.

In retrospect, we do not recommend replacing one permanent synthetic implant with another in these patients. Based on our experience and also the findings of this study, we recommend erring on preventing implantation of any other forms of synthetic or permanent mesh upon initial mesh removal. However, in some situations, it is not technically possible to complete a mesh removal operation without reinserting some sort of mesh. In those situations where it is absolutely necessary to use an implant, we recommend using an implant with low inflammatory potential, such as a pure biologic mesh or a hybrid mesh with a predominance of biologic tissue. Though unproven, there are theories that such mesh types that have a lower inflammatory potential than standard synthetic and permanent meshes may be less likely to elicit ASIA. That said, 11% of our patients in this study developed MII after implantation of biologic mesh. At this time, we cannot make judgements about the relationship between the type of mesh and risk of MII. Further studies with a larger sample size may be able to shed light on this relationship.

The outcomes from the use of permanent suture, such as polypropylene, polyester, nylon, or PTFE, is unclear in these patients. Though it is considered standard of care for hernia repairs to use permanent suture, it is unclear if the sutures themselves may elicit a reaction. In our study, two patients who had MII underwent mesh removal and tissue-based hernia repair with polyester and polypropylene. Though both improved after mesh removal, they both required removal of their permanent sutures in order to be cured of their ASIA symptoms, showing that in some patients, even the use of permanent sutures may induce an abnormal systemic reaction.

Furthermore, we noticed our mesh reaction population included 3 patients (11%) with a history of an autoimmune disorder and 11 patients (39%) with a history of multiple allergies to either food or medications. Although patients with suspected MII were almost two times more likely to have a history of autoimmune disease, 6% of non-MII patients also had a history of autoimmune disease. Thus, patients with autoimmune diseases can safely have mesh implants without MII. In certain circumstances, we conduct allergy testing and skin patch testing on patients to help determine to what mesh or sutures they may react. That said, at this time, allergy testing is not considered standard of care as we have shown the results in our experience to be inaccurate with low sensitivity (27).

We aim to provide insight based on our experiences into the presentation and treatment options of this subset of patients experiencing MII after mesh-based hernia repair. In patients who we suspect to have MII, we perform complete mesh removal and limit the tendency toward further mesh use. However, our practice and knowledge about this entity is currently evolving. There remains much to be studied about this subset of patients and the cause of their reaction, as we do not know enough about why patients develop ASIA or MII, nor which patients are likely to develop these systemic reactions to their implants in order to help prevent this life-altering problem. Further studies are also needed to develop an algorithm and/or diagnostic tool to determine patients' susceptibility to MII.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Written informed consent was obtained from the patients prior to the pictures, and they have agreed to their use for educational and research purposes, including for publication.

AUTHOR CONTRIBUTIONS

NF: Data collection, data analysis, article writing, article review, editorial changes. DH: Data collection, data analysis, article review, editorial changes. ZK: Data collection, data analysis, article review, editorial changes. LM: Data collection, data analysis, article review, editorial changes. IC: Data collection, article review, editorial changes. ST: Principle investigator, article writing, article review, editorial changes.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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If Evidence is in Favor of Incisional Hernia Prevention With Mesh, why is it not Implemented?

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Keywords: prevention, hernia, mesh, incisional, implementation

INTRODUCTION

Incisional hernias are associated with increased cost to the patient and hospital, and decreased quality of life for patients. Furthermore, the rate of hernia recurrence increases with each subsequent repair, which further compounds this cost and morbidity (1). The rate of incisional hernia requiring operative intervention in high-risk patients approaches 70%, costing the United States greater than $3 (2). billion dollars (2, 3). The true incidence of incisional hernia ranges with estimates from 2% to 50% and are due to both surgical and patient factors (4). In a study conducted from 2010 to 2014 utilizing a Nationwide Readmission Database analyzing 15, 935 patients undergoing incisional hernia repair, 19% of them were readmitted within 1 year of their index operation. Of these patients, 35% required reoperation and overall, 5% of them had recurrence of their incisional hernia and intensified the burden to patients and on the healthcare system (5). Incisional hernias develop in 13% (0%–36%) of all patients after any type of midline abdominal incision and one third (35%) will undergo subsequent repair. More-over, signs of a stabilized incidence (not an increasing incidence) in the USA were recently reported (6–8). While some risk factors for incisional hernia formation are non-modifiable, there has recently been an interest in surgical modifiable risk factors that can help decrease the incidence of incisional hernia.

One of the most important risk factors for formation of incisional hernia that the surgeon can impact relates to the closure of the abdominal incision. The two most studied factors associated with abdominal wall closure and hernia prevention relate to the suturing technique of the abdomen and the use of prophylactic mesh augmentation (PMA). There is strong evidence to support using specific suturing techniques, such as the so-called short stitch technique, as well as the use of prophylactic mesh (6). Despite well-supported evidence and recent guidelines, skepticism and a perceived lack of adoption of certain surgical techniques that could impact incisional hernia rates remain.

This paper reviews and explores some presumed reasons why hernia prevention techniques are not followed despite evidence to support their practice. Possible reasons for the lack of adoption are explored, ranging from distrust in the evidence to concern of complication, cost, and societal factors. Strategies to help improve awareness and mitigate some of these factors are also discussed, with some recommendations given on how to move this area forward in the future.

METHODS

A review of the literature including meta-analyses, randomized controlled trials, prospective cohort studies, and surveys was performed related to hernia prevention, including abdominal wall closure and prophylactic mesh, focusing on reasons why surgeons do not adhere to evidence-based practices. Secondary to paucity of published literature on this subject, expert opinions and theories based on opinion and experiences were hypothesized.

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TABLE 1 | Review of literature with common reasons documented on reasons PMA is not used.

Study [Ref]	Type of Publication	Publication Date	Type of support (1–4)*	Summary
(1)	Systemic literature review	July 2015	Financial 2	Cost-utility analysis of Primary Suture Closure (PSC) vs. PMA for laparotomy closure demonstrates PMA to be more effective, less costly, and overall, more cost-effective than PSC
(4)	Systemic Literature Search	November 2020	Lack of knowledge/ expertise (4)	Evidence supports PMA, with significant reduction in incisional hernia rate. Implementation is limited. Surgeons should be questioning why they are not using mesh reinforcement, specifically in high-risk patients
(9)	Systematic literature search	January 2022	Technique 4	Recommendations for elective midline closure technique. Guidance in selecting the optimal approach and location of abdominal wall incisions
(10)	Survey	April 2019	Technique 4	Applications of hernia prevention principles and their controversy
(15)	Prospective Cohort Study	February 2018	Complications 3	The use of PMA in colorectal surgery, when using an algorithm for patient selection, is an effective measure for prevention of IH- at the expense of other known possible complications
(18)	Multicenter double-blind randomized controlled trial	Aug 2017	Lack of Evidence 1	Randomization of 480 patients for closure: PSC, onlay or sublay. There was a significant reduction in incidence of IH with onlay mesh reinforcement- showing potential to become standard of treatment in high-risk patients
(20)	Randomized control trial	May 2021	Complications 3	PMA is not associated with increased incidence, severity, or need of infectious complications compared to PCS
(21)	Multicenter randomized control trial	April 2016	Lack of Evidence 1 Technique 4	PMA during AAA repair is safe and effective in preventing IH, with proven 2 years follow up and only added mean operative time of 16 min
(22)	Meta-analysis	June 2020	Lack of Evidence 1	PMA using onlay technique, specifically in high-risk patients, leads to significant reduction in IH

*1. Lack of evidence/literature.
2. Financial.
3. Complications.
4. Lack of training/knowledge/expertise.

RESULTS

The reasons behind the lack of use of PM for IH prevention have not been well studied. We found four main reasons cited by surgeons (**Table 1**). The first reason is a perceived lack of evidence and literature base to support its use. While there is strong and emerging evidence to support PM in subsets of populations, the data tends to be short term and clustered to European centers. This leads surgeons to question the long-term outcomes, as well as the applicability to their practice. The second reason is concerns over financial implications of using PM. While every country has different healthcare systems and finances, the addition of mesh at an index operation often financially impacts the hospital system and surgeon, which is currently unfavorable in many instances and can lead to long-term positive financial implications being overlooked. The third reason is that surgeons seem concerned about complications associated with prophylactic procedures, especially mesh-related complications in the context of current medicolegal climates present in many countries today. Lastly, while the placement of mesh and knowledge of the abdominal wall may seem routine to hernia surgeons, many other surgeons lack the training, knowledge, and expertise to place PM, which likely contributes to its limited use.

DISCUSSION

This review highlights some of the often-cited reasons why hernia prevention principles are not practiced. Addressing these concerns will increase implementation and help facilitate these techniques becoming more widely practiced.

It is very unlikely to change surgeons' practices if they do not believe in what they are doing or do not feel that their current practice is optimal. Disbelief and lack of awareness of current evidence are cited reasons for why surgeons have failed to embrace hernia prevention strategies. A recent survey by Fischer et al. explored reasons why surgeons did not practice current hernia prevention strategies (1). A total of 497 surgeons were included in the survey, most of whom do practice some of the recommended suturing techniques. Slowly absorbing sutures were used by 81% of respondents with 63% stating they closed using a 4:1 suture to wound (S:W) length ratio (although they did not routinely measure) and 58% stating they used the short stitch technique (although they did not routinely measure) (10, 11). Only 3% and 4% of respondents stated they have never heard of the 4:1 S:W length ratio and the short stitch technique, respectively. While these numbers relay adherence to suturing techniques, it must be remembered that this survey is likely biased and may not represent current practices in the United States and Europe, as this survey was sent to members of the European and American Hernia Society, as well as through an online Facebook group mostly comprised of hernia surgeons. It is also important to note that while the majority of surgeons stated they used a 4: 1 S:W length ratio and short stitch technique, only 16% and 14%, respectively, of respondents reported measuring their ratios, which is a recommended practice (16, 10). There was less familiarity and trust of the literature for the use of PMA, with 11% of respondents stating they were unfamiliar with the

literature and 23% of respondents stating they were unconvinced of the efficacy of the use of PMA.10 Despite this, it is has been proposed that high-risk patients, including those with morbid obesity, diabetes, and hypertension, could provide the most cost-effective and efficient way to target individuals that could benefit from PMA (1).

While there is evidence to support abdominal wall closures techniques and PMA, well-designed prospective randomized trials are needed. Replicating short stitch technique trials in a more diverse patient population that includes obese patients is also needed, as this patient population was not captured in many of the initial studies. Given the associated risks and concerns of PMA, this may not be appropriate for all patients, but utilizing risk calculators to identify high-risk patients who would benefit from more aggressive prevention strategies is needed. Additionally, ideal closure methods for emergent surgeries are another understudied group. Ultimately, algorithms and guidelines on when to use specific prevention strategies in specific clinical situations will be helpful in guiding and supporting surgeons.

Cost is often a barrier for new procedures and devices to overcome prior to widespread adoption. This variable can be difficult to elucidate and is frequently used to support one's bias or opinion without performing a comprehensive cost-benefit analysis, which accounts for the long-term cost savings associated with preventative strategies. Alli V et al. used a large administrative database with over 14,000 patients to show that incisional hernia were common and increased the cost of care for individuals from 97% to 310% over 3 years (17). Gillion et al. reported the cost burden of incisional hernias in France and found that reducing the incidence of incisional hernia by 5% could result in a national cost savings of 4 million euros per year (18). Despite these data, cost is often cited as a cause for concern for lack of adoption of some hernia prevention principles. Even in comparing suture closure methods where the cost of a prosthetic material is not being considered, some surgeons argue the extra time it takes to perform a short stitch suture closure may be associated with higher operating room costs. Interestingly, the STITCH trial noted an increase of only 16 min between methods (19). The main cost concerns, however, relate to the use of prophylactic mesh as a cost-saving endeavor in hernia prevention despite good evidence to the contrary.

Time associated with the placement of PMA has also been cited as a reason why surgeons may not want to perform, although in the survey by Fischer et al. only 6% of respondents state this was the reason for not practicing (10). Studies have reported that the extra time for mesh placement ranges between ten to 20 min and is dependent on the technique performed (17–20). One way to address this barrier to adoption is to make the technique of PMA straightforward and reproducible. Onlay techniques, which have been shown to have similar efficacy in the PRIMA trial and easier and quicker fixation strategies, are being studied to help to try to improve efficiency (12).

An additional financial consideration for these techniques is reimbursement. This is further complicated by the concept of closing teams in which a surgical team will participate in the abdominal closure alone for a primary abdominal operation, such as Abdominal Aortic Aneurysm repair, which is the setting in which PMA is employed rather than during incisional hernia repair in which mesh placement is included in the primary procedure code. Whether PMA is performed by a closing team or the primary surgeon, it is important that the providers employing hernia prevention strategies are compensated for their time and expertise. A significant development for this was the approval of CPT code specifically for PMA, 0437T. This tracking code is reportedly beginning to help surgeons get reimbursed and, with additional use and outcome data, will hopefully transition to a reliable reimbursement code for performing PMA.

Related to cost, it is imperative that surgeons performing hernia prevention strategies, such as PMA, get reimbursed for their work and hopefully the tracking code will soon become a permanent code. Healthcare policymakers and insurers will also need to help ensure that ultimately what is good for the patient can be safely implemented into practice through a holistic approach to patient care.

Another often-cited reason for the lack of adoption of hernia prevention techniques is a concern for associated complications. This most often relates to the use of prophylactic mesh, but also regarding the concern that small stitch techniques may lead to abdominal dehiscence or burst abdomen, especially in the obese population. Another concern relates to the use of mesh in patients that may not have gotten a hernia and the overtreatment that would occur by using the mesh. In these patients, you subject a patient to potential mesh related complications and infectious complications for no reason, hence why risk prediction models are so important in these patients.

The use of prophylactic mesh is particularly sensitive towards today's medical legal climate, highlighted by class action lawsuits for mesh failures. The survey by Fischer et al. saw that the most common reason for not using PMA was fear of mesh infection or mesh-related complications, cited by 46% of respondents (10). Although there is a large amount of fear related to the use of PMA, data regarding its benefits should be thoughtfully considered. The concept of "primum non-nocere: first do no harm" can be seen from both aspects of using or not using prophylactic mesh. As the data from the PRIMA trial suggests, the use of prophylactic mesh decreases risk of incisional hernia formation among high-risk patients. However, it is important to note that we do not know what risk of hernia development justifies using prophylactic mesh and therefore should be cautious in applying this concept broadly without discretion (22).

There have been two landmark randomized controlled trials (RCT) assessing incidence of incisional hernia after midline laparotomy. The PRIMA trial included 480 patients across 12 different countries undergoing elective midline laparotomy for abdominal aortic aneurysm repair or with body mass index of 27 kg/m^2 or higher and incidence of incisional hernia formation over a two-year follow-up period. Patients were randomly assigned to one of three groups, including primary suture repair, sublay mesh repair, or onlay mesh repair. A significant reduction in the incidence of incisional hernia was achieved with onlay mesh reinforcement compared with sublay mesh reinforcement and primary suture only. There was

no difference in rate of infection, re-intervention, or re-admissions between groups (12). This study suggests that PMA in an onlay fashion should be a new standard treatment for high-risk patients undergoing midline laparotomy. Van den Dop et al. further elucidated that there is no increased incidence, severity, or need for invasive treatment of infectious complications in the PRIMA trial PMA group compared to suture closure (13).

Another multicenter RCT by Muysoms et al. assessed the incidence of incisional hernia at two-year follow-up after conventional closure versus PMA with a large-pore polypropylene mesh in a retromuscular fashion for patients undergoing midline laparotomy for elective abdominal aortic aneurysm repair. There were no adverse effects seen related to PMA, apart from an increased mean time to closure of the abdominal wall for the PMA group compared with the control group. Specifically, this was 46 min compared to 30 min, and there was a significant reduction in incidence of incisional hernia from 28% in the conventional closure group to 0% in the PMA group (14). Both RCTs suggest that PMA results in decreased incidence of incisional hernia, with no difference in infectious complication rate.

Studies have shown that lack of education contributes to the low use of prophylactic mesh. In the survey by Fischer et al. 11% were unfamiliar with the literature, 24% were familiar but would still not use, 12% were unfamiliar enough with the methods to correctly execute, and 23% were unconvinced of the benefits (10).

This would suggest that education for the general surgeon population should be two-fold. First would require education about the safety and efficacy of using prophylactic mesh. Safety concerns mainly include concern for elevated surgical site infections (SSI) with the use of prophylactic mesh. 46.9% of surgeons surveyed do not use prophylactic mesh due to concern for SSI or other mesh complications.10 Systematic reviews by Depudyt et al. and Jairam et al. showed no difference in overall infection when evaluating RCTs and cohort studies (15, 4). There is also evidence indicating that prophylactic mesh has a lower rate of SSI compared to mesh that is placed for the repair of an incisional hernia.4 The second part of surgeon education would be addressing unfamiliarity with surgical techniques. This is a less common reason for not using prophylactic mesh, however it is still prevalent with 12% of surgeons reporting not being comfortable with mesh insertion (neither sublay nor onlay) (10). Although sublay mesh is known to be more physiological, it is also more technically demanding than onlay mesh repairs. The 2017 PRIMA follow-up study determined that onlay mesh and sublay mesh were equivalent in effectiveness (12). The ability to place mesh in either position may lead to more surgeons adopting the use of prophylactic mesh placement, depending on their comfort level with either procedure. In the small percentage of surgeons that are unfamiliar with either, it will be important to encourage CME, videos, and other learning opportunities to help increase surgeons' comfort levels, so they use mesh more routinely.

Teaching and education are also important components of ensuring new techniques related to hernia prevention get implemented safely. Education and training must be available at all levels, including medical students, residents, and fellows as well as practicing surgeons with methods based on each learner's needs. It is imperative that education is performed as a surgical community and not siloed, as many surgical subspecialties will need to be involved. To leverage expertise, partnerships with surgical societies, along with industry and surgical educators, should be established.

Lastly, and most importantly, we as surgeons must be vigilant to ensure that we care for our patients in the best way possible and take part in shared decision-making related to hernia prevention. This involves making sure we are up-to-date on new technologies, practicing evidence-based medicine, and following our outcomes. There are many groups and societies that have implemented or are in the process of implementing registries for abdominal wall closure and prophylactic mesh. These registries are important for patient safety and will help with research, including long-term outcomes.

In conclusion, there are several cited reasons why hernia prevention strategies are not implemented. While some of the reasons have validity and need attention, most are due to lack of awareness and unwarranted fear. Efforts are currently underway to help promote hernia prevention principles. These need to be expanded through the support of many stakeholders, including surgeons, industry, societies, and healthcare policymakers. Ultimately, by working together, we can make a major impact on patient care and help alleviate the burden of incisional hernias.

AUTHOR CONTRIBUTIONS

Manuscript preparation-all authors. Critical review-WH. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

WH-Honorarium from WL Gore, BD, intuitive, Medtronic for consulting/research.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

PUBLISHER'S NOTE

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REVIEW
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The Role of Releasing Incisions in Emergency Inguinal Hernia Repair

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The majority of inguinal hernia repairs worldwide are performed on an outpatient basis. However, incarceration and concern for strangulation of abdominal contents necessitates emergent repair in order to address visceral ischemia. In the setting of salvageable ischemia, this necessitates release of strangulation of blood supply by the hernia defect and reduction of visceral contents into the abdominal cavity. In certain cases, this cannot be achieved with simple manual reduction, and requires enlargement of the aperture of the hernia defect with releasing incisions in order to allow reduction. We aim to describe strategies for releasing incisions via open, laparoscopic, and robotic approaches in emergency inguinal hernia repair.

Keywords: inguinal hernia, hernia repair, robotic surgery, releasing incision, emergency hernia surgery

INTRODUCTION

Inguinal hernia repairs are one of the more common general surgical procedures performed worldwide, with estimates of greater than 20 million repairs performed annually worldwide and over 800,000 annually in the United States [1]. Studies have estimated approximately 9% of inguinal hernia repairs are performed emergently, most often because of incarceration, strangulation, and visceral compromise [2]. Emergent inguinal hernia repairs comprise significantly higher risk of morbidity and mortality compared to elective repair, up to 32% and 5%–5.5% compared to 8% and 0.2%–0.5% after elective repair, with the majority of risk due to visceral compromise due to strangulation [3–5]. In particular, these risks are elevated in individuals over 65 years of age, female patients, femoral hernias (especially right sided femoral hernias), those with prolonged symptom duration or multiple hernia-related hospitalizations in the year prior to presentation, bowel obstruction, and delay in treatment [3].

Inguinal hernias may be congenital or acquired. Regardless of cause, the principal of abdominal wall hernia formation is a defect in the musculo-aponeurotic wall allowing protrusion of subfascial contents through the defect, either from the peritoneum, pre-peritoneal space, or retroperitoneum. With advancements in cross-sectional imaging, exceedingly small hernia defects are being detected, with openings too small to allow herniation of structures. Similarly, hernia defects with exceptionally large apertures allow for free movement of structures. Hernia incarceration occurs when structures within the hernia sac are unable to be reduced back into their anatomical space, potentially leading to strangulation, when the blood flow to hernia structures becomes obstructed leading to ischemia. In defect apertures of intermediate size, structures within the hernia sac may be constricted at the level of the defect. This initially impedes the venous outflow resulting in edema and expansion of hernia structures, further preventing reduction of structures. Eventually, this edema leads to restriction of arterial inflow causing ischemia.

The mainstay of emergent hernia repair is to address the visceral compromise with reduction of hernia contents prior to the development of irreducible ischemia and subsequent repair of the hernia.

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It is important to recognize and prioritize in these circumstances, hernia is a secondary problem. Efforts to reverse visceral ischemia, prevent or control enteric spillage, and limit systemic sepsis are the priorities to limit morbidity and mortality associated with strangulated hernias. However, reduction of hernia contents, even operatively, is occasionally not possible due to the amount of visceral edema in the herniated structures resulting in a size mismatch between the herniated structures and hernia defect aperture. Additionally, strain on edematous, distended, and compromised bowel risks perforation and wound contamination, increasing the risk of morbidity. To allow safe reduction, releasing incisions may be required to enlarge the defect and reduce herniated viscera. This may be performed via an open approach, but can also be utilized in emergent minimally invasive laparoscopic and robotic hernia repairs. While releasing incisions have been described in operative lectures, anecdotes, and discussions, there is a paucity of literature describing their role in the practical management of emergency hernia surgery.

RELEASING INCISIONS IN OPEN SURGERY

The inguinal canal is a tubular structure comprised of four walls and two openings. The anterior wall is formed from the aponeurosis of the external and internal oblique muscles. Through the anterior wall, the superficial or external ring is formed in an opening of the anterior wall. This opening transitions to the covering of the inguinal contents. The deep ring, also known as the internal ring, is formed from the floor of the canal, which is comprised of the transversalis fascia and conjoint tendon. The roof of the canal is formed from the transversus abdominis, internal oblique, and part of the external oblique. The inferior wall of the canal is formed by the inguinal and lacunar ligaments [6].

In open inguinal hernia repair, the anterior wall is opened along the extent of the canal inferomedially to the external ring. Emergent repair involves reduction of dilated and strangulated viscera and reinforcement of the floor of the canal. Due to compression of venous outflow in strangulation, herniated visceral contents swell significantly after passing through the hernia defect, often making reduction difficult. In the majority of cases, application of circumferential pressure to squeeze edema out of the herniated viscera allows for ample size reduction to allow reduction of herniated contents through the hernia aperture. However, in emergency cases in which this fails and acute incarceration precipitates impending strangulation or perforation, the aperture size may be enlarged to allow for safe reduction of hernia contents.

For indirect hernias, the viscera is herniated through the deep ring. Thus, when indirect hernia contents cannot be reduced manually through the deep ring, releasing incisions may be required to release the tension and allow for reduction of herniated viscera. In relation to the deep ring, the transversus abdominis marks the superior border, with the ilioinguinal nerve coursing posterior to it superolaterally. The inferior epigastric vessels mark the medial border of the deep ring, and the iliac vessels inferiorly. Thus, releasing incisions should be aimed cephalad and medially in the transversus abdominis muscle to avoid injury to the ilioinguinal nerve and inferior epigastric vessels. The iliohypogastric nerve typically courses cephalad and medial to the internal ring and can often be identified and avoided when opening the aperture of this orifice. In some cases, the iliohypogastric nerve may follow a subaponeurotic course running deep to this area, so releasing incisions should be made superficially in the fascial ring only and the extent minimized to limit potential transection (**Figure 1**).

Direct inguinal hernias pass through Hesselbach's Triangle medial to the epigastric vessels in order to enter the inguinal canal. The boundaries of the direct defect are defined by the inguinal ligament inferolaterally, the deep ring and epigastric vessels superiorly, and the conjoined tendon and lateral border of the rectus medially. Opening the aperture of a direct defect in the cephalad direction risks bleeding from the epigastric vessels or injury to the spermatic cord. Inferolateral release in the inguinal ligament is unnecessarily destabilizing and risks neurovascular injury to the iliofemoral vessels, femoral nerve, anterior cutaneous nerve of the thigh, and femoral branch of the genitofemoral nerve. Thus, to minimize the risk of injury, releasing incisions made in the setting of a strangulated direct hernia should be made in inferomedially in the internal oblique or transversalis fascia directed toward the conjoined tendon and rectus abdominus muscle, as this is the safest border of the direct space for enlargement (**Figure 1**). The iliohypogastric nerve runs medial to the direct space coursing from the cephalad direction and care should be taken to identify and preserve this structure if possible.

Femoral hernia contents pass through the femoral canal inferior to the inguinal ligament, lateral to the lacunar ligament, above Cooper's ligament, and medial to the femoral vessels. Thus, releasing incisions can safely be made by either opening the iliopubic tract if the floor of the inguinal canal is exposed, or the roof of the femoral canal, the inguinal ligament, if the thigh is exposed (**Figures 1**, **2**). Incision towards the lateral aspect of the femoral canal risk damage to the femoral vessels, and medial incisions of Cooper's ligament are inaccessible and ineffective. If division of the inguinal ligament is performed via and open approach, these should be repaired after visceral reduction, as they provide significant stability and anchoring of the anterior wall of the inguinal canal. In our practice, we reconstruct the released inguinal ligament with a permanent 2-0 Prolene suture.

RELEASING INCISIONS IN MINIMALLY INVASIVE LAPAROSCOPIC SURGERY

Traditionally, the majority of emergent hernia surgery for strangulation has been described via open approaches. However, as the proportion of surgeons trained to perform minimally inguinal hernia repairs increases, laparoscopy has been shown to be a safe approach for emergent inguinal hernia repair including in the context of acute incarceration and strangulation. This requires a comprehensive

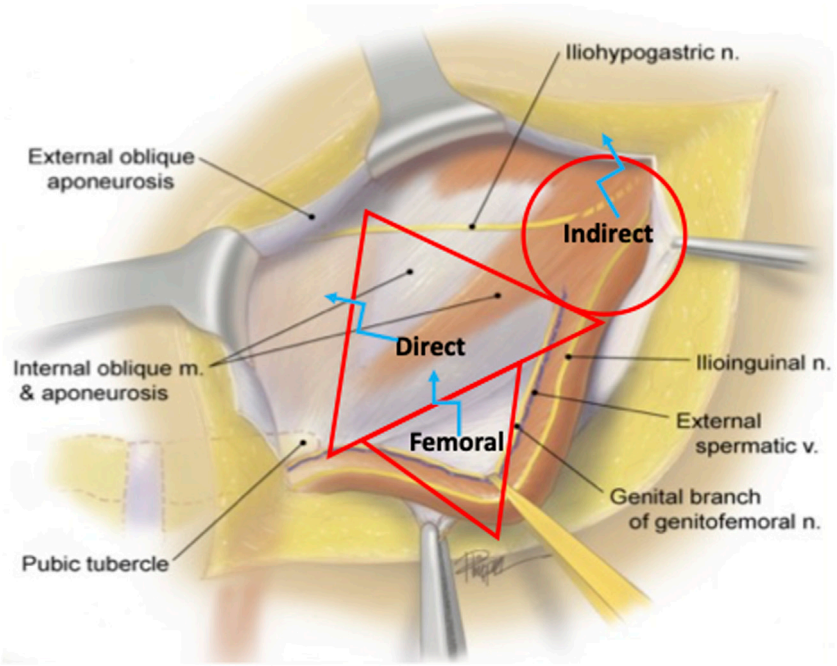

FIGURE 1 | Open Inguinal Hernia Releasing Incisions. Indirect, direct, and femoral hernia spaces are outlined in red. The optimal sites for releasing incisions are marked with blue.

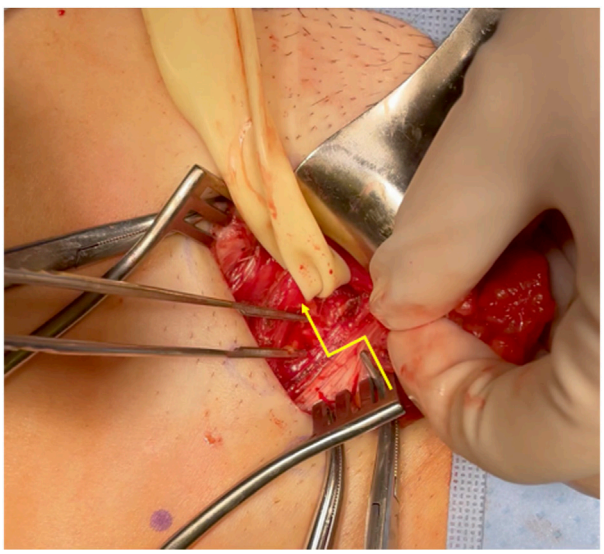

FIGURE 2 | Open Femoral Hernia Releasing Incision. The yellow line marks the releasing incision of the inguinal ligament in femoral hernia repair.

understanding of the posterior anatomy of the inguinal canal from a posterior view, described by Daes and Felix as the "critical view of the myopectineal orifice," defined as the appropriate exposure of the anatomy of the posterior inguinal canal prior to mesh placement in laparoscopic and robotic inguinal hernia approaches [7]. From this view, the iliopubic tract divides the space into the suprainguinal and infrainguinal spaces, with direct and indirect inguinal hernias coursing through the suprainguinal space divided by the inferior epigastric vessels and femoral and obturator hernias in the infrainguinal space (**Figure 3**).

Indirect hernias are bound inferomedially by the epigastric vessels, inferolaterally by the iliopubic tract, and superiorly by the transversus abdominis and internal oblique muscle. Additionally, the spermatic cord traverses the internal ring from the inferior direction. To release strangulated indirect hernias from this posterior approach, releasing incisions should be made superolaterally in the transversus abdominis and internal oblique to avoid damage to the inferior epigastric vessels, cord, and neurovascular structures below the iliopubic tract. The genital nerve enters the inguinal canal from the inferolateral direction and is thus avoided. The extent of the releasing incision should be minimized to prevent inadvertent injury to the ilioinguinal nerve which runs superficial and superior to this space within the inguinal canal (**Figure 3**).

The direct space is bound inferolaterally by the iliopubic tract, superolaterally by the inferior epigastric vessels, and medially by the rectus abdominis. When releasing incisions are needed for direct hernias from this posterior approach, releasing incisions may be safely made towards the rectus abdominis in a superomedial direction, avoiding injury to the inferior epigastric and cord vessels that run laterally to this space (**Figure 3**). If incisions are made too deep, however, there may be risk to the cord structures as they pass through the inguinal canal anteriorly, so caution should be taken to pull towards the muscle and peritoneum during dissection. The extent of the releasing incision should be minimized to prevent inadvertent

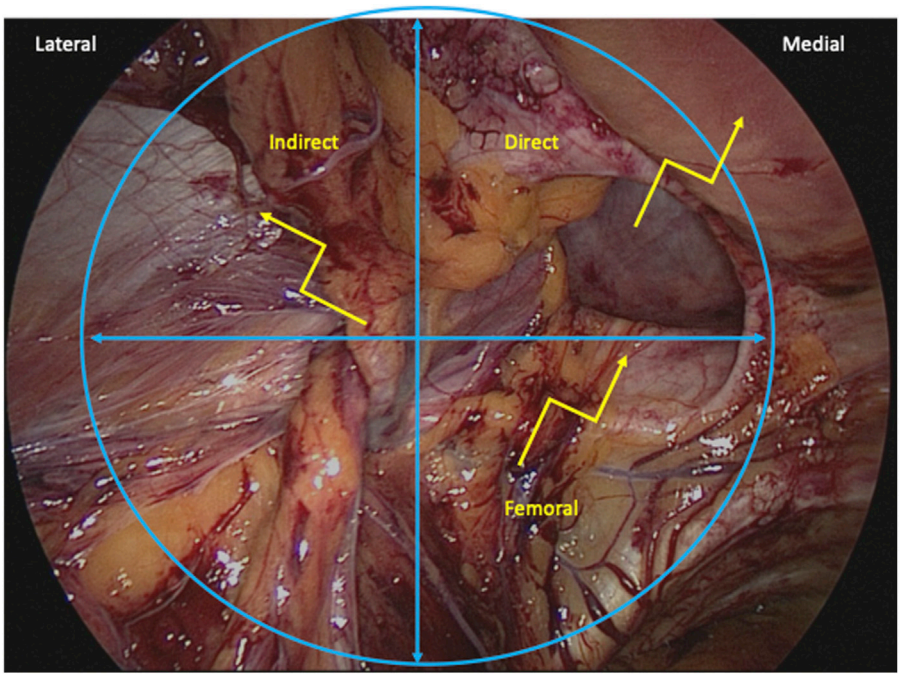

FIGURE 3 | Minimally Invasive Inguinal Hernia Releasing Incisions. Indirect, direct, and femoral hernia spaces are outlined in blue. The optimal sites for releasing incisions are marked with yellow.

injury to the iliohypogastric nerve which runs superficial and superomedial to this space within the anterior inguinal canal.

Femoral hernias are bound superomedially by the iliopubic tract, medially by the lacunar ligament, superolaterally by the femoral vessels, and inferiorly by Cooper's ligament. Releasing incisions should be made superomedially in the lacunar ligament or directly though the iliopubic tract which is seen from this view as the posterior aspect of the inguinal ligament. Releasing incisions in these approaches avoid damage to the iliac vessels. When mesh is placed in a posterior orientation from this approach, the iliopubic tract does not require reconstruction, in contrast to open femoral hernia releasing incisions, as the posterior placed mesh covering the myopectineal orifice provides support of the inguinal canal (**Figure 3**).

Obturator hernias are quite rare accounting for less than 1% of abdominal wall hernias, and are more common in thin elderly women, likely due to loss of supporting connective tissue and wider female pelvis. Incarceration and strangulation is occasionally encountered and poses a similar challenge. Understanding the boundaries of the obturator foramen can similarly direct a safe releasing incision in the setting of incarceration. The superolateral boundary of the obturator foramen heading in the direction of Cooper's ligament is bound by the superior pubis ramus and division will not confer any significant release. An accessory obturator vein, referred to as the corona mortis, will often connect the iliac vein to the obturator vein and should be avoided. Posterolaterally, the obturator nerve, artery and vein will travel along the inner table of the pelvis and enter the obturator foramen. These neurovascular structures should be preserved and avoided. In the case of an incarcerated or strangulated obturator hernia, a releasing incision in the obturator internus muscle of the obturator membrane directed inferomedially heading directly down the pelvis away from Coopers and the neurovascular structures will allow for release and reduction of the contents of the obturator canal.

From a technical standpoint, when performing laparoscopic releasing incisions, we recommend using hook cautery with a pulling technique to direct cautery posteriorly, away from cord structures, neurovascular structures, and hernia contents. Alternatively, harmonic scalpel may be used with the hot blade oriented away from hernia contents in order to prevent inadvertent thermal injury (**Supplementary Video S1**). Monopolar shears are typically avoided or used only without energy to prevent secondary thermal injury to the entrapped viscera.

RELEASING INCISIONS IN ROBOTIC SURGERY

Robotic approaches to emergent inguinal hernia repair are fundamentally the same as laparoscopic approaches, but with the distinct advantages of increased instrument articulation and enhanced optics and visualization. Use of robotic hook cautery allows for greater precision while making releasing incisions to allow incision of the aperture of the hernia neck by articulating the hook into the defect. Robotic shears may also accomplish similar maneuvers, and can be used without cautery or very focal

energy depending on risk of thermal injury. Additionally, the availability of *in vivo* fluorescence imaging with indocyanine green (ICG) infusion provides an enhanced adjunct to assess visceral viability in these challenging cases.

In both robotic and laparoscopic approaches, the view of the myopectineal orifice allows intervention on incarcerated bowel prior to reduction in cases where irreversible ischemia has occurred prior to intervention. A vessel sealer may be used to devascularize the loop of compromised bowel, preventing systemic circulation of inflammatory cytokines after reducing the loop and relieving strangulation. Additionally, a stapler may be used to divide proximal and distal limbs of strangulated bowel prior to reduction to prevent spillage.

CONCLUSION

Releasing incisions are beneficial in the technical management of incarceration and strangulation in emergent inguinal hernia management. A strong understanding of inguinal anatomy in both anterior and posterior approaches helps minimize potential collateral damage to both hernia contents and the native inguinal canal in order to minimize secondary risk and safely manage these challenging abdominal wall emergencies.

AUTHOR CONTRIBUTIONS

ZW researched and wrote manuscript on topic. DC directed, reviewed, edited, and supplied expertise in experience in this topic. Additionally, DC provided video of performance of this procedure. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/jaws.2023.11378/full#supplementary-material

SUPPLEMENTARY VIDEO S1 | Laparoscopic Direct Inguinal Hernia Releasing Incision. Hook cautery is used to make a releasing incision in the rectus abdominis.

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ORIGINAL RESEARCH
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Outcomes of Robotic Transabdominal Retromuscular Repair: 3-Year Follow-up

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Background: Our study addresses the gap in ventral hernia repair literature, regarding the long-term effectiveness of robotic transabdominal retrorectus umbilical prosthetic repair (r-TARUP) for primary and incisional ventral hernias. This study aimed to report the 3-year recurrence rates and overall patient outcomes including quality of life.

Method: A retrospective review of prospective collected data analyzed 101 elective r-TARUP patients from August 2018 to January 2022. Data collected included demographics, hernia sizes, mesh types, postoperative outcomes and the European Hernia Society Quality of Life questionnaire (EuraHS-QoL) before and after surgery.

Results: The average age of the group of patients was 53, having a mean body mass index (BMI) of 32 kg/m, with 54% incisional and 46% primary hernias, with mean length and width of 4.4 cm and 6.1 cm, utilizing synthetic 58% and bioabsorbable 42% mesh types. The majority were classified as Centers of Disease Control and Prevention (CDC) class I wounds. Postoperative complications included seroma (2%), hematoma (3%), which required surgical intervention, with no significant correlation to mesh type. A strong positive correlation was found between Transversus Abdominis Release (TAR) and increased length of hospital stay (correlation coefficient: 0.731, $p < 0.001$). Preoperative quality of life assessments demonstrated statistically significant improvements when compared to postoperative assessments at 3 years, with a mean (±SD) of 61.61 ± 5.29 vs. 13.84 ± 2.6 ($p < 0.001$). Mean follow up of 34.4 months with no hernia recurrence at 1 year and 3 recurrence at the 2-3 years follow up (3.2%).

Conclusion: The r-TARUP technique has proven to be safe and effective for repairing primary and incisional ventral hernias, with a low recurrence rate during this follow up period with a noticeable improvement in quality of life (QoL).

Keywords: ventral hernia, long-term, r-TARUP, incisional hernia, EuraHS-QoL, umbilical hernia, retromuscular

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INTRODUCTION

Minimally invasive transabdominal approach to the retromuscular plane for ventral hernia repair has been a topic of interest in the field of surgical abdominal wall reconstruction. Chowbey et al. [1] and Schroeder [2] initially described this approach using a laparoscopic platform. Chowbey reported an increased amount of dissection resulting in increased operative time; Schroeder reported it to be a technically demanding procedure, and similarly reported increased operative times. The robotic

transabdominal retromuscular umbilical prosthetic hernia repair (r-TARUP) described by Dr. Filip Muysoms in 2018 [3] was developed to ameliorate the challenges encountered during the lateral transabdominal laparoscopic approach. Muysom was noted to have a shorter operative time than that of the laparoscopic transabdominal retrorectus technique described in the literature. Using the robotic platform through a single-dock lateral approach facilitates the dissection of the planes, and wrist instruments improve suturing of the ipsilateral posterior rectus sheath, thereby improving the overall operative time. Minimally invasive transabdominal approach to the retromuscular plane for ventral hernia repair has evolved over the years.

The use of robotic transabdominal retrorectus hernia repair has been expanded to include the repair of concomitant rectus diastasis by Cuccurullo et al. [4, 5] with a 1-year follow-up and for more complex abdominal wall pathologies, such as the management of parastomal hernias, first described by Maciel et al. [6]. These studies demonstrated the safe, reproducible, and potential applications of robotic transabdominal wall pathologies including concomitant rectus diastasis and parastomal hernias. However, there is limited information regarding the long-term outcomes of transabdominal retrorectus repair in the treatment of primary and incisional ventral hernias.

This study aims to present the 3-year recurrence rates and identify factors that may predict hernia recurrence. Additionally, we aim to report on the preoperative and postoperative quality of life scores, utilizing a hernia-specific quality of life assessment tool.

MATERIALS AND METHODS

Study Design

In accordance with Institutional Review Board (IRB) approval, a retrospective analysis of prospectively collected data was performed on patients who underwent the robotic transabdominal retrorectus approach from August 2018 to January 2022 at a single institution. The inclusion criterion was the use of r-TARUP for the treatment of primary ventral and incisional hernias in patients aged 18 years and older. Excluded from the study were patients who underwent hybrid robotic abdominal wall repair, as well as those with flank hernias, or parastomal defects. Patients who underwent laparoscopic surgery were excluded from the study. The American Society of Anesthesiologist (ASA) classification of 4 were excluded from the study. The database was reviewed for demographics, risk factors, hernia size, hernia type, mesh type and size, surgical outcomes, length of hospital stay, and return to work. Hernia defect characteristics adhered to the current ventral hernia classification guidelines by the European Hernia Society [7].

Surgical outcomes included Wound Classification according to the Centers for Disease Control and Prevention guidelines: I Clean, II Clean-Contaminated, III Contaminated, IV Dirty [8], Length of Stay, Return to Work, Surgical Site infection (SSI), Surgical Site Occurrence (SSO), and Surgical Site Occurrence requiring Procedural Intervention (SSOPI) [9]. The SSO classification adhered to the VHWG [10], including seroma, wound dehiscence, enterocutaneous fistula, cellulitis, hematoma, and delayed wound healing. We also measured the recurrence rates and administered the validated hernia-specific quality of life questionnaire.

Our study utilized the European Hernia Society Quality of Life (EuraHS-QoL) questionnaire, proposed by the European Hernia Society Working Group [11]. Developed with significant contributions from Dr. Filip Muysoms. This specialized instrument focuses on three critical variables: pain, activity limitations, and cosmetic discomfort. It provides a straightforward and comprehensive evaluation of a patient's wellbeing. Each variable is scored on an 11-point scale, ranging from 0 (no discomfort) to 10 (severe discomfort); with the domain scores summed to produce a total score from 0 to 90. Lower scores indicate a better quality of life, while higher scores suggest a worse quality of life (**Figure 1**). The EuraHS-QoL's capability to assess patients before and after surgery, along with its validated effectiveness and user-friendliness, led us to prefer it over other instruments. For instance, the Hernia-Related Quality of Life Survey (HerQLes) [12], although similar, does not effectively capture more subjective aspects of quality of life such as cosmesis and is more cumbersome to complete. Moreover, the Carolinas Comfort Scale (CCS) [13, 14], while detailed, requires answering 23 questions, which can also be cumbersome during phone interviews. Its trademarked status also necessitates a tedious licensing process and restricts publishing in open access journals.

In this study, the handling of missing data for the quality of life questionnaire was guided by a validated method developed by Filip Muysoms [15] [**Table 1**]. The purpose of these criteria for managing missing values is to address discrepancies that may arise when patients respond to the questionnaire. Such discrepancies can stem from human error, misunderstandings of the questions, or specific responses like "I do not perform this activity" in the domain addressing restrictions of activities.

Follow-up occurred at 2 weeks, 3 months, 12 months, and 2-3 years postoperatively. Quality of life assessments were conducted preoperatively and at 3 months, 12 months and 3 years postoperative. For follow-ups beyond 12 months, a telephone questionnaire was administered at two and 3 years using the standardized Validated Ventral Hernia Repair-Telephone Survey (VHR-TS) [16] [**Table 2**], along with the EuraHS-QoL questionnaire. In-office visits were scheduled if hernia-related complications were suspected.

Setting

The study was conducted at Willowbrook Methodist Hospital in Houston, Texas, a regional teaching hospital, by two surgeons employing the Intuitive Da Vinci Xi Surgical platform.

Standardized Work-Up Protocol

All patients received comprehensive information through oral and presurgical documentation. Ventral hernias were meticulously classified following the guidelines set by the European Hernia Society (EHS) [7] and measured using dynamic abdominal ultrasonography (US) or computed tomography (CT) [17]. Following informed consent, each

EuraHS-QoL Preoperative

Pain at the site of the hernia												
	0 = no pain										10 = worst pain imaginable	
In rest (lying down)	0	1	2	3	4	5	6	7	8	9	10	
During activities (walking, biking, sports)	0	1	2	3	4	5	6	7	8	9	10	
Worst pain felt during the last week	0	1	2	3	4	5	6	7	8	9	10	
Restrictions of activities because of pain or discomfort at the site of the hernia												
	0 = no restriction										10 = completely restricted	
Daily activities (inside the house)	0	1	2	3	4	5	6	7	8	9	10	X
Outside the house (walking, biking,driving)	0	1	2	3	4	5	6	7	8	9	10	X
During sports	0	1	2	3	4	5	6	7	8	9	10	X
During heavy labour	0	1	2	3	4	5	6	7	8	9	10	X
	X = If you do not perform this activity											
Cosmetic discomfort												
	0 = very beautiful										10 = extremely ugly	
The shape of your abdomen	0	1	2	3	4	5	6	7	8	9	10	
The site of the hernia	0	1	2	3	4	5	6	7	8	9	10	

EuraHS-QoL Postoperative

Pain at the site of the hernia repair												
	0 = no pain										10 = worst pain imaginable	
In rest (lying down)	0	1	2	3	4	5	6	7	8	9	10	
During activities (walking, biking, sports)	0	1	2	3	4	5	6	7	8	9	10	
Worst pain felt during the last week	0	1	2	3	4	5	6	7	8	9	10	
Restrictions of activities because of pain or discomfort at the site of the hernia repair												
	0 = no restriction										10 = completely restricted	
Daily activities (inside the house)	0	1	2	3	4	5	6	7	8	9	10	X
Outside the house (walking, biking,driving)	0	1	2	3	4	5	6	7	8	9	10	X
During sports	0	1	2	3	4	5	6	7	8	9	10	X
During heavy labour	0	1	2	3	4	5	6	7	8	9	10	X
	X = If you do not perform this activity											
Cosmetic discomfort												
	0 = very beautiful										10 = extremely ugly	
The shape of your abdomen	0	1	2	3	4	5	6	7	8	9	10	
The site of the hernia and the scars	0	1	2	3	4	5	6	7	8	9	10	

FIGURE 1 | European hernia Society quality of life questionnaire.

TABLE 1 | Validating the EuraHS-QoL for missing data.

Domain	Condition	Action Taken
Pain Domain		
	1 question unanswered	Replace with the mean of the two answered questions
	2 or 3 questions unanswered	Domain score considered missing
Restrictions Domain		
	1 or 2 questions unanswered	Replace missing values with the mean of answered questions
	3 or 4 questions unanswered	Domain score considered missing
Cosmetic Domain		
	1 question unanswered	Replace the missing value with the score from the other question
	Both questions unanswered	Domain score considered missing
Overall Score		
	1 domain score missing	Use the mean of the remaining two domain scores
	2 or more domain scores missing	Overall score considered missing

Note: Muysoms et al. [15].

TABLE 2 | Validated ventral hernia repair-telephone survey (VHR-TS).

1. Do you feel that your hernia is back?
2. Has any physician told you that your hernia is back?
3. Do you have a bulge/lump where your hernia used to be?
4. Do you have any painful areas on your abdominal wall?
A positive answer to any of the questions is considered a recurrence until proven otherwise

Note: Novitsky et al. [16].

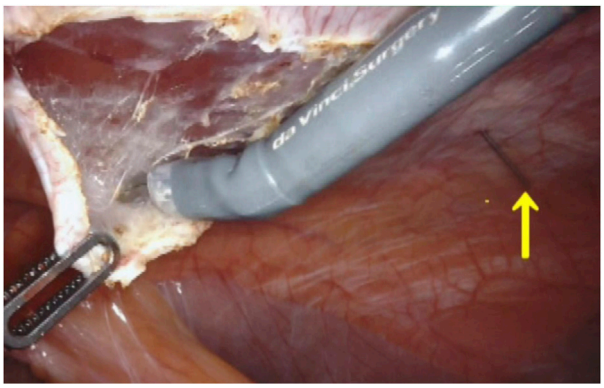

FIGURE 2 | Spinal needle preventing medial or lateral deviation of the incision after identification of the rectus muscle fibers.

patient with a complex ventral hernia underwent a specialized Enhanced Recovery After Surgery (ERAS) [18–20] protocol tailored to hernia-specific needs. Additionally, patients completed the preoperative EuraHS-QoL questionnaire. We provided active counseling and support to ensure that patients achieved smoking cessation for at least 4 weeks before surgery, achieved optimal glycemic control for diabetic patients, and maintained an optimal mental, physical, and nutritional status.

Standardized r-TARUP Technique

Our standard lateral approach for the r-TARUP procedure begins with establishing pneumoperitoneum at 12 mmHg using a Veress needle. Three 8 mm trocars are placed laterally along the anterior axillary line.

The Da Vinci Xi robot is docked from the patient's right side. Adhesiolysis and hernia content reduction proceed. The ipsilateral PRS is opened at least 5 cm from the hernia's lateral border. Transabdominal spinal needles, placed by the bedside assistant, help correct the orientation of the PRS longitudinal incision to avoid lateral deviations or medial wandering (**Figure 2**).

The longitudinal muscle fibers of the left rectus muscle are exposed, and a lateral-to-medial dissection in the retromuscular space is performed until the junction between the anterior and posterior rectus fascia is identified.

A crossover maneuver is initiated by incising the medial aspect of the PRS approximately 0.5–1 cm from its junction with the anterior sheath, granting access to the preperitoneal space. During this, the linea alba is kept ventral and the peritoneum

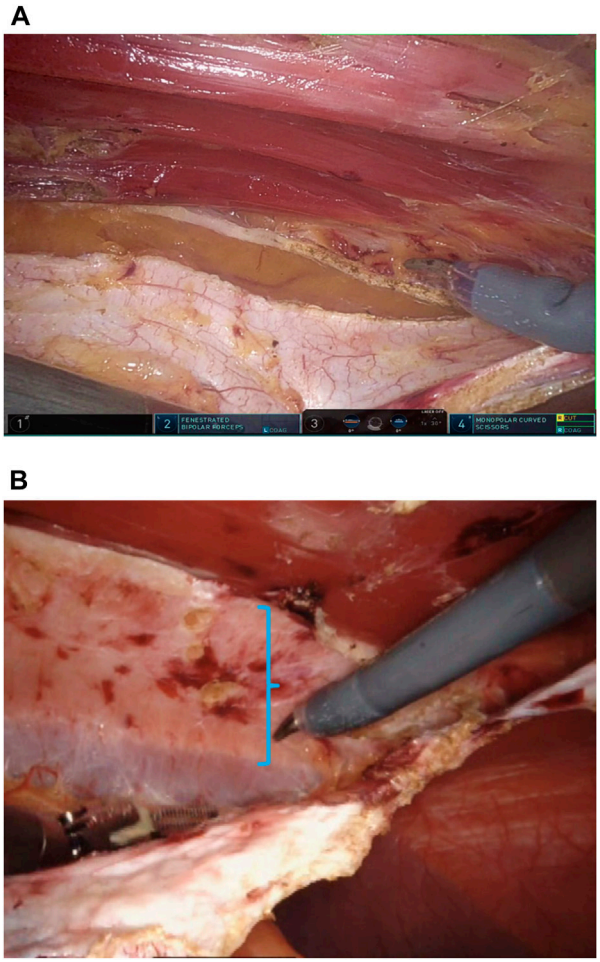

FIGURE 3 | (A) Opening of the posterior rectus fascia 0.5–1 cm before its junction with the anterior rectus sheath. **(B)** Diastasis highlighted. Shadowing fibers of the contralateral rectus muscle coming into view.

dorsal, and any concomitant diastasis is evaluated (**Figures 3A, B**). The contralateral PRS is then opened, and retrorectus dissection progresses from medial to lateral, identifying the perforating neurovascular bundles and linea semilunaris (**Figure 4**). Once cranial and caudal dissections adjacent to the hernia defect are completed, the so-called "volcano sign" is achieved (**Figure 5**), hernia sac and preperitoneal fat reduction proceeds.

If inadequate mesh overlap, increased tension during midline closure, or large peritoneal fenestrations are encountered, unilateral robotic Transversus Abdominis Release (r-TAR) may be safely performed, as described by Novitsky et al. [21].

The anterior fascial defect is closed with a running 1-0 absorbable barbed suture for synthetic mesh and a 2-0 non-absorbable suture for bioabsorbable mesh (**Figure 6**). Plication of the hernial pseudo-sac is performed to reduce the risk of seroma formation. For larger hernia sacs, a 15 Blake Jackson-Pratt drain is inserted into the sac to decrease seroma formation. If diastasis was present, inward plication using a horizontal mattress suture is

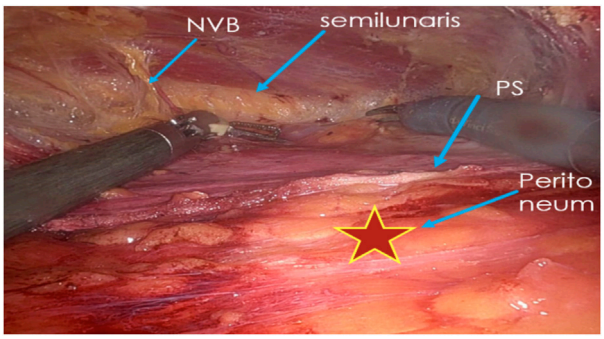

FIGURE 4 | Medial to lateral dissection within the contralateral retrorectus space.

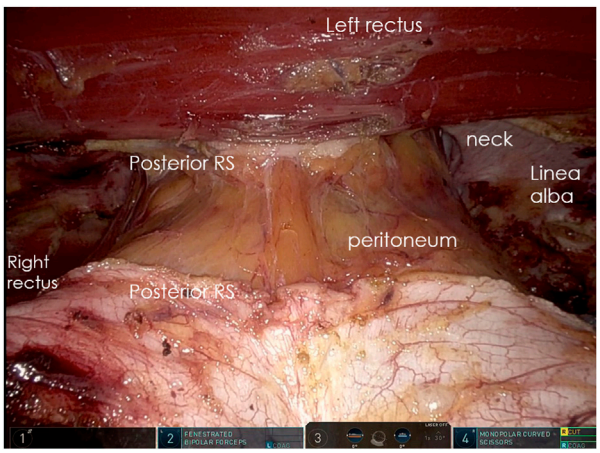

FIGURE 5 | Volcano sign. Bilateral retrorectus space connected medially by the bridging peritoneum.

performed to minimize postoperative midline vertical ridges, especially in thin patients. Mesh is inserted within the retromuscular space, typically without fixation. Finally, the ipsilateral posterior rectus sheath is closed with an absorbable 3-0 barbed suture, incorporating the ipsilateral mesh edge into the suture line at the cranial and caudal borders (**Figure 7**).

Mesh Selection and Suture Rationale

In our study, the choice of mesh type was strategically guided by clinical scenarios, surgeon preferences, and patient requests. Primary ventral hernias and all clean-contaminated cases were repaired using absorbable mesh, per the surgeon's preference. We avoided using absorbable sutures with absorbable mesh to prevent suture absorption or fracture during the mesh absorption period and potential rapid hydrolysis before integration. Instead, we used permanent sutures, crucial in the critical post-surgery weeks, to ensure mesh integration and load transfer. Permanent sutures also prevent bridging defects that could cause hernia recurrence if absorbable sutures dissolve prematurely. This hypothesis requires further validation.

For incisional hernias, which demonstrate different outcomes compared to ventral hernias [22], we prioritized optimizing prognosis. Consequently, we selected polypropylene mesh due to its well-documented long-term efficacy in the literature.

Statistics

In this study, continuous variables were presented as mean ± standard deviation (SD), while categorical variables were expressed as frequency (proportion). Comparative analyses were performed to examine the differences in numerical outcomes, and in categorical outcomes. Specific statistical tests included t-tests for comparisons of means, particularly for analyzing the impact of variables such as age and Body Mass Index (BMI) on surgical outcomes. Chi-square and Fisher's exact tests were used for

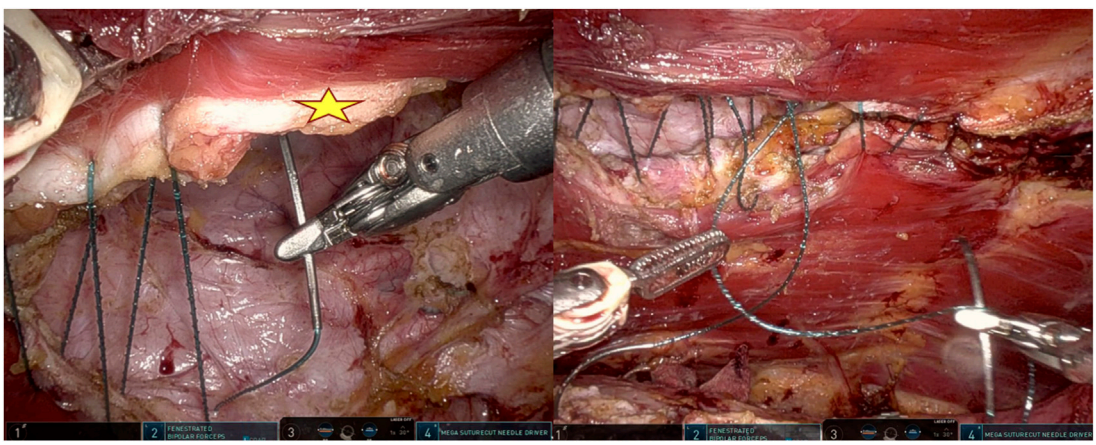

FIGURE 6 | Closure of the hernia defect. Star marks the medial edge of the posterior rectus sheath. For larger defects, closing the cranial and caudal edges first can help to decrease and distribute the tension.

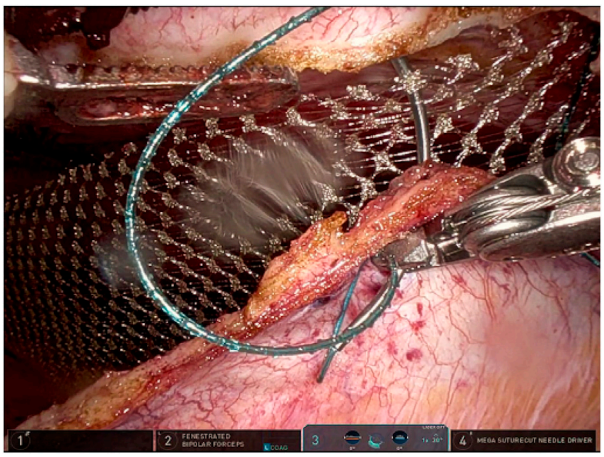

FIGURE 7 | Closure of the ipsilateral posterior rectus sheath with a running absorbable barbed suture incorporating the mesh edge.

TABLE 3 | Patient demographics.

	Patients (n = 101)	
Age, years mean ± SD [range]	53 ± 13.3	[28–81]
Gender, n (%)		
Female	43 (42.6)	
Male	58 (57.4)	
BMI, kg/m^2 mean ± SD [range]	32.10 ± 5.6	[20.3–47]
Comorbities, n(%)		
Diabetes	9 (8.91)	
COPD	6 (5.94)	
Immunosupression	8 (7.92)	
Morbid Obesity	9 (8.91)	
Smoker, n(%)	11 (10.89)	
ASA Classification, n (%)		
Class I	13 (12.87)	
Class II	77 (76.23)	
Class III	11 (10.89)	
Wound class, n(%)		
Clean	98 (97.1)	
Clean contaminated	3 (2.9)	
Contaminated	0 (0)	

Morbid obesity BMI ≥40 kg/m^2.
BMI, body mass index; ASA, american society of anesthesiologists; COPD, chronic obstructive pulmonary disease.

comparisons of categorical data, such as for evaluating the association of mesh types with postoperative complications. The Wilcoxon signed-rank test was used to compare paired data, specifically in the analysis of preoperative and postoperative EuraHS-QoL scores at 3 years follow-up. Point-Biserial correlation was applied to assess relationships involving numerical and binary variables, such as examining the association between Transversus Abdominis Release and the length of hospital stay. All tests were two-sided, and a p-value < 0.05 was considered to indicate statistical significance.

Statistical analyses were conducted using Python (Version 3.12.0, Wilmington, Delaware) on the Jupyter Notebook, supported by libraries including Pandas, SciPy, and Matplotlib. Microsoft Excel was used for initial data organization and preliminary analysis.

TABLE 4 | Hernia and mesh characteristics.

	Patients (n = 101)
Hernia size, cm	
Length	4.4 ± 1.5
Width	6.1 ± 1.1
Hernia type, n(%)	
Incisional	54 (53.4)
Primary	47 (46.5)
Mesh type, n(%)	
Synthetic	58 (57.4)
Bioabsorbable	43 (42.6)
Mesh size, cm^2	105.05 ± 44.92

Mean ± Standard Deviation.

RESULTS

Patient Demographics

A total of 101 patients who underwent r-TARUP mean age was 53 years (±13 years). The mean BMI was 32 kg/m2, indicating that the patient group was primarily in the overweight to obese category, surgical site conditions were predominantly "Clean" with 97% of cases, followed by "Clean-Contaminated" cases constituting 3% of the total [**Table 3**]. Regarding hernia types, 53% of the patients had incisional hernias, while the remaining 4% had primary ventral hernias. The dimensions of the hernia fascial defects had a mean width of 6.1 cm and a mean length of 4.4 cm [**Table 4**]. In all repairs procedures, defect closure was achieved in all the patients. Hernia repair was reinforced with mesh placement in the sublay space for all patients; 57% of cases utilized synthetic mesh, and 42% employed bioabsorbable mesh, while the latter required permanent suture 0 V-loc for the defect closure.

In patients who required unilateral Transversus Abdominis Release (TAR), a strong positive correlation was observed with an increased length of hospital stay (correlation coefficient: 0.731, $p < 0.001$) [**Table 5**].

Post-Operative Complications

Postoperative complications included symptomatic seroma (2%) (2/101) in the subcutaneous space at 1–3 months postoperative and hematoma (3%) (3/101) in the retromuscular space at 2 weeks postoperatively (**Table 6**). One patient had delayed wound closure due to skin burn at the umbilicus. There were no statistically significant differences in complications related to mesh type, with p-values of 0.611 for seroma and 0.416 for hematoma.

Surgical site occurrence requiring procedural intervention was 5% (5/101), of which two patients required drainage of seroma, one evacuation of hematoma from the retromuscular space.

The mean follow up of 34.4 months (range 4–42 months), with no hernia recurrence within the first year follow up. Three

TABLE 5 | Patient surgical outcomes.

	ASPO	2 WPO	3 MPO	12 MPO	2-3 YPO
	n = 101	*n* = 101	*n* = 101	*n* = 101	*n* = 92
Surgical Site Occurrence, *n*(%)					
Seroma	–	–	2 (1.9)	–	–
Hematoma	–	3 (2.9)	–	–	–
Delayed wound clossure	–	1 (1.4)	–	–	–
Surgical Site Occurrence Requiring Procedural Intervention, *n*(%)	–	3 (2.9)	2 (1.9)	–	–
Surgical Site Infection, *n*(%)	–	1 (0.9)	–	–	–
Recurrence, *n*(%)	–	–	–	–	3 (3.2)
TAR, *n*(%)	19 (18.8)	–	–	–	–

ASPO, after surgery postoperative; WPO, weeks postopertive; MPO, months postoperative; YPO, years postopertive.
Surgical Wound class CDC guidelines.
TAR, transversus abdominis release.

TABLE 6 | Hospital stay & return to work outcomes.

		r
Length of stay, days mean ± SD		
No TAR	< 0.1 ± 0.23	0.731*
w/TAR	2.3 ± 0.47	
Return to work, days mean ± SD	6.2 ± 1.2	

TAR, transversus abdominis release.
** p-value significance, p < 0.001.*
Point-biserial correlation coefficient.

TABLE 7 | Overall scores EuraHS-QoL questionnaire.

Total overall scores		
Preoperative, *n* = 101		
Mean ± SD	61,61	5,29
Range	48,24	72,93
Median (P25-P75)	61,99	(58.78–65.38)
3 Months Posoperative, *n* = 101		
Mean ± SD	21,25	4.75*
Range	12	31,03
Median (P25-P75)	21,42	(18.09–24.01)
12 Months Posoperative, *n* = 101		
Mean ± SD	16,32	3.33*
Range	7,04	24
Median (P25-P75)	16,81	(14.08–24.01)
3 Years Posoperative, n = 92		
Mean ± SD	13,84	2.6*
Range	5,02	20
Median (P25-P75)	14,19	(12.08–16.01)

**significant results compared to preop, p < 0.001.*
Wilcoxon signed rank test for p-significance.

hernia recurrences were reported at 3-year follow-up. Nine patients were considered lost to follow up beyond the 12 months follow up period, after three phone call attempts and one email, representing a 91.09% retention rate.

Hernia recurrences were repaired robotically, with a preperitoneal repair for an epigastric defect in a patient with diastasis extending to the xiphoid process. The other two recurrences were repaired using the intra-abdominal preperitoneal underlay mesh (IPUM) technique.These two recurrences were related to decreased mesh overlap at the opening of the posterior rectus sheath flap. Two recurrences occurred with synthetic polypropylene mesh and one with bioabsorbable mesh, the latter in the epigastrium of a patient with concomitant diastasis that was not addressed in the initial surgery. Computed tomography imaging showed the recurrence at 2 years and 6 months postoperatively (**Supplementary Figure**).

Patient-Reported Quality of Life

The European Hernia Society Quality of Life (EuraHS-QoL) scores used in our study exhibited substantial postoperative improvements. Assessments were conducted preoperatively and at 3 months, 12 months, 2 years, and 3 years postoperatively. The overall mean score decreased significantly at 3 months (61.61 ± 5.29 vs. 21.25 ± 4.75, $p < 0.001$) [**Table 7**]. Individual domain median scores also improved significantly at 3 months, with pain scores decreasing from 4.7 to 2.1, restriction of activities scores from 7.7 to 2.7, and cosmetic discomfort scores from 8.6 to 2.5. These changes were statistically significant (Wilcoxon signed-rank test), demonstrating the positive impact of surgery on the patients' quality of life. The decrease in cosmetic scores was particularly significant, indicating greater improvement in this domain compared to pain and restriction of activities at all postoperative time points [**Table 8**] (**Figure 8**).

The use of corrected -values in this longitudinal study accounted for multiple comparisons, thus averting the risk of false positives. The substantial "Statistic" values derived from the repeated-measures ANOVA (F-statistic = 23980.73, $p < 0.001$) and pairwise t-tests with Bonferroni correction confirmed that there were statistically significant changes in QoL scores from preoperative to 3 years postoperatively across the four time points. All comparisons remained highly significant ($p < 0.001$) even after adjustment for multiple comparisons, indicating that enhancements in QoL were consistently significant at each pairwise comparison of time points.

TABLE 8 | Domain scores EuraHS-QoL questionnaire.

	n = 101	*n* = 101	*n* = 101	*n* = 92
	Preoperative	**3 MPO**	**12 MPO**	**3 YPO**
EuraHS-QoL, mean ± SD [median]	6.8 (0.5) [6.8]	2.3 (0.5) [2.3]*	1.8 (1.2) [1.7]*	1.5 (0.2) [1.5]*
Pain	4.7 (0.6) [4.7]	2.1 (0.6) [2]*	1.2 (0.9) [1.3]*	1.2 (0.34) [1]*
Activities	7.5 (1.7) [7.7]	2.7 (1.4) [2.7]*	2.3 (1.4) [2]*	2.03 (0.6) [2]*
Cosmetic	8.6 (0.8) [8.5]	2.03 (0.9) [2.5]*	1.6 (0.9) [1.5]*	1.1 (0.5) [1]*

MPO, months postopertive; YPO, years postopertive; EuraHS-QoL, European Hernia Society quality-of-life.
**significant results compared to preop,* p < *0.001.*
Wilcoxon signed rank test for p*-significance.*

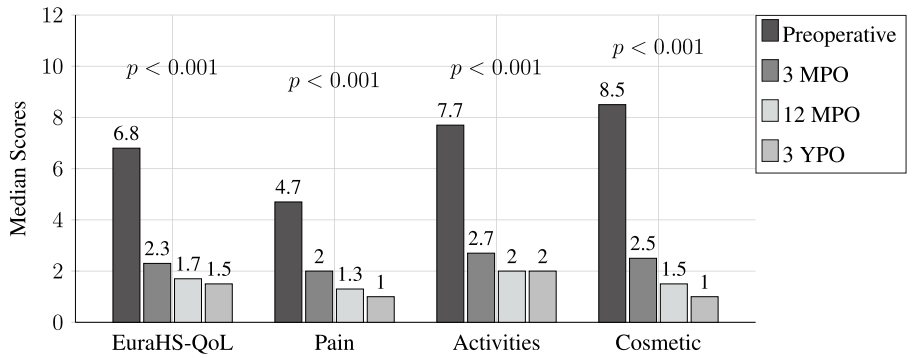

FIGURE 8 | Preoperative vs. Postoperative overall.

DISCUSSION

Our findings reveal a compelling narrative about the advantages of r-TARUP, showing a notably low recurrence rate of 2.97%, with no statistical significance based on the type of mesh used. Quality of life improvements were particularly notable in the immediate postoperative period and were sustained over the 3-year follow-up period.

This study provides a comprehensive analysis of the r-TARUP hernia repair technique and reflects its efficacy and implications for hernia repair. The technique's ability to facilitate closure of hernia defects, as reported in our results, with mean defect width measurement of 6.1 [**Table 4**], highlights its effectiveness in addressing small to moderate size hernias, although larger hernias W3 (> 10 cm) can be address with adjuvant unilateral Transversus Abdominis muscle Release (TAR), further enhancing its versatility.

In cases where there was tension in closing the hernia defect or the posterior rectus sheath flap did not provide sufficient overlap for the mesh ipsilaterally, our approach included a TAR procedure as an adjunct to retrorectus release. As described by Novitsky et al. [21, 23, 24], this technique involves opening the posterior lamella of the internal oblique muscle, medial to the linea semilunaris. This process exposes the transversalis muscle, allowing it to be divided and released from its fascia, thus providing additional medialization of the anterior fascia and rectus muscle.

A key feature of the r-TARUP technique is its ability to facilitate mesh placement in a well-vascularized retrorectus space. This strategic placement is significant because it avoids mesh placement within the abdominal cavity, thereby potentially reducing the complications associated with intraperitoneal mesh placement. A disadvantage of r-TARUP repair is the ipsilateral opening of the posterior rectus sheath to access the retrorectus space. Improper closure can lead to intraparietal hernias. Therefore, it is crucial to ensure that the posterior rectus sheath is properly closed at the end of the procedure with careful checks for rent in the peritoneum or sheath. Additionally, improper lateral opening of the sheath without precise ultrasound guidance or anatomical delineation increases the risk of neurovascular bundle injury [25]. Such injury could lead to rectus muscle atrophy and bulging.

In our study, we found that all hernia defects were successfully closed by reconstructing the linea alba, which is crucial for ensuring the integrity of abdominal wall repair. The use of both synthetic and bioabsorbable meshes in our study aligns with the current trends in hernia repair, and offers valuable insights into the effectiveness of different materials.For the bioabsorbable subset of patients, an extended follow-up period of 5 years will be essential to provide comprehensive data on their durability, recurrence rates [26].

Trials in hernia repair have consistently reported improvements in quality of life following minimally invasive techniques for abdominal wall hernia repair [27]. Our study aligns with these findings. In particular, we emphasize the role of hernia-specific questionnaires [13,

28], such as EuraHS-QoL, in accurately capturing patient outcomes. Using this specific assessment in our study provides a deeper and more precise understanding of patients' before and after surgical experiences. Although other QoL assessments are available, the EuraHS-QoL has been shown to be user-friendly and highly correlated with the CCS, while offering a more detailed and precise evaluation of quality of life [29]. HerQLes, another QoL scale, emphasizes abdominal wall functionality—a pivotal aspect in evaluating functional outcomes related to abdominal wall movement that we may have overlooked by using the EuraHS-QoL scale [12].

One advantage for the EuraHS-Qol is its ability to be validated during inevitable circumstances such as inability to understand the questions making it a precise tool that avoids biases.

Significant improvements were noted from preoperative to 3 years postoperative, with the most substantial improvements observed in the 3 months postoperative period for pain, activity limitations, and aesthetic concerns (**Table 8**) (**Figure 8**).

A noteworthy finding of our study was the correlation between the use of posterior component separation TAR and the duration of hospital stay [**Table 6**]. Patients who did not require the posterior component separation TAR procedure had shorter hospital stays and fewer post-surgery restrictions, highlighting the potential benefits of less invasive techniques for enhancing patient recovery.

The increased hospital stay was due to the surgeon's preference for careful monitoring of several critical recovery factors. Beyond drain monitoring, the overnight stay allowed for observation of pain, monitoring and adherence to established enhanced recovery protocols for diet and early ambulation which are crucial to patient outcomes. These ERAS principles have been previously described by Fayezizadeh et al. [30] and in recent publications by Marckmann et al. [31].

The complication rates reported with other robotic retromuscular repairs, such as r-TAR and r-eTEP, are significantly low (9%) [32–35]. Postoperative complications in our study occurred at an equal low-frequency, with a seroma rate of 2%, hematoma rate of 3%, and surgical site infection rate of 1%. The literature notes a lack of differentiation between seroma rates within the subcutaneous tissue or retromuscular space. In our study, seromas requiring procedural intervention with a clinical duration greater than 1 month occurred in the subcutaneous space. This rate has decreased since the installation of a tunneled 15 Blake JP drain for large hernial sacs.

Hematomas requiring procedural intervention were located in the retrorectus space and were effectively managed using a laparoscopic approach in two patients, without requiring mesh removal or debridement. The other patient required open hematoma evacuation at the epigastrium and debridement of a small segment of the free-floating mesh. Jackson-Pratt (JP) drain catheters were placed during these interventions. It is important to note that the drains are not routinely used in the TARUP procedure, except in cases where a Transversus Abdominis Release (TAR) procedure is performed. In this subset of patients, none of the JP drains resulted in related complications and the drains were typically removed between postoperative days 7 and 10. This outcome highlights the selective and effective use of JP drains in specific cases within our surgical approach without introducing additional complications.

CDC Class II and III during the robotic incisional hernia repair has been reported to affect the outcomes [36]. In the series, wound contamination occurred in 2.9% of the cases, absorbable mesh was used, surgical site infections occurred in 1%, and the reported surgical site infections did not differ between the clean and contaminated cases. The benefits of minimally invasive repair and inset of wound infection complications are estimated 1.0% [37]. In our study, the average BMI was 32.1 kg/m2 which is quite normal today's patient population in our geographic area, with an obesity rate of 36.1% [38]. In addition, it was not a predictor of wound infections in our study. The benefits of decreasing wound infection in obese patients by utilizing minimally invasive surgery for hernia repair were evident in our robotic approach, although other patient comorbidities were maximized preoperatively as part of our ERAS pathway, including optimization of diabetes and smoking cessation.

Regarding the subset of patients who underwent absorbable mesh implantation, we believe in the mesh's ability to integrate with host tissue, supporting fibroblast infiltration and collagen deposition to restore tissue strength [39]. However, longer-term follow-up extending to 5 years or more is crucial to provide more definitive data on the longevity of retromuscular repairs with bioabsorbable mesh (P4HB) and the incidence of late recurrence.

Our study's 3-year follow-up demonstrated a low recurrence rate of 2.97%, comparable to other MIS retromuscular repairs described by Aliseda et al. [40] We noted that hernia recurrence showed no significant dependence on mesh type. Instead, recurrence rates were related to surgical technique rather than mesh selection. A higher incidence of recurrence was observed in the synthetic mesh group due to decreased mesh overlap.

The decreased mesh overlap at the ipsilateral opening of the posterior rectus sheath is primarily caused by medial wandering during the opening of the PRS. Notably, hernia recurrence in the absorbable mesh group was identified in the epigastrium, particularly at sites of rectus diastasis not fully addressed up to the xiphoid process. To mitigate these issues, our current practice includes the transabdominal placement of spinal needles. This technique helps prevent medial deviation when opening the posterior rectus sheath and ensures complete reconstruction of the linea alba, especially in cases of diastasis.

The r-TARUP technique serves as a robust platform for more complex robotic hernia repair procedures. Its utility extends to techniques such as robotic Extended Totally Extraperitoneal repair (eTEP) and robotic Transversus Abdominis Release (r-TAR), making it a pivotal development in hernia treatment and during the robotic learning curve.

To optimize the application of the r-TARUP technique, it is imperative to understand the abdominal wall anatomy, ensure proper mesh overlap, and address concomitant diastasis to achieve reproducible outcomes. Looking ahead, we advocate for further research on absorbable mesh.

STRENGTHS AND LIMITATIONS

Strengths

The strengths of our study include the 3-year outcomes for the r-TARUP technique, which expand the body of literature on long-term outcomes for ventral hernia repair. Moreover, by incorporating Quality of Life assessments using the EuraHS-QoL scores, we provided a more comprehensive evaluation of patient outcomes. This highlights the positive long-term effects of the r-TARUP technique on patient wellbeing over a 3-year follow-up period.

Limitations

Limitations of our study include those inherent to a single-institution retrospective study. The study was conducted by two surgeons, which may limit the generalizability of the results to broader populations. Additionally, the relatively small sample size constraints our ability to perform subgroup analyses. However, despite the small sample size, our study has greater power than many existing studies in the r-TARUP literature, for which are limited.

CONCLUSION

Our study confirms the safety, efficacy, and enduring success of the r-TARUP technique in treating primary and incisional ventral hernias. The main finding at the 3 years follow up was a low recurrence rate, minimal postoperative complications, and a noticeable improvement in quality of life.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published, and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

AUTHOR CONTRIBUTIONS

AG: conceptualization, data curation, formal analysis, writing–original draft, writing–review and editing. GA: conceptualization, data curation, writing–original draft, writing–review and editing. CA-R: data curation, writing–original draft. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

PUBLISHER'S NOTE

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/jaws.2024.12907/full#supplementary-material

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Short-Term Outcomes of Transabdominal Preperitoneal Ventral Hernia Repair With Rectus Aponeuroplasty (TAPPRA) for the Management of Incisional Hernias

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Introduction: Options for minimally invasive ventral hernia repair continue to evolve as a function of our understanding of the abdominal wall and the development of new techniques. We describe a robotic transabdominal pre-peritoneal repair with concurrent rectus aponeuroplasty (TAPPRA) for incisional and recurrent ventral hernias.

Methods: All patients in this retrospective cohort study underwent TAPPRA repair between October 2023 and March 2024. This study aimed to determine intraoperative feasibility of the technique and to assess immediate postoperative outcomes.

Results: Twelve patients underwent TAPPRA repair for incisional and/or recurrent ventral hernias at an academic hernia center. The median case duration was 135 min with no significant intraoperative complications noted. Average defect size for the hernias measures 6.5 × 8.5 cm. Polypropylene mesh was used to reinforce all defects, with the average dimensions being 19.7 × 21.5 cm. 83% of patients were discharged within 24 h of their procedure. No significant postoperative complications were noted.

Conclusion: We describe the first use of a novel ventral hernia repair technique, TAPPRA, and demonstrate that it is safe, feasible, and associated with appropriate short-term outcomes for repair of moderate sized incisional hernias.

Keywords: ventral hernia repair, extraperitoneal mesh placement, preperitoneal mesh repair, robotic abdominal wall surgery, rectus aponeuroplasty

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INTRODUCTION

Ventral hernia repair is one of the most commonly performed procedures in general surgery [1]. The approach to repair has evolved dramatically in the modern era. Hernia repair strategies have pushed towards the utilization of broad, extraperitoneal positioned mesh with a premium placed on defect closure [2, 3]. The advent of modern techniques such as transversus abdominis release (TAR), have provided safe and reproducible approaches for achieving broad mesh coverage for complex reconstruction, while simultaneously reducing wound morbidity traditionally present for advanced procedures such as anterior component separation [4–6]. Further enhancing surgeons' ability to deliver complex repair options while minimizing morbidity has been the revolutionary

robotic approaches to abdominal wall reconstruction, which have been allowed surgeons to attain comparable long term outcomes and reduce morbidity further [4, 5].

Minimally invasive abdominal wall reconstruction is in its early phase of adoption. Spurred by procedures like intraperitoneal onlay mesh repair (IPOM), transabdominal preperitoneal repair (TAPP), and enhanced totally extraperitoneal techniques (eTEP), general surgeons have expanded their armamentarium to address ventral hernia defects [7]. Expert opinion on the best technique for a given defect is diverse and dependent on a variety of factors. However, one common and emerging theme among abdominal wall specialists is the realization that hernias may be considered a chronic disease process, and that abdominal wall planes should be preserved to allow for future operations to be performed. Beyond preservation of hernia repair options for the future, many experts have noted that over utilization of advanced techniques such as TAR, can be associated with major complications [8].

We sought to develop a technique to allow for broad mesh coverage, decrease tension on fascial closure while minimizing the potential for injuries to the neurovascular elements of the abdominal wall. As such, an extended transabdominal preperitoneal dissection with concurrent rectus aponeuroplasty (TAPPRA) was developed. We share our initial experience and the development of the TAPPRA technique. Further, we describe early perioperative outcomes for patients who have had this operation. Our study aims to assess the safety, efficacy, and results of TAPPRA technique for moderate sized ventral hernia defects.

METHODS

Hernia and Abdominal Wall Center

All procedures were performed at an academic hernia and abdominal wall center in the Pacific Northwest of the United States. The operation was developed and performed by the same surgeon (VCN). The operations were performed using the Intuitive DaVinci Xi robotic platform (Intuitive Surgical, Sunnyvale, CA United States).

Data Collection

A prospective maintained database for all patient undergoing hernia repair has been established by our center. Patient demographics were collected including body mass index (BMI), prior hernia repair attempts, and common comorbidities. Intraoperative variable including estimated blood loss, case duration, mesh type and size, fixation strategy, and suture types were collected. Short-term outcomes related to length of stay, postoperative complications, and procedural interventions were assessed. Given the fact that this was a feasibility study, long term data related to our surveillance was limited and has not been included in this initial review.

Surgical Technique

TAPPRA technique is a derivative of two commonly performed and well described techniques in ventral hernia repair. It combines preperitoneal dissection for extraperitoneal mesh positioning with intracorporeal rectus aponeuroplasty [9, 10]. These previous techniques have typically been used for smaller defects, but we have aimed to apply it towards moderate hernia defects ranging in size from 4–10 cm in transverse dimension.

The operation is initiated with abdominal access and placement of lateral robotic trocars. A peritoneal incision is made 5–7 cm from the ipsilateral hernia defect margin. A preperitoneal dissection is conducted, taking advantage of the falciform and periumbilical fat. The preperitoneal dissection is carried to the contralateral abdominal wall, often extending to the contralateral retroperitoneum. Upon completing the dissection, defect closure is performed. To facilitate closure and minimize tension on the fascial closure, a posterior rectus sheath aponeuroplasty is performed. The posterior sheath is identified and incised roughly 1 cm from the linea alba. No dissection is performed in the retrorectus space, to preserve this area and minimize injuries to the neurovascular elements present in the retrorectus space. Fascial closure is completed typically with a #1 permanent barbed suture. Following closure, the decision is made for either double docking the robotic trocars on the contralateral abdomen to perform an extended preperitoneal dissection and accommodate a large mesh, or to maintain the original docking position and perform a less extensive retrograde pre-peritoneal dissection on the ipsilateral side. For larger defects (generally, greater than 7 cm in width), our team favors using broad mesh coverage and will readily double-dock the robotic platform and perform preperitoneal dissection. Depending on the decision for single unilateral docking vs. double docking, mesh and peritoneum are managed in the following ways:

1) Single site docking: Macroporous polypropylene mesh is placed fixated to the anterior abdominal wall with interrupted stitches using 3-0 fast-absorbing suture. The peritoneal flap is closed using a 3-0 slow absorbing V-loc suture. Fenestrations in the flap are identified and closed.
2) Double site docking: the visceral sac is reconstructed and all fenestrations closed. Once completed, mesh is placed and opened above the peritoneal flap and the space is de-sufflated. Representative videos of these techniques from VCN may be viewed in the following links:

1) Single dock:[1]
2) Single dock with case set up:[2]
3) Double dock for moderate defect:[3]
4) Double-dock for larger defect:[4]

Key steps in the operation are depicted in **Figure 1**.

Postoperative Care

At the completion of the case, patients were extubated after reversal of paralysis using Sugammadex. Patients are provided

[1]https://youtu.be/hax1A6TxdnY?si=eJTuB_QJ5Uv201Tm
[2]https://youtu.be/s1ly18jbt6Q?si=PqaGka45iFIfpI9b
[3]https://youtu.be/XG7iIPkdXvA?si=vyzydbxp3YTWFtWl
[4]https://youtu.be/sZ_Wt_okoL4?si=GeSwztpabHaet7Q-

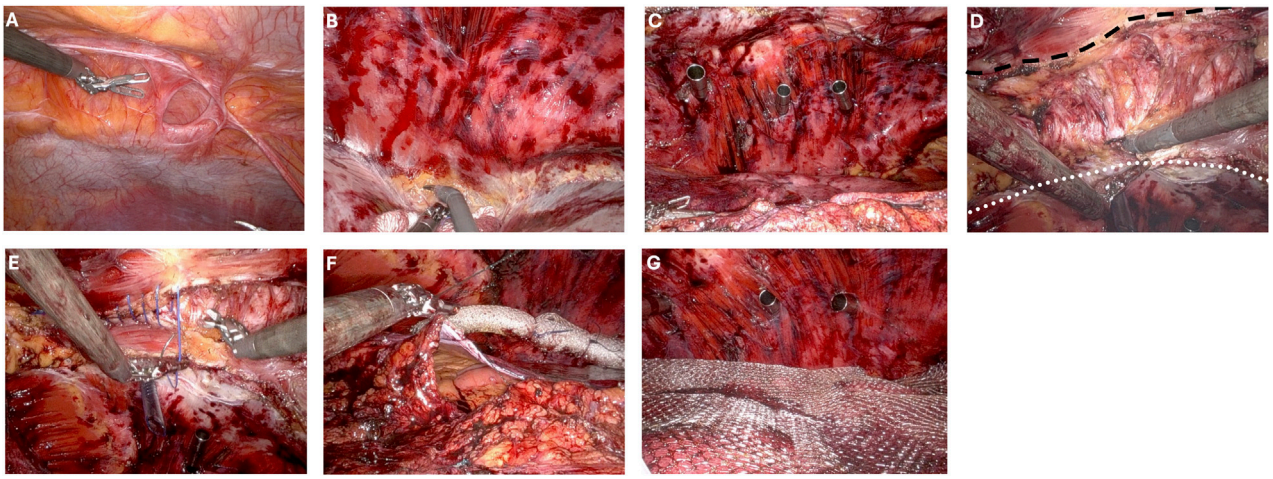

FIGURE 1 | Critical steps of double-dock transabdominal preperitoneal ventral hernia repair with rectus aponeuroplasty **(A)** Ventral defect prior to dissection. **(B)** Preperitoneal dissection to contralateral pretransversalis space. **(C)** Placement of contralateral trocars in preperitoneal/pretransversalis space. **(D)** Rectus aponeuroplasty with dotted line defining the line of transection lateral to the linea alba. Dashed line along the ipsilateral rectus margin with completed rectus aponeuroplasty and exposed rectus muscle. **(E)** Anterior fascial defect closure. **(F)** Visceral sac closure. **(G)** Mesh placement.

TABLE 1 | Preoperative patient specific factors.

Factors	Total patients N = 12 (n%)
Age, years; mean (range)	60.75 years (44–79 years)
Male gender	7 (58%)
Primary Insurance	
Medicare	6 (50%)
Private	6 (50%)
Incisional hernia	10 (83%)
Recurrent hernia	1 (8.3%)
Modifiable Risk Factors	
BMI; mean (range)	31.5 (23–42)
BMI >25	9 (75%)
BMI >30	7 (58%)
Diabetes, HbA1c > 7%	0 (0%)
HTN	6 (50%)
Anti-platelet medications	3 (25%)
Anti-coagulation medications	13 (6%)

TABLE 2 | Intraoperative patient specific factors.

Factors	Total patients N = 12 (n%)
European Hernia Classification Hernia Location[a]	
M1	1 (8.3%)
M2	5 (42%)
M3	12 (100%)
M4	5 (42%)
Defect width, average (range)	6.5 cm [4–10]
Defect length, average (range)	8.6 cm [4–16]
Operative time (min), mean (range)	135 min (60–252)
Operative Approach	
Single dock	9 (75%)
Double dock	3 (25%)
Mesh use	
Macroporous polypropylene (mid-weight)	10 (83%)
Microporous polypropylene (heavy-weight)	2 (17%)
Mesh width, average (range)	19.7 cm (12–30)
Mesh length, average (range)	21.5 cm (15–30)
Mesh fixation strategy	
Suture to anterior wall	9 (75%)
Fibrin sealant to visceral sac	1 (8.3%)
None	2 (16.7%)
Drain placement	
Adjacent to mesh in preperitoneal plane	3 (25%)
Subcutaneous drain	1 (8.3%)

[a]*Some patient with hernias that spanned multiple regions of abdominal wall.*

an abdominal binder and encouraged to wear compression garments in the initial postoperative period. Multimodal pain control strategies are utilized, with a preference for non-narcotic analgesics. Same-day discharge is the anticipated postoperative plan, but all procedures are performed in venues that have the possibility of admitting patients for post-operative observation. Initial follow up occurs within a few weeks of the operative date. All patients are enrolled in our hernia surveillance program to assess for long-term outcomes [11].

Institutional Review Board

This research secured approval from our institutional review board at Oregon Health & Science University, Portland, OR. Given the retrospective nature and minimal risk classification of this study, patient consent was determined to be unnecessary and implied.

RESULTS

Preoperative Patient Factors

TAPPRA ventral hernia repair technique was used to address ventral hernias in 12 patients during the observation period. During that time period, 202 total ventral hernia repair operations were performed, resulting in a use rate of 5.9%. The average age of patients undergoing TAPPRA was 61 years

TABLE 3 | Postoperative patient outcomes.

Outcomes	Total patients N = 12 (n%)
Length of Stay	
Same day discharge	8 (66%)
Overnight observation	2 (17%)
2-3 nights	2 (17%)
Surgical site occurrences (SSO)	0 (0%)
Procedural interventions	0 (0%)
Narcotic utilization[a]	
No narcotic utilization	8 (66.7%)
1–10 tablets	3 (25%)
>15 tablets	1 (8.3%)
Short-term Follow-up (y/n) at 3 months	12/12 (100%)
Clinical recurrence	0 (0%)
Follow up duration, median (range)	7 (3–9) months

[a]*all patients discharged with oxycodone 5 mg tablets.*

(range 44–79 years), with an average BMI of 31.5 kg/m2. Indications for surgery included incisional hernias (10 patients, 83%) and recurrent hernias (1 patient, 8.3%). Patient modifiable comorbidities included BMI >30 kg/m2 (n = 7, 58%). A summary of patient factors is provided in **Table 1**.

Intraoperative and Hernia Specific Variables

Intraoperative factors were reviewed. The majority of patients presented with defects centered around the umbilicus (M3, per European Hernia Society nomenclature) [12]. The average defect size measured 6.5 cm by 8.6 cm, with the large defect width being 10 cm. Operations were performed via unilateral port placement (docking) in 75% of cases. The remaining operations to address larger defects (generally, greater than 7 cm in width) were managed with a double docking strategy. Mesh preference in these cases was for macroporous polypropylene mid-weight mesh (10 patients, 83%). The average mesh size was 19.7 × 21.5 cm (range 12–30 cm in transverse, 15–30 cm in cranial-caudal dimension). A summary of the intraoperative factors is provided in **Table 2**.

Postoperative Outcomes

Given the novel nature of this operative technique, we have limited data on long term outcomes. The majority of patients (n = 8, 66%) were discharged on the same day of their procedure. Only 2 patients (17%) required hospitalization beyond one night. Surgical site occurrences and/or procedural interventions were not required in any patient and narcotic utilization was less than 10 tablets/patient for all but 1 patient (91.7% narcotic free). The median length of surveillance was 7 months, with a range of 3–9 months for all participants. A summary of postoperative outcomes is provided in **Table 3**.

DISCUSSION

The optimal surgical approach for moderate sized ventral hernias is complex and dependents on multiple patient, surgeon, and institutional factors. We report our initial experience of a novel technique for robotic ventral hernia repair, TAPPRA, and demonstrate that short-term outcomes are appropriate with expected findings related to intraoperative reproducibility and immediate postoperative outcomes. We are encouraged by these findings which allow for yet another technique to minimally invasive hernia repair with ventral defect closure and broad mesh reinforcement.

Contemporary ventral hernia repair has evolved dramatically in the last two decades. Many of the principles of hernia repair have been derived from retromuscular techniques proposed by Rives and Stoppa—namely prosthetic reinforcement of the visceral sac [13]. Over the decades, this approach has allowed for multiple iterative changes that have led to the modern day hernia practice [14]. Traditional open ventral hernia repair with myofascial advancement techniques have been associated with good outcomes in select populations. However, these techniques carried high rates of wound complications and perioperative morbidity. As such, surgeons explored minimally invasive techniques such as IPOM, with a goal of minimizing wound complications [7]. IPOM, though effective in the short term, had many weaknesses as defect closure was often not achieved. Further, the ability for surgeons to use IPOM to address hernias in atypical locations was poor, as circumferential penetrating fixation was required for success [9]. As a function of robotic technology, and expansion of our working understanding of the abdominal wall, newer techniques/approaches such as IPOM+, LIRA, rTAPP, and eTEP have since been introduced which allow for ventral hernia repair that results in more durable outcomes than IPOM [7, 10]. Our proposed procedure takes elements of these operations, specifically LIRA and rTAPP, to allow for surgeons to address moderate defects with an extraperitoneal mesh.

TAPP ventral hernia repair is now a common procedure among surgeons. For smaller defects, it serves a valuable role, allowing for defect closure, extraperitoneal mesh, and minimizes the need for penetrating fixation of mesh [9]. However, for larger defects, the TAPP approach can be associated with excessive tension during defect closure. For many surgeons, rather than attempting a preperitoneal repair for moderate defects, a retromuscular repair is conducted, which results in medialization of the rectus abdominis and anterior fascia through a variety of maneuvers [15]. The process of myofascial advancement in these techniques has been attributed to many factors, including incision of the posterior rectus sheath, dissection of the retrorectus space, incision of the posterior lamella of the internal abdominal oblique aponeurosis, and for advanced procedures, transection of the transversus abdominis muscle and subsequent dissection in the pretransversalis space [16, 17]. Unfortunately, complications related to retromuscular repair are significant and can burn many bridges to future repair [18]. Our described technique predominantly performs a dissection the preperitoneal plane and has a limited retromuscular component. By performing rectus aponeuroplasty, we are able to off-load tension, allowing for closure of larger defects.

Extended preperitoneal dissections have been described for many decades, but have been considered to be challenging and difficult to reproduce [19]. Outcomes at high volume centers have demonstrated iterative improvement in this technique. As general surgeons have become more comfortable with retromuscular dissection, this complex technique now appears to be more attainable. We find that TAPPRA is a reproducible option for hernia repair that does not obviate any other options for reconstruction. The operation may proceed with unilateral docking or a double docking technique. The double docking strategy is typically reserved for wider defects that will require broad mesh coverage. Rather than a traditional TAR procedure, this extended preperitoneal dissection allows for extension of the dissection beyond the semilunar line without disrupting the muscular and aponeurotic elements of the abdominal wall. Similar strategies have been implemented by the Madrid group, but often require a retrorectus dissection which may result in increased potential for neurovascular trauma to the abdominal wall [20].

This study has several notable limitations. First, it is a retrospective review of select cases performed at a high-volume hernia center. The surgeon included in this study has completed a formal fellowship in abdominal wall reconstruction and has overcome their initial learning curve in robotic ventral hernia repair. Second, this study exclusively evaluates feasibility of performing these repairs with limited information on long-term outcomes. Though those findings will be paramount, this technique is a derivative of commonly performed operations that are well described in the hernia literature and have demonstrated acceptable long-term results. We have been encouraged by the low rate of short-term complications and look forward to long-term follow up with these patients. Third, the operations are performed using robotic surgical platform. Though these techniques can be performed with traditional laparoscopic instruments, robotic assisted surgery facilitates management of complex peritoneal flaps and may make broad adoption challenging. More robust evaluation of this technique is necessary. We are currently collaborating with other hernia centers to evaluate the utility of this technique and compare it to other MIS techniques for ventral hernia repair.

In summary, we report our first experience of performing robotic TAPPRA technique for the management of moderate sized ventral hernias. This technique appears to be associated with a low complication profile and can be applied to many patients. Future studies evaluating the optimal patient selection strategy and long-term outcomes will be important in determining if this technique can be more broadly applied.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving humans were approved by the Oregon Health & Science University. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because of the minimal risk and retrospective review of surgical records.

AUTHOR CONTRIBUTIONS

All authors participated in the design, interpretation of the study, analysis of the data, writing of the manuscript, and review of the manuscript; VN performed the operations. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

VN received consultant payments from Intuitive Surgical, Caresyntax, Medtronic, Allergan, and Bard.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

PUBLISHER'S NOTE

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REVIEW
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The Impact of a Specialized Hernia Center and Standardized Practices on Surgical Outcomes in Hernia Surgery: A Systematic Review and Meta-Analysis

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Aim: Hernia registries report that guidelines are not always implemented by general surgeons and suggest that the success rate of this procedure is higher in hernia specialty centers. There are many definitions of hernia centers, but their objectives consist of improving healthcare by homogenizing the clinical practice. We performed a systematic review and meta-analysis to analyze hernia centers' definitions and compare hernia centers with non-specialized centers.

Material and Methods: Cochrane Central, Scopus, Scielo, and PubMed were systematically searched for studies defining a hernia center or comparing hernia centers and non-specialized centers. Outcomes assessed were recurrence, surgical site events, hospital length of stay (LOS), and operative time. We performed subgroup analyses of hernia type. Statistical analysis was performed with R Studio.

Results: 3,260 studies were screened and 88 were thoroughly reviewed. Thirteen studies were included. Five studies defined a hernia center and eight studies, comprising 141,366 patients, compared a hernia center with a non-specialized center. Generally, the definitions were similar in decision-making and educational requirements but differed in structural aspects and the steps required for the certification. We found lower recurrence rates for hernia centers for both inguinal (1.08% versus 5.11%; RR 0.21; 95% CI 0.19 to 0.23; $p < 0.001$) and ventral hernia (3.2% vs. 8.9%; RR 0.425; 95% CI 0.28 to 0.64; $p < 0.001$). Hernia centers also presented lower surgical site infection for both ventral (4.3% vs. 11.9%; RR 0.435; 95% CI 0.21 to 0.90; $p = 0.026$) and inguinal (0.1% vs. 0.52%; RR 0.15; 95% CI 0.02 to 0.99; $p = 0.49$) repair.

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Conclusion: Our systematic review and meta-analysis support that a hernia center establishment improves postoperative outcomes data.

Systematic Review Registration: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42024522263, PROSPERO CRD42024522263.

Keywords: hernia center, ventral hernia, inguinal hernia, incisional hernia, hernia specialist

INTRODUCTION

Over the last two decades, there has been an increase in the alternatives of hernia surgery for both open and minimally invasive procedures [1]. Considering the constant emerging evidence and technologies regarding abdominal wall surgery, with novel surgical devices and techniques, it has become harder and more demanding for the general surgeon to master the new advances and manage patients using a tailored approach [1, 2]. In this regard, there has been debate concerning the need for the accreditation and certification of hernia centers, aiming to establish guideline-based practices and provide education and specialization in hernia surgical techniques to improve the quality of hernia surgery [3–5].

Despite the hernia repair being a common procedure in the general surgeon's routine, evidence suggests that the success rate of this procedure is lower when compared to a hernia specialist's or a hernia specialty center's rate [6]. Gilbert et al. [7] showed that general surgeons have a significantly higher recurrence incidence following hernia procedures. In addition, despite the scientific evidence brought by the most recent literature, general surgeons often do not follow the guidelines regarding the adoption of these new practices in their clinical approach [2, 7].

The certification process for hernia centers has been implemented by some societies and organizations worldwide, such as the German Hernia Society (GHS) along with the German Society of General and Visceral Surgery [8], and others have proposed accreditation requirements, such as the Italian Society of Hernia and Abdominal Wall Surgery [9]. Despite the definitions of hernia centers being different between the societies, their purposes consist of improving healthcare in hernia surgery by homogenizing the clinical practice and by following the guidelines in a standardized manner [10].

No previous systematic review and meta-analysis is available assessing the outcomes of hernia center facilities, therefore, we aimed to perform a systematic review and meta-analysis to compare hernia centers with non-specialized centers regarding intraoperative and postoperative outcomes.

METHODS

This meta-analysis was performed in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) Statement and recommendations from the Cochrane Collaboration Handbook for Systematic Reviews of Interventions [11]. We prospectively registered our research protocol in the International Prospective Register of Systematic Reviews (PROSPERO) (ID CRD42024522263)

Eligibility Criteria

In the qualitative systematic review, we included all studies that defined a hernia center or presented data regarding hernia center outcomes/patient characteristics. For the meta-analysis, we included studies that met all the following eligibility criteria: 1) Defined a hernia center; 2) included patients undergoing ventral hernia repair (VHR) or inguinal hernia repair (IHR); 3) compared the hernia center sample with a control group of non-specialized center or pre-quality improvement/hernia center certification. We excluded studies with 1) analysis of experience instead of the definition of a hernia center, 2) no control groups, 3) conference abstracts, 4) editorials or 5) reviews.

Search Strategy and Data Extraction

Two authors (C.S. and A.R.) independently and systematically searched PubMed, Embase, Cochrane Library, ScieLO (Scientific Electronic Library Online), and LILACS (Literatura Latino Americana em Ciencias da Saúde) from inception to 15 October 2023. The following terms were used without filters, publication date, or language restrictions: ("specialty" OR "referral centers" OR "reference units" OR "center of reference" OR "specialized surgeon" OR "specialized surgeons" OR "hernia center" OR "abdominal wall surgery center" OR "hernia specialty" OR "hernia centre" OR "hernia centers" OR "hernia centres" OR "abdominal wall surgery specialization" OR "hernia service" OR "hernia specialist" OR "hernia specialists" OR "referral center" OR "hernia referral center" OR "referral centre" OR "referral centres" OR "hernia program" OR "abdominal wall program" OR "hernia unit" OR "abdominal wall unit" OR "abdominal wall surgery unit" OR "dedicated hernia" OR "hernia dedicated") AND (hernia OR abdominal wall). The references from all included studies, previous systematic reviews, and meta-analyses were also searched manually for any additional studies. Eventual conflicts were resolved by consensus among the authors. Two authors (C.S. and A.R.) independently extracted the following data from selected studies: 1) country, 2) number of patients, 3) study design, 4) hernia center definition, and 5) year.

Quality Assessment

We evaluated the risk of bias using the Cochrane Risk of Bias Assessment Tool for Non-Randomized Studies (ROBINS-I) [12] for comparative studies, wherein each study is scored as high, moderate, or low risk of bias. The assessment was performed by two independent authors (J.K. and V.S.), and disagreements were resolved through consensus after discussing reasons for discrepancies.

Outcomes

Data was analyzed separately for inguinal and ventral hernias. Our outcomes consisted of postoperative events, such as 1)

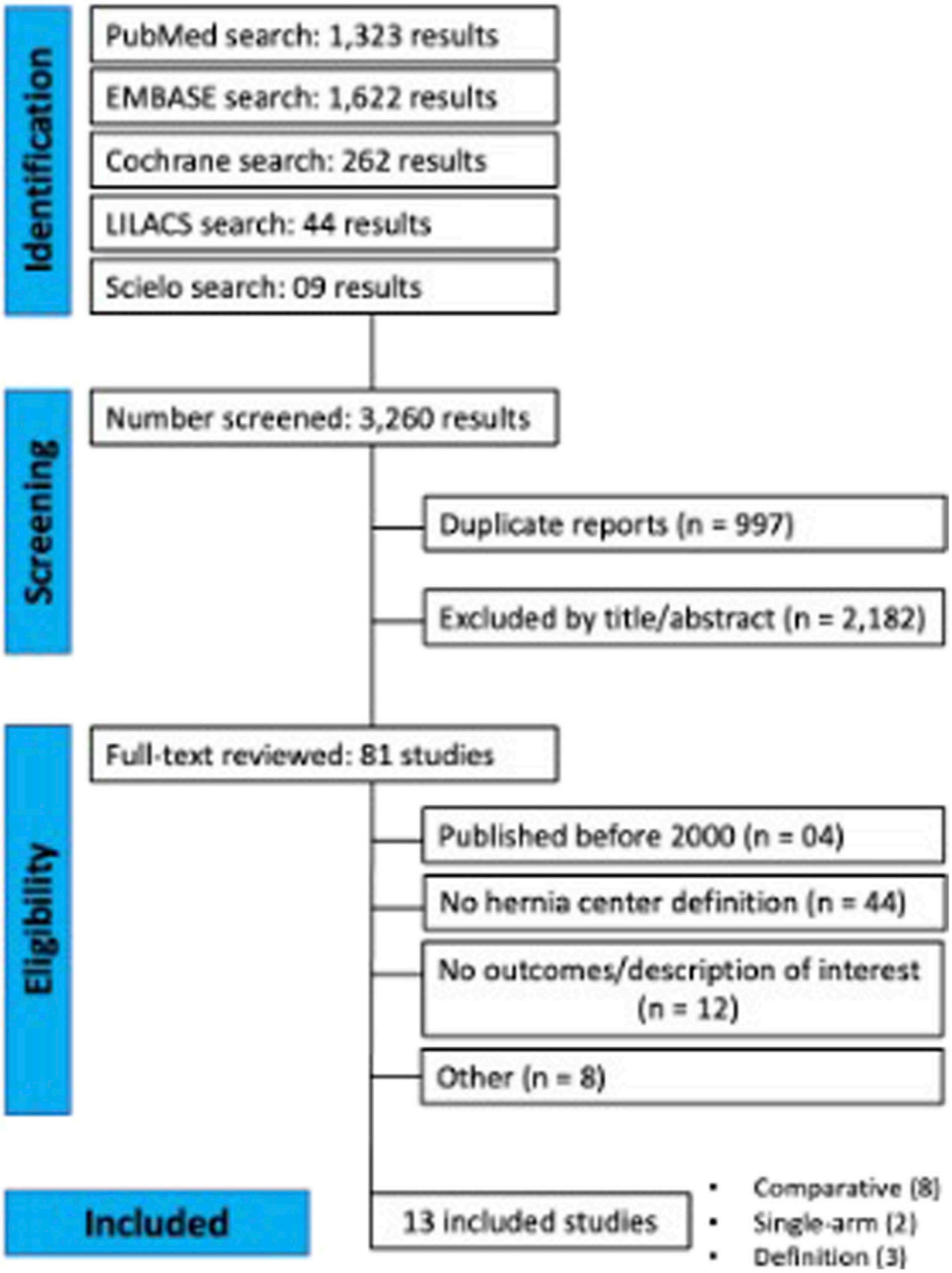

FIGURE 1 | PRISMA flowchart of selected studies.

recurrence, 2) surgical site infection (SSI), 3) seroma, 4) hematoma, 5) reoperation, and 6) mortality rates.

We also collected descriptive data regarding 1) hernia center definitions, 2) mesh use, 3) financial aspects, and 4) referral patterns before and after hernia centers' establishment.

Statistical Analysis

We computed risk ratios (RR) using the Mantel-Haenszel test for dichotomous outcomes and used 95% confidence intervals (CI) to measure effect size. We considered *p*-values of less than 0.05 to be statistically significant. We used mean differences

TABLE 1 | Characteristics of the studies included.

Author	Study type	Year	Hernia
Cheong et al [13]	Single-arm retrospective cohort	2014	Inguinal
Cherla et al [14]	Comparative retrospective cohort	2017	VHR
Haskins et al [4]	Database (ACHQC) comparative retrospective cohort	2023	VHR
Katzen et al [15]	Comparative retrospective cohort	2023	VHR
Krpata et al [5]	Comparative retrospective cohort	2016	All
Malik et al [16]	Comparative retrospective cohort	2016	Inguinal
Pereira et al [17]	Comparative retrospective cohort	2019	VHR
Rodrigues-Gonçalves et al [18]	Comparative retrospective cohort	2023	Inguinal
Willms et al [6]	Comparative retrospective cohort	2023	VHR + Inguinal
Williams et al [19]	Single-arm retrospective cohort	2014	All hernias

VHR, Ventral hernia repair; ACHQC, abdominal core health quality collaborative.

(MD) as the effect measure for continuous outcomes, with 95% CI.

To assess heterogeneity, Cochran's Q test and I^2 statistics were utilized. We classified I^2 values of <25%, 25%–75%, and >75% as representing low, moderate, and high heterogeneity, respectively. To account for potential disparities in both clinical and methodological aspects across studies, we applied the restricted maximum-likelihood estimator and random effects models for outcomes presenting with moderate to high heterogeneity. We performed sensitivity analyses using leave-one-out analysis for outcomes presenting statistically significant results with high heterogeneity. Publication bias was assessed for all the outcomes which included more than 10 studies by Egger's Test. Furthermore, we performed a funnel plot to investigate heterogeneity between study-specific estimates. Our meta-analysis used the metafor package for RStudio version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Study Selection and Characteristics

The initial search yielded 3,260 results. After removing duplicate studies, 2,263 records were identified through database searching, and their summaries were screened for eligibility. Of these, 81 remained and were fully reviewed based on predefined eligibility criteria. A total of 8 comparative studies were included, comprising 141,366 patients, of whom 81,989 (58%) were in the hernia center group (**Figure 1**). Two single-arm studies were also included for quantitative analysis. The studies' characteristics are detailed in **Table 1**.

Quality Assessment

We used the ROBINS-I tool in the risk of bias analyses for all the included studies. Five studies were rated as low risk of bias, four as having a moderate risk of bias, and one as with a serious risk of bias. Overall reasons for the risk of bias between the moderate to serious risk studies raised from confounding factors, selection of participants, classification of interventions, missing data, or measurement of outcomes. Full risk of bias analyses and specific domain rating of individual studies are presented in **Figure 2**.

Hernia Center Definition

We included three studies comprising hernia centers' definitions, including technical, structural, educational, and scientific requirements for a hernia center certification according to the European Hernia Society (EHS) [10], the German Hernia Society [8], and the Italian Hernia Society [9]. Almost all societies divide the process into steps of specialization until the unit reaches the classification of reference or highly specialized center. Both the Italian and German Hernia Society divide the specialization into three steps, while the EHS society used non-specific divisions. The most common requirements for all three societies are focused on the number of specialists available, structural aspects, including intensive care unit, outpatient clinic, and material for minimally invasive surgery, and also updated with training, including attending scientific meetings yearly. Full specialization requirements are available in **Table 2**.

Furthermore, there are specific criteria used for hernia center definition by the German and Italian Hernia Society which were based on the center's annual caseload and a maximum complication rates cutline. In this regard, for the German Hernia Society, the unit needs to present a total of 250 hernia repairs per year, comprising at least 50 incisional hernia repairs, 5 complex hernias, and 5 hiatal hernias. On the other hand, the Italian Society requires a minimum of 150 inguinal hernia repairs, comprising 30 complex cases, and a minimum of 50 abdominal wall reconstructions, comprising 20 complex cases yearly. Concerning postoperative complication rates, both societies analyzed maximum surgical site infection rates depending on hernia type and surgical approach. Also, there were specific criteria used by each society regarding recurrence and other postoperative complication rates, such as chronic pain and mortality. Full postoperative complication and annual caseload requirements are available in **Table 3**.

Among the comparative studies included, two analyzed IHR only, four studies analyzed VHR, one analyzed both IHR and VHR separately, and one analyzed both IHR and VHR together.

Ventral Hernia Repair

Three studies analyzed recurrence rates for VHR. We found lower recurrence rates for surgeries performed in hernia centers (3.2% vs. 8.9%; RR 0.425; 95% CI 0.28 to 0.64; $p < 0.001$; $I^2 = 7\%$; **Figure 3**). Leave-one-out sensitivity analysis showed no differences in heterogeneity reduction or loss of significance.

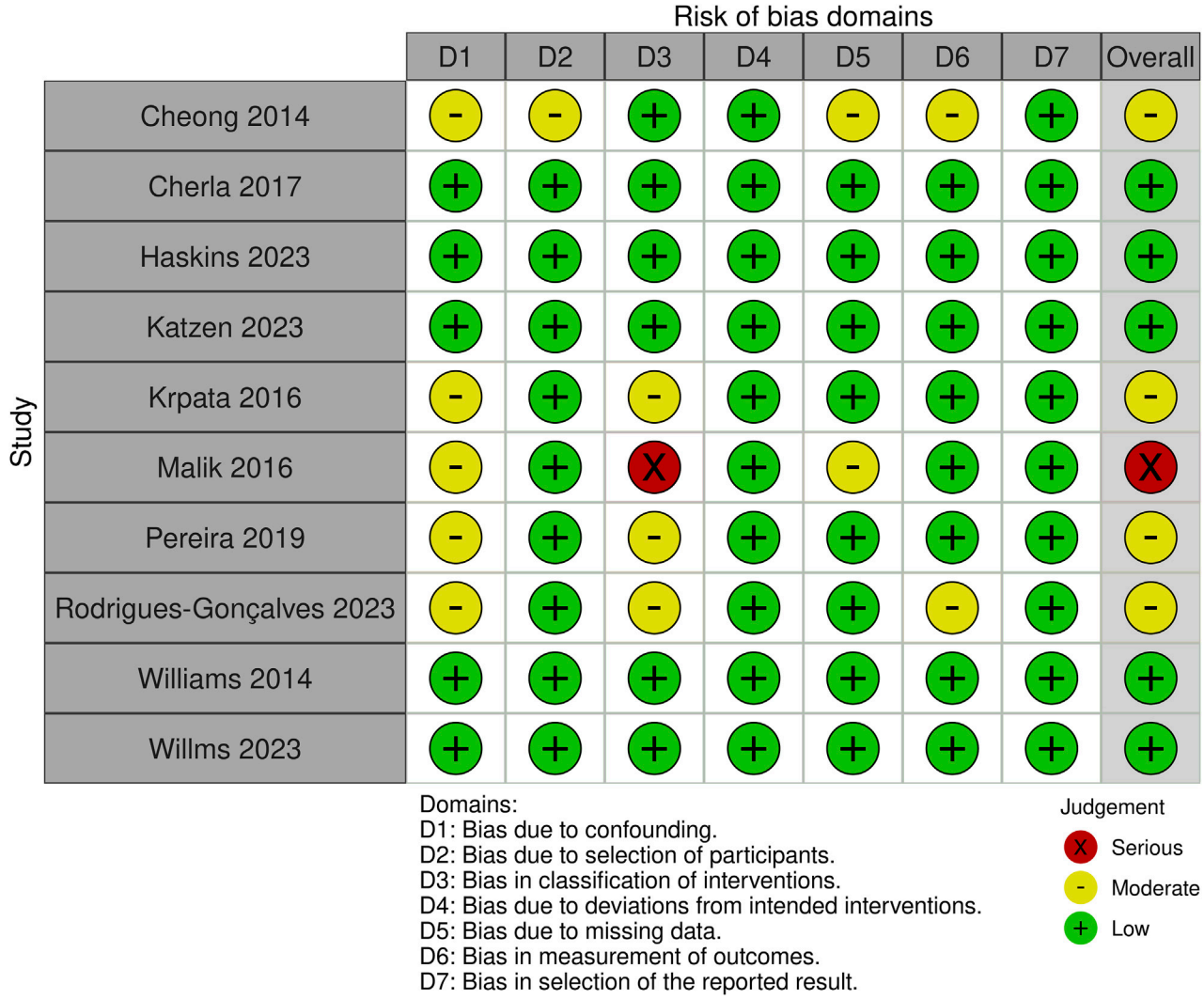

FIGURE 2 | Risk of bias of included studies.

However, no statistically significant differences were found in reoperation rates between the groups in the analysis with three studies (1.3% vs. 1.4%; RR 0.68; 95% CI 0.33 to 1.40; p = 0.3; I^2 = 47%).

SSI following VHR was analyzed by four studies. Specialized hernia centers presented a lower SSI rate following VHR (4.3% vs. 11.9%; RR 0.435; 95% CI 0.21 to 0.90; p = 0.026; I^2 = 61%; **Figure 4**). Leave-one-out sensitivity analysis showed no differences in heterogeneity reduction or loss of significance.

We analyzed seroma rates with three available included studies. No statistically significant differences were found between the groups (9% vs. 10.9%; RR 0.81; 95% CI 0.64 to 1.04; p = 0.098; I^2 = 0%). Also, we found no differences between the groups in hematoma rates (0.79% vs. 0.95%; RR 0.53; 95% CI 0.16 to 1.68; p = 0.29). The statistical significance did not change after the leave-one-out sensitivity analyses of both seroma and hematoma rates.

Only two studies analyzed mortality rates. We found a reduction in mortality for specialized hernia centers (0.72% vs. 1.66%; RR 0.49; 95% CI 0.29 to 0.85; p = 0.01; I^2 = 0%; **Figure 5**).

Inguinal Hernia Repair

Recurrence rates after IHR were analyzed by two studies. The pooled analysis showed a lower recurrence for hernia centers (1.08% vs. 5.11%; RR 0.21; 95% CI 0.19 to 0.23; $p < 0.001$; I^2 = 0%; **Figure 3**). Also, we found that the effect of hernia centers on recurrence reduction for IHR was even more impactful compared to VHR (Test for subgroup differences $p < 0.01$; **Figure 3**).

Two studies analyzed SSI rates for IHR. Our analysis showed a reduction in SSI for specialized hernia centers (0.1% vs. 0.52%; RR 0.15; 95% CI 0.02 to 0.99; p = 0.49; I^2 = 0%; **Figure 4**).

Also, we found a significant reduction in hematoma rates for specialized centers (RR 0.365; 95% CI 0.2 to 0.68; p = 0.001; I^2 = 0%; **Figure 6**). No statistically significant difference was found in

TABLE 2 | Hernia center definitions.

Study	Steps	Specialized surgeons	Structural aspects	Decision-making	Education and science	Data management
ACCESS Project, 2019 (Europe—EHS)	Certification levels and requirements to upgrade to a high level	Experienced surgeons meeting annual caseload and conference requirements	QI conferences; diagnostic tools (CT, MRI); MIS equipment ICU.	Current scientific recommendations	Staff responsible for science, education, and training programs	Cases register prospectively in a registry or quality database
Stabilini, 2018 (Italy)	(A)First level (Single surgeon)	(A)General surgeon + Minimum learning curve for all procedures and minimum year caseload	—	Current scientific recommendations	—	—
	(B) Referral centers (at least 2 surgeons)	(B) Minimum 1 year after "A" + Members of the society, with a minimum year caseload + Plastic surgeon available	(B) Outpatient clinic Emergency service ICU Transfusion center Diagnostic (CT, Laboratory) Advanced wound management	Current scientific recommendations	(B)Training site for the Italian School + Provide data + Attend to 3 meetings/ workshops yearly + EHS meeting each 2 years	—
	(C) Highly specialized (at least 2 board surgeons and a fellow surgeon)	(C) Minimum 1 year after "B" + Formal research assigned surgeon fellow, PhD or resident	(C) Same as "B"	Current scientific recommendations	(C) Yearly: Organize 1 course + 2 of the following: 1 publication or collaborative trial organization or EHS meeting participation or research on new technologies	—
Köckerling, 2014 (Germany)	(A) Seal of participation in a society-registered database (3 years minimum)	(A) Surgeons must be full members of the German and European Hernia Societies	—	Current scientific recommendations	—	(A) Cases registered in the Herniamed Registry (60% follow-up data in 3 years)
	(B) Competence center (minimum 1 year of the seal of participation)	(B) "A" requirements + At least 1 meeting/ conference yearly	(B) Monthly QI conferences; Special consultations weekly for the patients; Postoperative pain regimen protocol	Current scientific recommendations	—	(B) All "A" requirements + 1-year follow-up for 60% of the patients
	(C) Reference center (minimum 2 years of competence center)	(C)All "B" requirements + Plastic surgeon available	(C) All "B" requirements + Facilities to perform all laparoscopic procedures	Current scientific recommendations	(C) Education seminars and guest visits credited by medical board + 2 publications or presentations at meetings	(C) All the previous requirements

EHS, European hernia society; QI, quality improvement; CT, computerized tomography; MRI, magnetic resonance imaging; MIS, minimally invasive surgery; ICU, intensive care unit.

seroma rates between the groups (RR 0.367; 95% CI 0.034 to 3.965; $p = 0.41$; $I^2 = 84\%$).

DISCUSSION

In this comprehensive systematic review and meta-analysis comprising 141,366 patients, we found that specialized hernia centers were associated with a lower recurrence and lower SSI for both IHR and VHR. Also, specialized centers presented lower mortality rates for VHR and a reduced hematoma incidence for IHR. No differences were seen regarding seroma and reoperation rates for both IHR and VHR.

The first centers dedicated to hernia surgery emerged in the 1980s, with a common focus on standardizing surgical techniques for better patient treatment [20]. Since then, despite the interest in establishing specialized centers, societies criticized hospitals for self-claiming specialized hernia centers without specific criteria

TABLE 3 | Minimum procedural volume and maximum complication rates requirements for a hernia center.

Study	Steps	Learning curve	Minimum volume (per year)	Maximum complication rates					
				Recurrence (1 year)	Reoperation	Mortality	General complications (%)	Infection (%)	Chronic pain
Köckerling, 2014 (Germany)	(A) Seal of participation in a society-registered database	—	30 hernia patients/year	—	Inguinal: <2% Incisional: <10%	—	Inguinal: <5	Open incisional: <10 Laparoscopic Incisional: <3	—
	(B) Competence center	—	200 hernia operations/year (30 incisional)						
	(C)Reference center	—	250 hernia operations/year (50 incisional; 5 complex; 5 hiatal)						
Stabilini, 2018 (Italy)	(A) First level (Single surgeon)	120 Inguinal Hernias (60 MIS and 60 open) 40 AWR (20 MIS and 20 open)	50 Inguinal Hernias (25 MIS and 25 open) 50 AWR (25 MIS and 25 open)	Inguinal: <2% AWR: <5% Complex AWR: <10%	—	Inguinal: <0.5% AWR: <1% Complex AWR: <5%	Inguinal: <10 AWR: <30 Complex AWR: <50	Inguinal: <3 AWR: <10 Complex AWR: <30	Inguinal: <15%
	(B) Referral centers	—	100 Inguinal Hernia 50 AWR (10 complex cases)						
	(C) Highly specialized centers	—	150 Inguinal Hernia (20 complex cases) 50 AWR (20 complex cases)						

MIS, Minimally invasive surgery; AWR, abdominal wall reconstruction.

for such a definition [8]. In 2014, aiming to address this issue, the German Hernia Society proposed the creation of a pathway for considering a center as specialized in hernias, focusing on postoperative outcomes [8]. Our review highlighted the status of the literature regarding definitions of what constitutes a specialized hernia center. Despite divergences among societies, there are common features among them, focusing on prospective data registration, regular participation in annual meetings, availability of advanced technology encompassing the latest hernia surgical techniques and support for complications, as well as a minimum annual caseload, and most importantly, expected annual complication rates. In terms of the complexity of annually operated cases, societies recommend that 10%–20% of the total annual ventral hernias operated be considered complex hernias [8, 9], according to the complexity definition proposed by Slater et al [21]. In this sense, the hernia center should serve as a reference center, where patients with complicated conditions have optimal access to technology and skilled surgeons for their care [22, 23].

To achieve those results, establishing cutoffs for outcomes such as recurrence rates becomes necessary. Our pooled analysis found reduced recurrence rates for specialized centers, with 3.2% and 1.08%, compared to 8.9% and 5.11% recurrence incidence for non-specialized centers, for VHR and IHR, respectively. This is an important quality marker to support the complications cutoff establishment for hernia center definition. The Italian society recommends a recurrence rate of less than 2% for inguinal, 5% in 1 year, and less than 15% in 3 years for ventral hernia repair, which is consistent with our findings [9]. Furthermore, in their definition, it is described specific cutoffs for complex cases. This definition is crucial as it encompasses the previous requirement of the minimum annual caseload of complex surgeries, being the complications cutoff grounded in the contemporary literature on complications associated with complex and non-complex cases separately. That definition is particularly vital post-establishment of the unit as a reference center. Individual studies have shown that the admitted patient profile becomes more complex with the establishment of a specialized center, attracting patients from greater distances [22, 23], making it imperative to stratify the expected complication rates based on the complexity of each case.

Parallel to recurrence rates, the hernia center's SSI cutoffs are also important postoperative quality markers, as increased

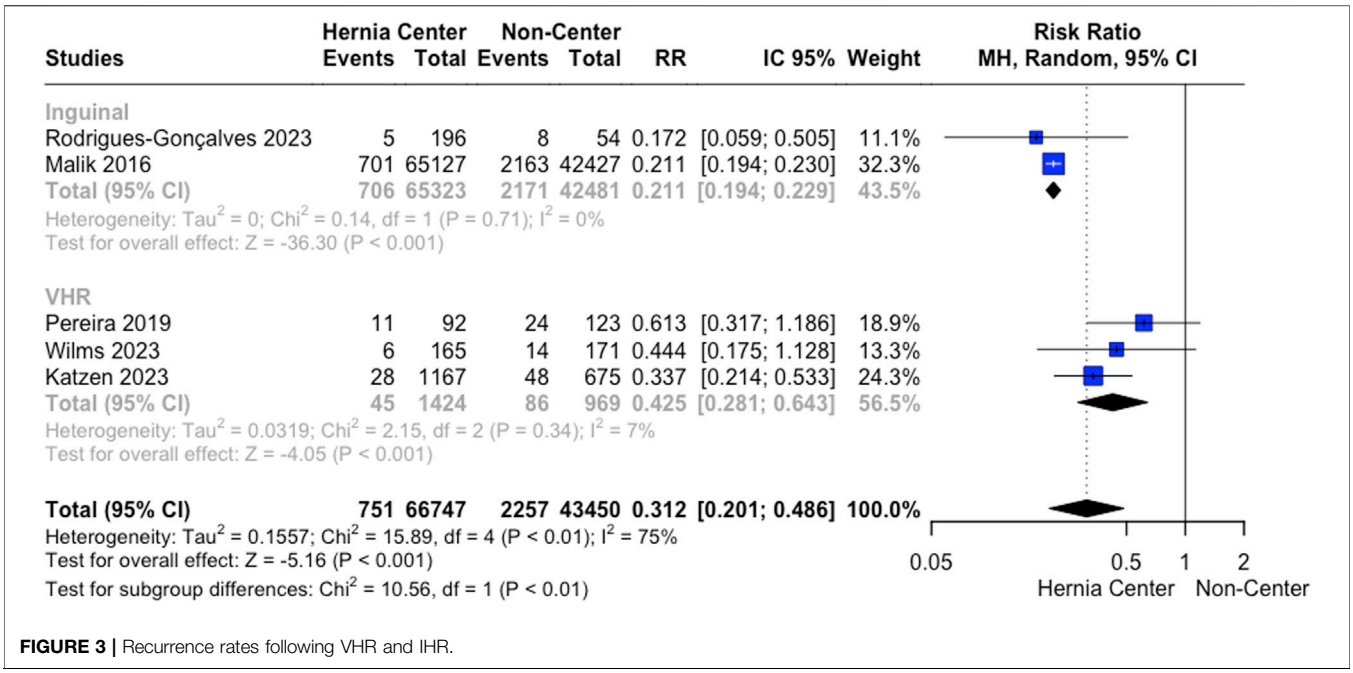

FIGURE 3 | Recurrence rates following VHR and IHR.

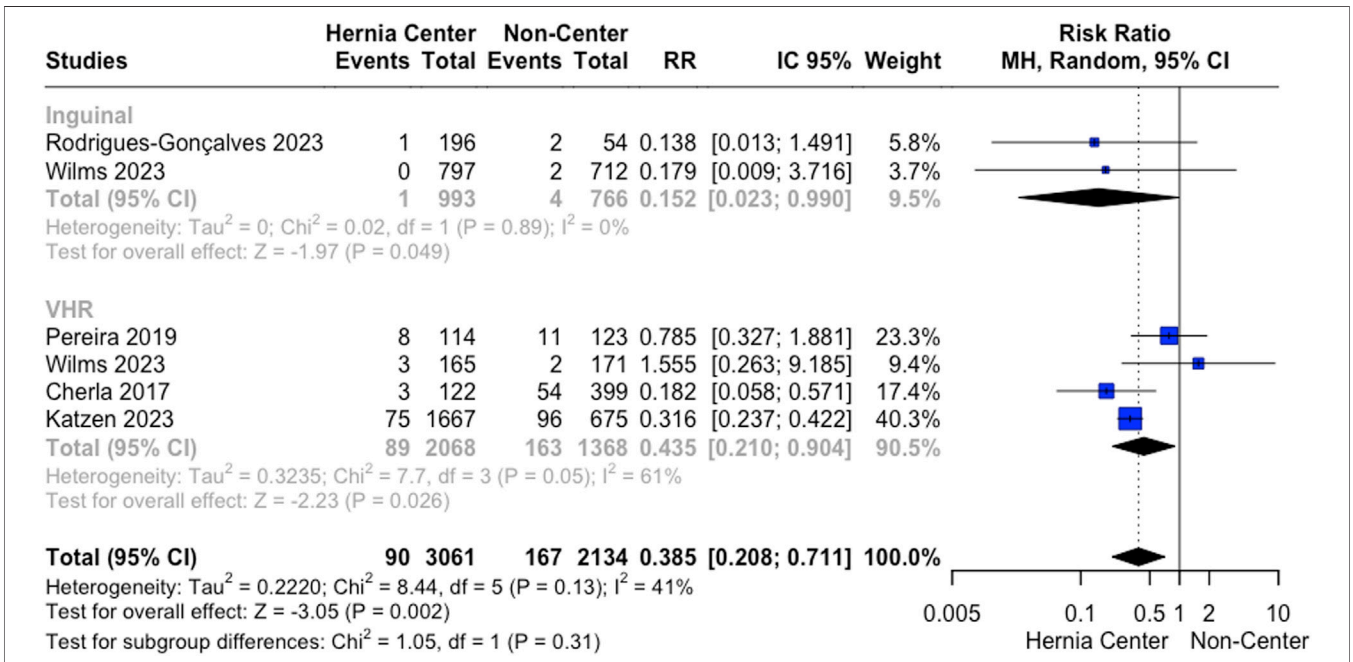

FIGURE 4 | A. Surgical site infection rates following VHR and IHR.

infection rates are directly related to recurrence, increased length of hospital stay, and overall morbidity, especially in complex cases [14, 24, 25]. We found an increased SSI for non-specialized centers, while the pooled analysis of specialized hernia centers showed rates of 4.3% and 0.1% of SSI for VHR and IHR, respectively. Between the hernia center pathways guidelines, established cutoffs for SSI only for ventral hernia repair, which are defined as less than 10% as a consensus, and as less than 30% for complex cases [8, 9]. In addition, it is expected that a specialized hernia center presents less than 1% of mortality rates for VHR. We found a mortality rate of 0.72% for hernia centers, compared to 1.66% for non-specialized centers, also supporting guidelines recommendations.

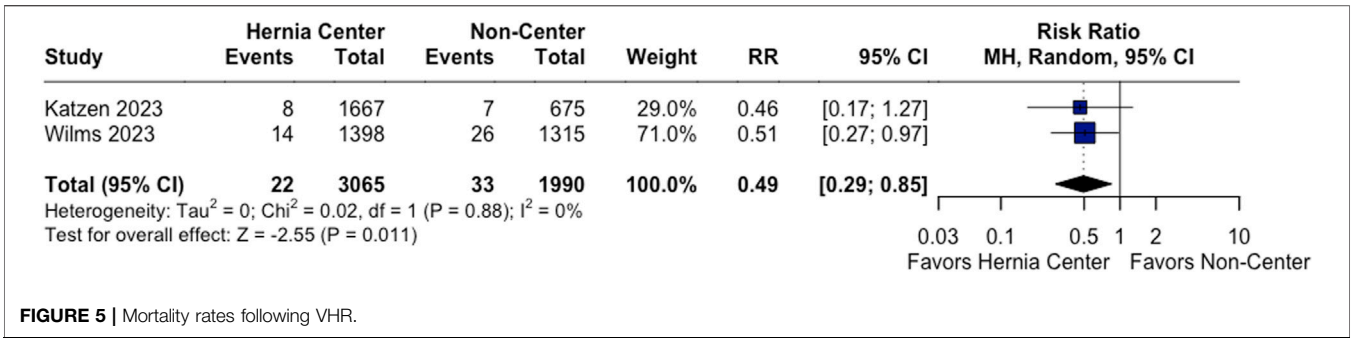

FIGURE 5 | Mortality rates following VHR.

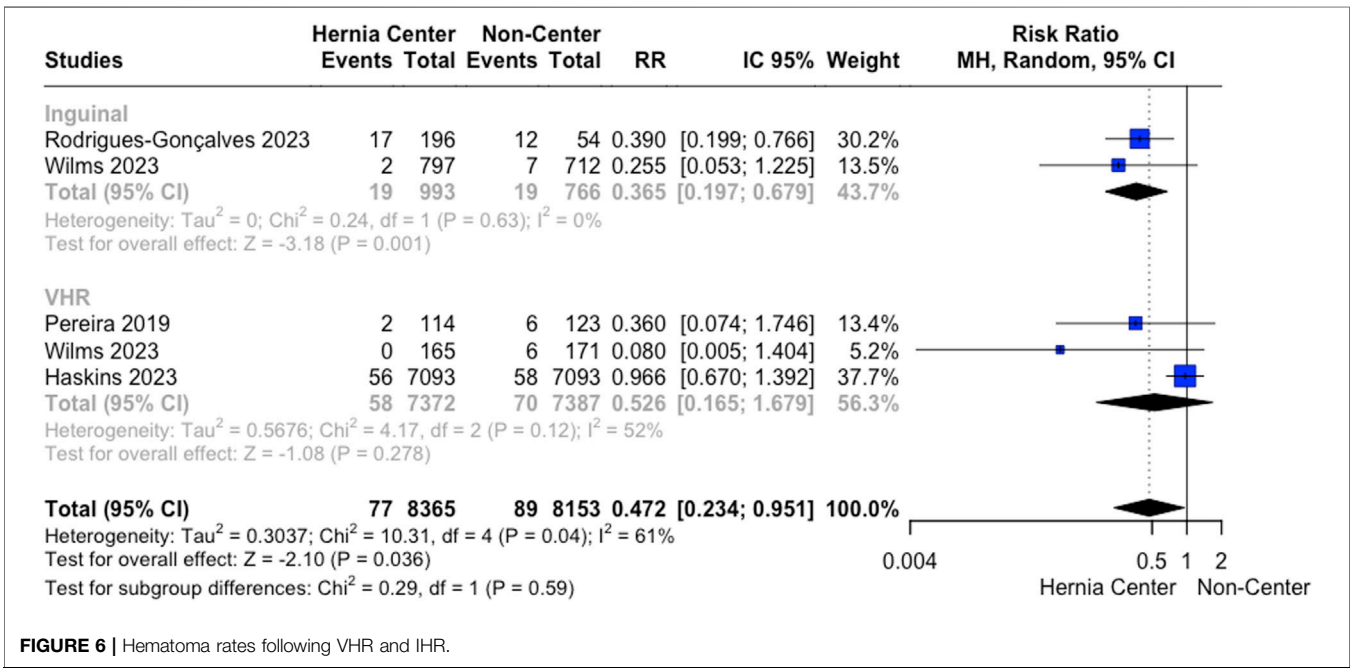

FIGURE 6 | Hematoma rates following VHR and IHR.

Furthermore, it is important to highlight that the process of becoming a specialized hernia center needs to be based on steps. In addition to societies, individual studies propose pathways for establishing a specialized hernia surgery center. Smith et al [3], in this context, dissect the structure and distribution of a hernia-based service, suggesting that it should involve the reception of referred patients, with clinical and imaging evaluation, proper preoperative optimization, as well as adequate follow-up for necessary patient feedback. Current evidence suggests that this longitudinal process, including preoperative adequate management, reduces postoperative complications, and may be a part of the hernia center establishment criteria [26–29]. Despite adjustments for baseline comorbidities, hernia complexity, and intraoperative complications, our findings of reduced complications for hernia centers may be justified by evidence-based decision-making, including the listed preoperative optimization and choice of adequate surgical techniques by trained surgeons. However, a national profile study conducted by Shulkin et al showed that among hernia center surgeons, only 3.3% are hernia board certified [23]. This finding highlights the importance of not only the academic title but also the experience and annual caseload of the surgeons as an expertise parameter.

Finally, it is important to highlight our analysis limitations. First, it is important to highlight that all hernia center literature was written by authors from hernia centers, which can generate bias associated with the complexity of the cases operated on, as well as the technical capability of these surgeons. Also, the definitions of hernia center were very heterogeneous between the studies. However, we tried to control and share specific heterogeneity by providing Cochran's Q test and I^2 statistics for each outcome analyzed. Furthermore, almost all included studies did not present separate data according to the surgical technique and approach (minimally invasive or open), so a subgroup analysis of those groups was not available. However, we believe that the results found on overall analyses would be similar for individual technique and surgical approach results, demonstrating hernia center's fewer complications compared to non-specialized centers. Also, our qualitative analysis evidenced some studies as presenting a moderate and serious risk of bias, which also limits our data extrapolation. However, we made a comprehensive analysis including all clinical studies available on

the topic, providing the only pooled analysis on this topic in the current literature.

CONCLUSION

Our systematic review and meta-analysis support that hernia center establishment improves postoperative outcomes data for both inguinal and ventral hernia repair. We found lower recurrence, SSI, and hematoma rates for hernia centers compared to non-specialized centers. These findings highlight the potential of standardized and guideline-based interventions to improve patient outcomes and justify their consideration as an aim of future hernia societies' discussions and establishment.

AUTHOR CONTRIBUTIONS

CS, AR, DL, RN, VS, JK, LC, PS, and FM worked equally in writing, editing the manuscript and performing statistical analysis. FM was the principal investigator. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

PUBLISHER'S NOTE

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CASE REPORT
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Case Report: Robotic Repair of a Perineal Hernia Following Abdominoperineal Resection

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Introduction: Perineal hernias, protrusions through the pelvic diaphragm, are a rare complication post-abdominoperineal resection. The shift to extralevator APR techniques could be linked to a potential increase in these hernias. This case series evaluates the surgical management of perineal hernias, focusing on the evolving role of robotic surgery. Given the limited existing research on robotic repairs in this context, it highlights its potential as an innovative approach.

Presentation of Case: In a case series, we report three patients who underwent robotic abdominoperineal resection (APR) for rectal and anal canal carcinoma after neoadjuvant chemoradiation. The 65-year-old female developed a perineal hernia 7 months post-operatively, the 67-year-old male after 4 years, and the 63-year-old female presented with a recurrent perineal hernia post-APR with gracilis flap reconstruction. All patients underwent successful robotic hernia repairs with mesh placement and demonstrated symptomatic improvement post-operatively.

Discussion: Perineal hernia management lacks a standardized protocol, with methods ranging from open to laparoscopic techniques. A review of recent literature suggests increasing favorability towards laparoscopic and robotic approaches due to their less invasive nature. Our cases demonstrate the advantages of robotic surgery's precision and improved visualization, supporting its use in perineal hernia repair, although more research is needed to confirm.

Conclusion: Robotic-assisted surgery for perineal hernia repair post-APR shows promise, enhancing the benefits of laparoscopic methods. This series underlines the potential of this approach, though further investigation in larger studies is essential to establish its advantages.

Keywords: perineal hernia, robotic surgery, rectal cancer, abdominoperineal excision, extralevator abdominoperineal excision

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INTRODUCTION

Perineal hernias can be defined as the protrusion of intraperitoneal or extraperitoneal contents through a congenital or acquired defect of the pelvic diaphragm into the perineum [1]. The occurrence of post-operative perineal hernia after abdominoperineal resection (APR) is rare, with incidence reported below 1% [2]. However, a growing body of evidence suggests its true incidence

may be higher because of under-reporting and technical updates. In general, perineal hernias proceed asymptomatically, which, unfortunately, results in a large number of unreported cases [3]. Additionally, there is concern that the rate may be increasing due to the growing popularity of extra levator APR, which, despite its oncological advantages, may lead to more significant pelvic defects and, subsequently, higher rates of hernia occurrence [4, 5]. Two larger studies by West et al. and Sayers et al. reviewed the frequency of perineal hernias post-extra levator abdominoperineal excision (eAPR). They reported frequencies of 2.8% and 26%, respectively, highlighting the variability of reported incidences [6, 7].

The scarcity of perineal hernias has limited the scope of large-scale studies, leaving the majority of treatment guidelines to be derived from case reports and small series. Asymptomatic perineal hernias are often managed conservatively; however, when symptomatic, presenting with discomfort, bulging, or complications such as urinary dysfunction, intestinal obstruction, or skin erosion, surgical intervention becomes necessary [5].

Recent literature has increasingly examined the merits of laparoscopic versus open-surgical approaches for perineal hernia repair. This case series contributes to the discussion by summarizing the advantages of laparoscopic techniques and exploring their integration with robotic surgery. Three cases of perineal hernia repairs performed post-APR between 2020 and 2024 were included in this series. The report delves into the shared benefits and distinct strengths of robotic surgery in pelvic procedures and hernia repairs, applying these insights to perineal hernia management. Notably, the literature reveals only two prior cases of robotic repair post-APR, underscoring the novelty and potential of this approach [8, 9].

CASE PRESENTATION

Case 1

A 65-year-old woman with a history of malnutrition and smoking presented to the clinic to discuss the surgical resection of her rectal cancer. She had completed neoadjuvant chemoradiation prior to her visit. The case was deliberated with the referring oncologist, and after thorough discussions with the patient and her family, it was decided to proceed with robotic abdominoperineal resection (APR). The surgery was executed without intraoperative complications, and subsequent pathology revealed a T2 tumor invading the muscularis propria with clear resection margins.

Seven months post-APR, the patient reported a tender, fluid-filled swelling at the perineal closure site. Physical examination revealed a cystic fluid collection and surgical drainage was recommended. A non-diagnostic CT scan was conducted, and the patient consented to the surgical drainage procedure. Amber fluid was evacuated, the area was examined for further abnormalities, and the site was closed.

Approximately 1 year after the APR, the patient complained of a painful bulging in her perineum that improved when lying down but worsened upon standing or moving. She specifically noted that she could feel her intestines descend into the hernia sac, and she was manually able to reduce the hernia with pressure. A CT scan with oral and IV contrast was performed to distinguish between a perineal hernia and seroma. The imaging confirmed a perineal hernia with incarcerated small bowel and omentum. She was counseled about her diagnosis and treatment options, and she opted for robotic perineal hernia repair with mesh insertion (**Figure 1A**).

The patient underwent general anesthesia and was placed in the lithotomy position. Abdominal access was achieved via the Hasson technique in the right upper quadrant, and pneumoperitoneum was established. The camera was then introduced into the abdomen. 8mm trocars were placed in the upper quadrants bilaterally, followed by placement of a 12 mm trocar into the right upper quadrant, and the perineal hernia was identified containing small bowel and omentum. The contents were reduced, and adhesiolysis was performed to free adhesions. The hernia defect was sutured closed with a running 2-0 V-Lock stitch. A 4.5-inch Sepramesh IP Composite polypropylene mesh was selected and secured over the defect using a running 2-0 V-Lock suture. Absorbable tacks were used for additional mesh anchoring. Post-reduction, the abdomen was inspected, ports were removed, and the pneumoperitoneum was released. The incisions were closed with a 4-0 Monocryl in a subcuticular pattern. Postoperatively, the Early Recovery After Surgery (ERAS) protocol was followed to manage the patient's pain, advance her diet, and encourage early ambulation prior to discharge. One month after surgery, the patient reported gradual pain relief and complete resolution of the perineal sliding and bulging symptoms. Imaging performed at the 1-month follow-up confirmed that the hernia repair was successful (**Figure 1B**). The patient was then evaluated at 2 months, 6 months, and 1 year postoperatively, with imaging performed at the 1-year visit to assess for recurrence (**Figure 1C**).

Case 2

A 67-year-old male initially presented to the gastroenterology clinic with rectal bleeding and concerns of hemorrhoids. A subsequent examination revealed a 6 cm rectal tumor, prompting a referral for surgical evaluation. At that time, his carcinoembryonic antigen (CEA) level was less than 1, and a CT scan indicated no metastasis. An MRI of the pelvis showed a low-lying rectal tumor with a cranio-caudal extent of approximately 4.4 cm. Following neoadjuvant chemoradiation, the patient underwent a robotic abdominoperineal resection (APR) due to the tumor's proximity to the anal area.

The operation proceeded without intraoperative complications, and pathology confirmed a T3N2M0 tumor extending through the muscularis propria into the perirectal fat. There was no involvement of the anal sphincters or mesorectal fascia, and clear margins were achieved. Later in the same month, the patient developed a perianal abscess, necessitating wound debridement. Two years post-operatively, a parastomal hernia presented as a large bulge at the ostomy site.

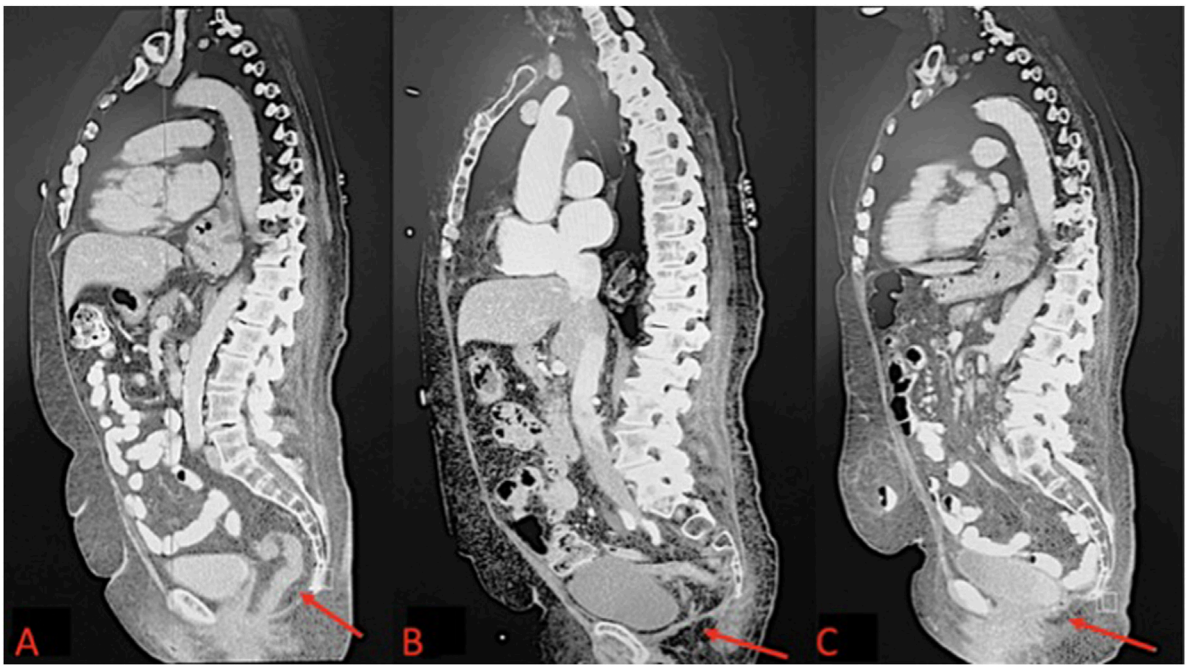

FIGURE 1 | (A) Pre-operative CT scan of perineal hernia (red arrow); **(B)** One month post-operative CT image showing surgical correction of perineal hernia; **(C)** One year post-operative CT Image.

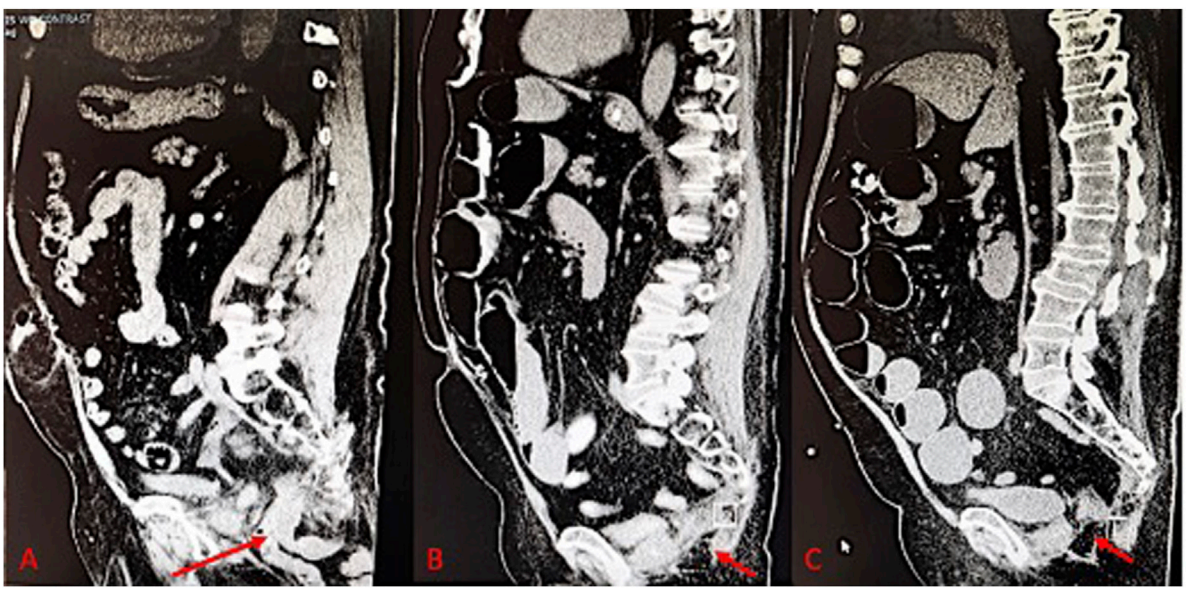

FIGURE 2 | (A) Pre-operative CT scan of perineal hernia (red arrow); **(B)** One month post-operative CT image showing surgical correction of perineal hernia; **(C)** One year post-operative CT Image.

The hernia was successfully repaired using robotic-assisted mesh placement.

Four years after the APR, the patient experienced perineal swelling diagnosed as a perineal hernia, accompanied by a sensation of visceral prolapse and the ability to reduce the herniation manually (**Figure 2A**). A laparoscopic robotic-assisted repair was performed. Under general anesthesia, in the prone position, an incision was made over the prior

perineal scar, and dissection revealed a hernia sac from which multiple loops of small bowel were reduced. The 5 cm × 5 cm defect was repaired with a 12 cm round Ventralex mesh, secured with PDS sutures, and the site was drained from the upper gluteal region. The closure included interrupted Vicryl sutures, a running 4-0 Monocryl, and a Dermabond dressing.

The patient was repositioned from prone to supine, allowing for mid-abdominal access through the rectus muscle, where a balloon trocar was placed for CO_2 insufflation. Camera inspection identified adhesions to the prior mesh. After adhesiolysis and bowel reduction, two additional robotic trocars facilitated the docking of the robot. The mesh was secured to the peritoneum with 2-0 V-Loc sutures, and the fascia and skin were closed with 0 Vicryl and 4-0 Monocryl, respectively. Postoperatively, the ERAS protocol was followed to manage the patient's pain, advance his diet, and encourage early ambulation prior to discharge. One month after surgery, the patient reported gradual pain relief and resolution of the hernia-related symptoms. A CT of the abdomen and pelvis was performed at the 1-month follow-up to confirm the successful repair of the perineal hernia (**Figure 2B**). The patient was then evaluated at 2 months, 6 months, and 1 year postoperatively, with imaging performed at the 1-year visit to assess for recurrence (**Figure 2C**).

Case 3

A 63-year-old female with a significant medical history of anal canal carcinoma initially treated with chemoradiation and robotic-assisted abdominoperineal resection with gracilis flap reconstruction presented for surgical evaluation. She has a history of hyperthyroidism, malignant neoplasm of the anal canal, and obesity. The patient also had advanced squamous cell carcinoma (SCC) of the anus following the Nigro protocol with radiation therapy and chemotherapy. Complications included a local recurrence leading to a malignant rectovaginal fistula, requiring resection and post-operative challenges such as recurrent urinary tract infections, radiation cystitis, and urethral stricture. Subsequent surgical interventions included a repair of the pelvic floor hernia and presentations of incisional and parastomal hernias.

The patient underwent a perineal hernia repair via a transperineal approach. Entry into the presacral space revealed bowel and omentum, which were reduced and resected, respectively. A pelvic defect was identified, partially obstructed by the uterus anteriorly. It was closed by securing a mesh from the coccyx to the top of the uterus, reinforced by an additional layer before multiple-layer pelvic soft tissue closure.

She underwent a diverting sigmoid ostomy followed by APR surgery for a recurrence. She completed additional chemoradiation and was on Eliquis for a left femoral vein DVT. Recurrent UTIs and persistent perineal hernia pain, rated at 5/10 in severity, were also noted. The hernia's size remained stable and was reducible with position changes (**Figure 3A**).

She had an open perineal hernia repair with mesh placement, partial omentectomy, and adhesiolysis. Despite these efforts, imaging later revealed a parastomal hernia with associated complications. The hernia had recurred, prompting further assessment and surgical planning. The most recent surgical intervention involved extensive adhesiolysis and hernia repair with a 15 cm × 12 cm Ventralight mesh placement via a robotic anterior approach. A distal appendiceal mass, suggestive of a mucinous neoplasm, warranted an appendectomy. The operative course included repositioning to prone for excision of the hernia sac and drainage of the perineal space, with meticulous attention to hemostasis and closure. She developed paralytic ileus postoperatively with nausea and vomiting, requiring NG decompression. Her diet was gradually advanced, and she tolerated regular food. Following the ERAS protocols, her Foley catheter and NG tube were removed, and her pain was well controlled. After successful ambulation and clearance by PT, she was deemed stable for discharge 7 days post operatively.

At her 1-month post-operative follow-up, she reported no significant complaints other than pain while sitting, which she felt was manageable. Examination of the perineal incision revealed appropriate healing and the presence of subcutaneous fluid collection, consistent with an expected seroma (**Figure 3B**). Stitches were removed without complications. Patient was seen at 2 months and 6 months post operatively with 1 year follow up scheduled.

Patient Perspective

The three patients in this case series provided their perspectives on the treatments they received, highlighting various outcomes and levels of satisfaction. Patient 1 reported doing well, expressing happiness with the surgery and no longer experiencing the bulging sensation while sitting. Patient 2 mentioned overall improvement but continued to experience perineal swelling due to the hernia, though the ostomy was functioning appropriately, and they denied any pain. Patient 3 had no significant complaints, aside from some pain while sitting, and felt that their bottom was intact. They also denied experiencing fevers, chills, or night sweats and overall felt well, with a functioning ostomy. Each patient signed consent forms prior to their procedures, agreeing to have their cases documented or presented.

DISCUSSION

Perineal hernia represents a complex post-operative complication following abdominoperineal resection (APR) and continues to pose a challenge for surgeons. While the incidence of perineal hernia post-APR is traditionally considered to be low, specifically under 1%, recent evidence suggests that this figure is an underestimate [2]. Surgical management of rectal carcinoma has evolved in recent years towards minimally invasive techniques, such as the extralevator abdominoperineal excision, which involves the removal of the entire pelvic floor muscle complex. Additionally, neoadjuvant and adjuvant chemotherapy are becoming more common [10]. These modifications to treatments collectively provide an improved oncological outcome; however, these changes could also contribute to an increased incidence of perineal hernias [6].

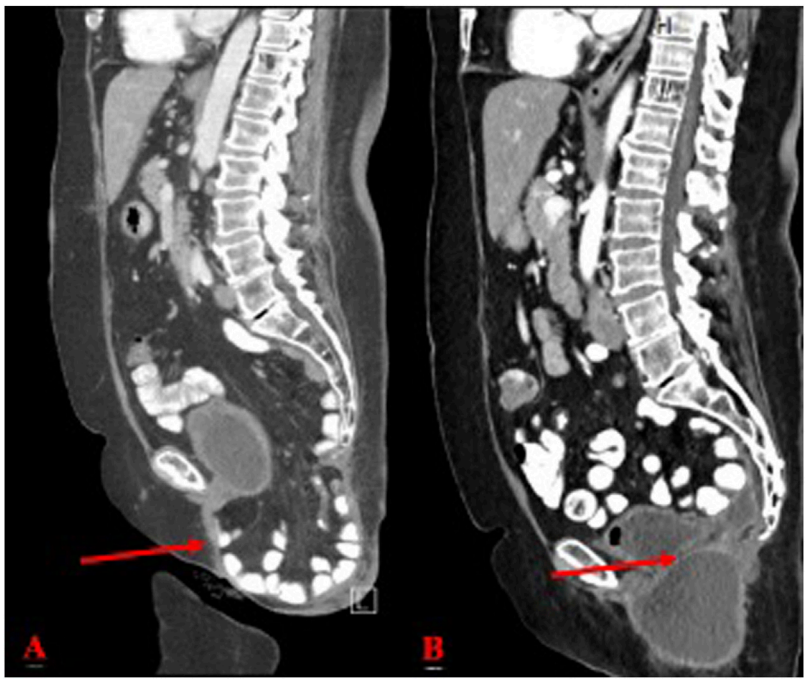

FIGURE 3 | (A) Pre-operative CT scan of perineal hernia (red arrow); **(B)** One month post-operative CT image showing surgical correction of perineal hernia.

Surgical modifications have led to a greater likelihood of the small intestine descending into the pelvic region. This has been reflected in the reported incidence of post-APR perineal hernias, which some studies suggest is between 2.8% and 26%. However, the actual rate may be even higher due to the underreporting of minor and asymptomatic hernias [6, 7]. Factors implicated in this increased incidence include the creation of larger pelvic floor defects, necessitating reliance on the weaker ischioanal fat and skin for defect closure, and a diminished rate of post-operative adhesion formation. Additional risk factors identified in the literature for perineal hernia include post-operative wound infection, pelvic radiotherapy, female gender, and obesity [3].

The surgical management of perineal hernias lacks a consensus regarding the optimal approach. Current approaches for hernia closure include open surgery with perineal, abdominal, or combined techniques and laparoscopic surgery with an abdominal approach. A systematic review of 30 studies, spanning a decade from 2012 to 2022, reveals various practices in addressing perineal hernia repairs. The laparoscopic method was employed in 36.7% of cases, open abdominal in 16.7%, a combined abdominoperineal technique in 26.7%, a strictly perineal approach in 13.3%, and a robot-assisted abdominal approach in 6.7% of the reported instances [11].

Open perineal and abdominal methods offer substantial exposure for mesh placement and suturing but carry an elevated risk of wound complications and infections due to their invasiveness [9]. In contrast, the laparoscopic abdominal approach is gaining favor for its superior intra-abdominal visualization, potential for assessing tumor recurrence, and obviation of an additional perineal incision, as opposed to perineal or open abdominal techniques [12]. However, it also presents challenges such as limited pelvic space and difficulties in mesh securing [13].

In this case series, the use of an abdominal robotic approach retained the advantages of the laparoscopic method while adding the unique benefits of robotic surgery. Robotic surgery, especially pertinent to pelvic operations, offers enhanced three-dimensional visualization, improved maneuverability, stability, ease of suturing, precise mesh positioning, and access to otherwise difficult areas [14–16]. Each feature is particularly advantageous when navigating the restricted space and complex anatomy of the pelvis.

In this case series, different approaches were taken in terms of patient positioning based on the complexity and size of the hernia. One of the patients was placed in the prone position, as this case involved a larger hernia that raised concerns about the ability to adequately close the fascia using a strictly robotic approach. Prone positioning allowed for better access and improved fascial closure in this more complex case, although it did result in a longer operative duration. In contrast, the other patients were managed in the supine position, which was deemed sufficient given the smaller size of the hernias and less challenging anatomy. This variation in patient positioning highlights the importance of tailoring the surgical approach to the specific characteristics of each case, ensuring optimal outcomes for each patient.

Although there are no readily available studies comparing the outcomes of laparoscopic vs. robotic repair of perineal hernias, numerous studies have highlighted the advantages of robotic surgery in various hernia repairs, such as shorter hospital stays, decreased rates of surgical site complications, and improved fascial closure rates [3, 17]. These advantages are theoretically applicable to

perineal hernia repairs as well. However, a notable limitation of robotic surgery is the increased time required for the procedure [3, 5, 14, 17]. In the present cases, the potential benefits of robotic repair were deemed to justify the longer operative duration.

Choosing an appropriate repair technique is critical to minimize the risk of hernia recurrence. Recent systematic reviews indicate that perineal hernia repairs have a 22% recurrence rate, underscoring the need for carefully selected surgical strategies [18].

CONCLUSION

This report has detailed three successful robotic-assisted repairs of a perineal hernia following an abdominoperineal resection (APR). Follow-up assessments indicated a favorable outcome, with the absence of hernia recurrence in all three cases. The integration of robotic assistance in the repair of perineal hernias has the potential to enhance the already established benefits of laparoscopic techniques, taking advantage of the proficiency robotic surgery has shown in the broader domain of hernia and pelvic surgeries. While research remains limited due to small sample sizes, larger cohort studies are warranted to validate efficacy and benefits, ultimately moving toward standardized protocols for robotic-assisted perineal hernia repair.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

MB and AH conducted the primary data collection, analysis, and initial manuscript writing. KB and WS provided clinical expertise and contributed to the interpretation of the data. KB and WS oversaw the project and provided critical revisions to the manuscript. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

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OPINION
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A Call to Change the Nomenclature of "Open" Inguinal Hernia Repair

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Keywords: inguinal hernia repair, laparoscopic inguinal hernia repair, MIS hernia repair, OPP, open preperitoneal inguinal hernia repair

In this edition of JAWS, many researchers have described numerous benefits of open preperitoneal (OPP) inguinal hernia repair. Overwhelming data suggests OPP inguinal hernia repair is a structurally sound, cost-effective approach for inguinal hernia repair with negligible rates of chronic groin pain and hernia recurrence [1–17]. The 2023 HerniaSurge Guidelines state that "open preperitoneal mesh techniques can achieve favorable results in terms of operating time, acute and chronic postoperative pain and return to work compared to Lichtenstein repair [17]." This is based on several recent randomized controlled trials that favor OPP to Lichtenstein for decreased pain and quicker recovery [18–21]. The guidelines also found that OPP and laparo-endoscopic approaches have comparable outcomes in terms of postoperative pain, recurrences and recovery, citing three randomized controlled trials [22–24]. Thus, OPP has outcomes that more similarly resemble those of Minimally Invasive Surgery (MIS) inguinal hernia repair [14, 17, 22–24] as opposed to Lichtenstein repairs.

Although OPP outcomes are more similar to those of MIS approaches, OPP is often categorized with Lichtenstein and tissue-based repairs in the broad category of "open" inguinal hernia repair [15]. We believe that categorizing these vastly different approaches together makes data collection and interpretation very difficult, leaving the surgical community unable to make clinically meaningful changes to improve patient outcomes. Furthermore, there are advantages of OPP compared to MIS approaches, such as decreasing cost, avoiding MIS equipment, and providing the opportunity to avoid general anesthesia [10, 14, 25–37]. We consider open preperitoneal repairs less invasive than the standard MIS operations as they do not enter the peritoneal cavity and are performed through one 3–4 cm incision instead of multiple incisions. The current standard, particularly in the United States, requires MIS equipment and general anesthesia to perform a preperitoneal inguinal hernia repair. In our view, this has created a platform for surgeons and device companies to market expensive technologies that may offer little to no benefit to individual patients while detrimentally increasing the cost of healthcare within our society. OPP provides a solution to this dilemma but needs more widespread acceptance, training opportunities and dedicated research with appropriate classification efforts to increase evidence-based recommendations.

The first step to distinguishing the benefits of OPP compared to other inguinal hernia repair techniques requires that the surgical community change the nomenclature regarding "open" inguinal hernia repairs. We have already done this for laparoscopic and robotic hernia surgery. We identify procedures by the anatomical planes, technology used, and location of mesh placement. We use terms like TAPP, TEP, and rTAPP to describe repairs that use laparoscopic or robotic technology to either enter the peritoneal cavity or stay in the pre-peritoneal plane. All of these procedures place mesh in the preperitoneal space and are commonly grouped together as "MIS" approaches in studies and publications. Similarly, several inguinal hernia repair techniques exist using an "open" approach. However, as previously mentioned, these approaches are significantly different from one another – both in planes dissected and placement of mesh - and have expectedly

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different outcomes. These open techniques must be clearly delineated in the literature and accepted in our surgical community in order to unify research efforts and guidelines. Therefore, we propose the following categorization of open inguinal hernia repair approaches:

- "Open tissue (OT)" repairs: This dissection occurs in the space below the external oblique aponeurosis and superficial to the pre-peritoneal space. These repairs include Bassini, Shouldice, Desarda and others.
- "Open Anterior Mesh (OAM)" repairs: This uniquely describes an anterior onlay mesh above the internal oblique musculature and deep to the external oblique aponeurosis, classically known as the Lichtenstein repair.
- "Open preperitoneal (OPP)" repairs: Describes open approaches where mesh is placed behind the abdominal wall, in the pre-peritoneal space. Examples include: TIPP, MOPP, TREPP, Kugel and various permutations of these repairs.
- "Open Anterior and Posterior Mesh (OAPM)" repairs: Although discouraged in international guidelines, many surgeons still utilize a hybrid technique where mesh is placed in both the anterior and posterior planes, such as Prolene Hernia System and Plug and Patch.

It is crucial that we correct the generalization that all "open" inguinal hernia repairs are equal. We must also overcome the marketing barrier that preperitoneal repairs require a laparoscope or robot. Only then can we objectively review the outcomes associated with various repairs, and identify specific operations that offer the best value to our patients, institutions and society as a whole.

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BRIEF RESEARCH REPORT
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Pilot Case Series of Robotic-Assisted Hernia Repair in Patients With Cirrhosis

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Umbilical and ventral hernias in patients with cirrhosis cause significant morbidity including flood syndrome, bowel obstruction, and pain and limit quality of life. Ascites and portal hypertension increase the risk of complications, resulting in apprehension with intervention and costly cycles of readmission. No studies have explored the safety or efficacy of robotic-assisted repair of primary umbilical hernias in this population. We performed a retrospective review of patients with cirrhosis at a single institution who underwent elective or emergent robotic hernia repair between June 2023 and May 2024. A total of 7 patients were included with a median MELD-Na of 17 (IQR 14–22) and the majority of whom (6 of 7, 85.7%) had ascites at the time of surgery. Three patients required emergent or urgent operations. No drains were required at the time of surgery. There were no Clavien-Dindo grade 3 or higher complications, no patients had leakage of ascites from their incisions, and no patients developed hernia recurrence (median follow-up 173 days). There were 2 Clavien-Dindo grade 1 or 2 complications: one superficial skin infection treated with antibiotics and one case of urinary retention. This limited series suggests that robotic hernia repair is technically feasible and safe in a select group of patients with cirrhosis including those with ascites. We propose an approach to robotic-assisted hernia repair in these complex patients.

Keywords: robotic abdominal wall repair, liver transplant, ventral hernia repair, cirrhosis & portal hypertension, ascites

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INTRODUCTION

The prevalence of hernias in patients with cirrhosis can be as high as 40% [1]. Umbilical and incisional hernias in patients with cirrhosis, particularly with ascites, cause significant morbidity including flood syndrome (uncontrolled leakage of ascites through a wound), small bowel obstruction, pain, malnutrition and liver decompensation [2]. Ascites and portal hypertension increase the risk of complications, resulting in fear about surgical repair. For patients with ascites, recommendations advocate for control of ascites followed by repair in ideal circumstances [3, 4]. However, this is not feasible for those with refractory ascites, or in the setting of bowel incarceration. For those with refractory ascites who are expected to undergo liver transplantation within 3–6 months, repair during or following transplantation is the preferred approach. If transplantation is not likely, drainage of ascites or a transjugular intrahepatic portosystemic shunt (TIPS) prior to repair are options [3, 5]. However, there are numerous

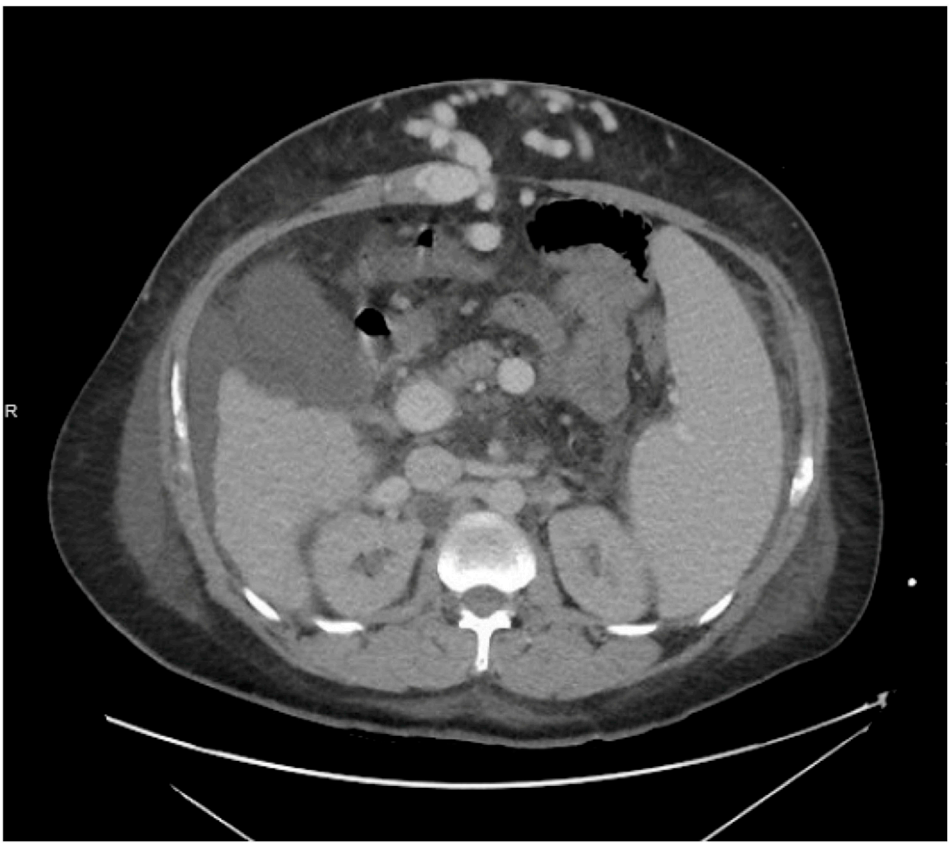

FIGURE 1 | Example of a CT scan showing varices within the hernia sac and splenomegaly (contraindications to robotic hernia repair).

patients for whom drainage or TIPS are not safe options, for example, those with hepatic encephalopathy, congestive heart failure or pulmonary artery hypertension. For these patients, conservative management is recommended [3]. However, this approach often remains perilous and commonly leads to costly readmissions for hernia-related issues (pain, obstruction), decompensation and even death [6]. When repair is attempted in these patients, it is often done out of necessity with an open approach and a significant risk of complications. As such, there is a need for novel surgical approaches to address hernias in patients with cirrhosis with refractory ascites. We present the first case series of robotic-assisted ventral hernia repair in patients with cirrhosis, the majority of whom had ascites, to assess whether it may be a safe and viable option in this population.

METHODS

Patient Population

We performed a retrospective review of patients with cirrhosis at a single institution who underwent robotic umbilical or ventral incisional hernia repair between 6/2023 and 5/2024. This study was approved by our institutional review board (IRB 20-31396).

Surgical Technique

All patients underwent pre-operative cross-sectional imaging. Patients with significant abdominal wall varices precluding safe minimally-invasive abdominal access, or large varices within the hernia sac (E.g., Caput Medusae, **Figure 1**), were not considered candidates for robot-assisted repair.

The robotic platform used was the Da Vinci Xi. Two 8 mm trocars and one 12 mm trocar were used with lateral placement (lateral to the linea semilunaris). First, the spleen was assessed and if there was no splenomegaly, a Veress needle approach was used at Palmer's point. An 8 mm optical entry was then performed using a 5 mm Stryker camera at the superior trocar site. If significant splenomegaly precluded Veress needle entry at Palmer's point or if ascites were present, we proceeded with direct optical entry. The second 8 mm trocar, used for the robotic camera, was then placed inferior to the initial trocar at a distance of at least 8–12 cm (approximately one fist length) away. The 12 mm trocar, used for needle and mesh insertion, was again placed at least 8–12 cm inferior to the second trocar to allow for adequate movement of the robotic arms. Care was taken to avoid the inferior epigastric vessels with the inferior trocar placement. Ports were placed laterally along the linea semilunaris so that the skin and fascial incisions were offset for each port site to reduce post-operative ascitic leakage. The laterality of the ports was

TABLE 1 | Baseline Characteristics and outcomes of robotic ventral and umbilical hernia repair in patients with cirrhosis.

Characteristics	Pre-transplant (n = 7)
Mean Age, years	57 (SD = 5.10)
Gender = Male	6
Race/Ethnicity	
Hispanic/Latino	3
White	4
Emergent/Elective Surgery	
Elective	4
Emergent	3
Etiology of Liver Disease	
MASH/ETOH	1
HH	1
ETOH	5
Median MELD Score	17 (IQR 14–22)
Dialysis = Yes	2
Hernia Type	
Umbilical	5
Ventral incisional	2
Preoperative Medication	
Spironolactone	5
Furosemide	5
Lactulose	5
Ascites Present	6
Paracentesis within the previous 6 months	3
History of Portal Venous Thrombosis	1
Previous TIPS	1
Transplant candidate	
Yes, SLK	2
Yes, LTX	2
Not listed	3
Hernia Dimensions, cm (length x width)	2 × 2, 2 × 2, 2 × 2, 3 × 2, 3 × 2, 3 × 3, 4 × 4
Mean Hernia Size, cm^2	7 (SD = 4.4)
At Least One previous Admission for Hernia	5
Median Admission for Hernia	1 (Range 0–4)
Surgery	
Mean robotic docking time, min	55.1 (SD = 26.7)
Mean estimated blood loss, cc	36.9 (SD = 72.4)
Total complications	2
Mean length of stay, days	2.57 (SD = 1.40)
Readmission	0
Drains placed at the time of surgery	0
Post-operative leaking ascites from incisions	0
Hernia Recurrence	0

ETOH, Alcoholic Cirrhosis; HH, Hereditary Hemochromatosis; LTX, Liver Transplant; MASH, Metabolic Dysfunction-Associated Steatohepatitis; MELD, Model for End-Stage Liver Disease; SLK, Simultaneous Liver-Kidney Transplant; TIPS, Transjugular Intrahepatic Portosystemic Shunt.

determined by the laterality of the ventral hernia. If midline, either side is viable. If off midline, the side that gave the most working distance was chosen (i.e., hernias slightly right of midline had ports placed on the left). Adhesions were taken down using a vessel sealing device. A #1 non-absorbable barbed suture was used for primary defect closure. Primary defect closure was performed in all cases, either as primary closure alone or with subsequent mesh placement. In all cases where mesh was used, an 11 × 11 cm Ventralight ST mesh with an echo system was used. The position of the mesh was in the intraperitoneal onlay mesh (IPOM) position. The mesh was secured using a 2–0 absorbable barbed suture. No mesh was used in patients with large volume ascites (defined as ascites requiring serial paracentesis) due to the risk of mesh infection in both spontaneous bacterial peritonitis and secondary bacterial peritonitis with serial paracentesis. No drains were left at the end of the case to reduce fluid shifts in the perioperative period. All port sites (including 8 mm port sites) were closed with a Carter Thomason suture passer. All other steps followed the standard robotic-assisted umbilical hernia repair.

RESULTS

Demographics

Seven patients (five with umbilical hernias, and two with ventral incisional hernias) were included (**Table 1**). Both ventral incisional hernias were midline in the umbilical region (M3), recurrent, and 2 cm in width (W1) according to the European Hernia Society classification system for incisional abdominal wall hernias [7]. The median follow-up was 173 days. The mean age was 57 years old (range 49–62) and the median MELD was 17 (IQR 14–22). The majority of patients (6 of 7) had ascites at the time of surgery and the majority of patients (5 of 7) had previous hernia-related admissions. Three required a paracentesis to manage large-volume ascites within the previous 6 months. Of the patients who did not require a paracentesis, all were on spironolactone and furosemide for ascite management. One patient had TIPS and one patient had a history of portal vein thrombosis. The average hernia size was 7 cm^2 (SD 4.4 cm^2). Three patients required urgent surgery.

Operative Characteristics and Outcomes

Mean robotic docking time was 55 min (SD 26.7), estimated blood loss (EBL) was 36.9cc (SD 72.37) and mean length of stay was 2.57 days (SD 1.4). Mesh was used in 4 patients with medically managed ascites. There were 2 Clavien-Dindo grade 1–2 complications: one superficial skin infection and one case of urinary retention. There were no Clavien-Dindo grade 3 or higher complications. No patients had post-operative ascitic leakage. No patients had recurrence.

Urgent Indications

Three patients underwent urgent repair. The first was a patient who was listed for a liver-kidney transplant with recurrent small bowel obstructions on five occasions leading to admission for incarceration each time causing decompensation. The second patient was listed for a liver-kidney transplant with spontaneous leakage of ascites from her umbilical hernia associated with an umbilical ulcer. The third patient had a recurrence of a non-reducible ventral hernia containing fat with severe pain requiring ongoing intravenous pain medication.

DISCUSSION

This study suggests the safety and efficacy of robotic-assisted umbilical hernia repair in a series of 7 patients with cirrhosis, 6 with refractory ascites and 3 who underwent surgery under urgent conditions. There is a paucity of data on this patient

population and robotic hernia repair is scarce, so we believe this is the first series to be published.

The majority of patients with hernias in the setting of cirrhosis and refractory ascites are not being operated on despite significant need. While the optimisation of ascites or repair at transplantation are attractive options, many patients with no imminent access to liver transplants fail attempts to eradicate ascites, especially at centres where average waiting times exceed 1 year. When relegated to "conservative management," these patients experience recurrent complications such as small bowel obstruction, pain, flood syndrome, and even risk of death each time they have a complication that causes their liver disease to decompensate acutely [6]. Even if decompensations are well managed, these hernias can be the driver for costly emergency room visits and admissions. Despite significant costs, these patients are often not offered surgery for fear of additional complications [8].

If repaired, the majority of these patients receive open repairs, which risk ascitic leakage through the wound and the repair itself and require drain placement and ongoing drain management [9, 10]. Debate exists on the usage of robotic-assisted surgery for other surgeries (e.g., hepatectomy) in patients with cirrhosis, but none has specifically explored its application for hernias [11, 12]. Guidelines have suggested using an open repair in patients with compromised liver function with low quality of evidence [13]. However, several studies have demonstrated the benefit of a minimally invasive repair over an open approach [13–15]. Validated risk calculators specifically in cirrhosis have shown favourable mortality and decompensation rates with minimally invasive surgery (MIS) compared to the open approach [16]. An MIS approach has also been shown to be associated with fewer wound-related complications and a shorter length of stay [15]. One additional point worth articulating is that many of these patients are either transplant candidates or have the potential to be. In these individuals who are likely to require a large incision later on, performing an open repair may increase adhesions and the complexity of the transplant.

A previously suggested exception to MIS repair may be patients with ascites, where laparoscopic surgery has been associated with greater complications in limited data sets [15]. Similar to robotic repair, laparoscopic repair allows for offset, minimally-invasive incisions to lower the risk of leaking from incisions [10, 14, 17]. However, we still advocate instead for robotic repair for several reasons. Laparoscopic repair involves ergonomics that make it more challenging to perform a technically sound primary hernia repair, where the placement and angle of each suture can have a large impact. These intuitions are supported by previous studies suggesting that there is a trend towards increasing robotic surgery in urgent general surgery cases with a lower conversion to open rate and shorter length of stay compared to laparoscopic approaches [18]. While previous studies have suggested that MIS repair is better than open repair in patients with cirrhosis with MELDs above 9 in general, laparoscopic repair has been associated with increased systemic complications and mortality specifically in those with ascites. Thus, achieving MIS closure (with its lower wound complication rates and shorter length of stay) in the setting of ascites may be an indication for robotic repair. Our initial experience shows that robotic repair is feasible with a low complication profile at short-term follow-up. If confirmed in a larger series of patients with cirrhosis undergoing robotic hernia repair, we believe that the cost of the robotic usage would be offset by the quality of the repair and reduced rates of readmissions and complications. We acknowledge that a small ventral hernia defect may be primarily closed laparoscopically by a subset of experienced surgeons. In contrast, robotic primary hernia closure, due to the strength of the robotic arm, articulating instruments and three-dimensional visualisation, can be achieved by the majority if not all surgeons with relative confidence in our experience. Thus, the robotic approach allows for a sound primary hernia repair as the strength of the robotic arms and the range of motion allow for the repair to be completely secured (i.e., with high quality, strong fascial bites and with primary closure prior to any possible mesh placement) as one would do in an open approach. In laparoscopic repair, primary closure is not always routinely performed despite the likely benefit, and as discussed previously it is likely to be more technically challenging [19–21]. In those with minimal ascites, it may be reasonable to consider mesh repair alone (which could be done laparoscopically or robotically) with the risk of recurrence if the patient goes on to develop ascites [13].

The majority of our repairs were closed primarily. While sutured repair with non-absorbable sutures has been reported to result in a high recurrence rate of 15%, even at a short-term 6-month follow-up, there were no recurrences in our cohort with a median follow-up of 6 months [13]. In our experience, the laxity of the abdominal wall and the weakened muscles in the end-stage liver disease population mean that small umbilical hernia defects are rarely closed under tension even when closed primarily. These advantageous factors protect against recurrence in this population, as long as a repair is undertaken. When the mesh was placed, we chose the IPOM location. Guidelines have suggested open repair with onlay or preperitoneal mesh placement for this patient population with low quality of evidence [13]. While the preperitoneal, retrorectus or onlay locations are preferred for standard hernia repair, our decision to use the IPOM location reflects the fact that this is a different category of patient in our experience. Abdominal wall varices and portal-systemic shunts are significant even in patients with compensated cirrhosis. While large varices are visible on cross-sectional imaging, all of these patients have portal hypertension and recanalised portosystemic shunting through the abdominal wall, which may not be readily visible on CT and still increase the risk of intraoperative bleeding, post-operative haematoma around the mesh, and subsequent risk of infection. For these reasons, we advise against preperitoneal/retrorectus dissection. Thus, the overriding principle of our repairs is to perform the repair without major morbidity. Bleeding and haematoma leading to infection are certainly possible and would be much more likely in patients with an INR greater than 2 and a preperitoneal or retrorectus dissection. With respect to adhesions, the 11 × 11 cm mesh in the IPOM location certainly carries a risk of adhesions and a more difficult subsequent liver transplant operation [22]. However, in our cohort, these were

generally umbilical hernias and the liver transplant incision is in the upper abdomen, so the risk of the mesh interfering with the subsequent transplant is lower. Additionally, we believe that the risk of an untreated hernia, and the risk of haematoma in the preperitoneal location outweigh the risk of adhesions with the IPOM. However, longer-term follow-up and further studies are needed to better evaluate these competing concerns.

In this report, we offered a strategy to give this underserved population an opportunity at surgery. While expensive upfront, robotic surgery can offer this marginalised population an opportunity at a better quality of life, taking these patients out of a cycle of decompensation and readmission, potentially helping them become or maintain transplant candidacy, which is life extending. From a technical point of view, we advocate 1) reviewing the CT scan to confirm that the entry area and hernial sac have no varices, 2) assessing for significant splenomegaly which may also affect entry trocar placement, 3) offsetting skin and fascial incisions to reduce the risk of leakage, 4) draining only enough ascites to see the working area, and 5) ensuring that the anesthesia team adequately replenishes ascitic losses in the operating room. These steps should serve as a baseline framework for minimising surgical risk and risk of decompensation for those undergoing robotic repair. All of our cases were performed at a major liver transplant centre. We also suggest that these repairs should be performed at or in coordination with a transplant centre, so that the patients have access to a transplant or additional expertise were they to decompensate.

It remains important to highlight that there are cases where we believe robotic-assisted surgery is contraindicated, specifically in patients with large varices herniating into the umbilical sac. Previous reports of robotic-assisted surgery in patients with decompensated cirrhosis have also emphasised the special consideration that must be given to trocar placement [23]. As a result, we believe that a contrast-enhanced CT scan including the venous phase is mandatory prior to surgery. In cases where contrast-enhanced CT is contraindicated (e.g., in patients with compromised renal function), we recommend non-contrast CT as an initial screening test and if there is suspicion of abdominal wall varices, MRI with a gadolinium-based contrast agent may be performed for better characterisation [24]. The risk of bleeding, and the risk of altering the mesenteric drainage by ligating a dominant varix during the hernia repair must be considered on a case-by-case basis. Generally, large varices should not be ligated, if possible, as this results in an abrupt increase in portal hypertension.

This study is limited by the small number of patients in this case series which limits the generalisability of the results. Our case series also reflects a heterogeneous population, patients with and without ascites, various levels of ascites, candidates, and non-candidates for transplantation and urgent versus elective surgery. Nevertheless, we believe that the description of these results in this underserved population with limited treatment options is warranted to stimulate further study. Even the largest societal guidelines have a self-acknowledged weak body of evidence supporting them [13]. Thus we believe that our case series provides valuable additional discussion in a relatively data-sparse area. An additional limitation is selection bias. No patients were refused surgery at our centre during the study period, but patients from referral hospitals with decompensated cirrhosis and hernias may not have been referred. Our centre is also a quaternary liver transplant centre with access to robotic-assisted surgery for both elective and urgent conditions. While this is something that other centres may be considering and may be growing in use [18], we acknowledge that there are limitations to the immediate widespread application of this technique. Our study also only involves mesh placement in the IPOM location for reasons previously discussed. Studies investigating mesh placement in other positions would better clarify the risk/benefit of different mesh positions in this patient population. Finally, the median follow-up was limited to approximately 6 months which is too short to fully assess the risk of recurrence. While our series suggests that robotic-assisted repair is feasible in the short term, additional studies are required to assess long-term outcomes.

In summary, we believe that this series demonstrates that robot-assisted repair can be offered to selected patients with cirrhosis even if they have refractory ascites when the hernia is symptomatic or when a transplant is not on the horizon. While this is a limited series, this establishes a framework for approaching these challenging cases and suggests that further refinement may be possible. As technical expertise in robotic-assisted surgery grows, robotic-assisted ventral hernia repair in patients with cirrhosis with refractory ascites is a promising frontier to provide access to a needed intervention in an underserved population.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving humans were approved by University of California, San Francisco IRB (IRB #20-31396). The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because the study is included under a IRB for quality improvement in surgical outcomes for pre-transplant and transplant recipients, involves only retrospective secondary chart review, and is minimal risk.

AUTHOR CONTRIBUTIONS

Study conception and design: DA and SS. Material preparation, data collection and analysis: DA, FS, RO-K, and SS. Writing: DA, GR, and SS. Critical review: DA, FS, RO-K, ML, IS, GR, and SS. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

IS has received honoraria for education and training from Intuitive Surgical, Inc.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

GENERATIVE AI STATEMENT

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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ORIGINAL RESEARCH
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Comparing Short-Term Outcomes of Ventral Hernia Repair Using Heavyweight Non-Woven Polypropylene Mesh With Heavyweight Knitted Polypropylene Mesh

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Introduction: The mesh choice for the majority of our retromuscular repairs is heavyweight knitted polypropylene (KP) mesh. However, supply chain issues necessitated a change to a newer non-woven polypropylene mesh (NWP). We aimed to evaluate our initial experience with using NWP mesh in retromuscular abdominal wall reconstruction.

Methods: We performed a retrospective review of all patients at our institution who underwent elective, open incisional hernia repair with NWP or KP mesh from January 2014 until December 2023. The analyzed variables included patient demographics, comorbidities, operative techniques, mesh type, position, and postoperative outcomes. A propensity score model and matching algorithms were implemented to address potential treatment-choice bias. Patients receiving NWP mesh were matched with patients receiving KP mesh in a 1:2 ratio.

Results: A total of 771 patients were included in the study, 63 (8.2%) patients had their hernia repaired with NWP and 708 (91.2%) patients with KP mesh. After propensity score matching, 63 patients in the NWP group and 126 in the KP were analyzed. At 30-day follow-up, there were significantly more deep SSIs in the NWP group, however, there were no differences in readmission, reoperation, hernia recurrence, and overall SSI, SSO, and SSOPI.

Conclusion: Retromuscular hernia repaired with non-woven polypropylene mesh showed no difference in readmission, reoperation, hernia recurrence, and overall SSI, SSO, and SSOPI when compared with knitted polypropylene. There were significantly

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more deep SSIs in the NWP group; however, in all cases, the mesh was salvaged with local wound care, and all patients made a complete recovery. In the short term, the use of NWP mesh appears to be safe, with outcomes comparable to KP mesh.

Keywords: hernia, mesh, mesh complications, abdominal wall reconstruction, hernia repair

INTRODUCTION

Mesh is widely accepted as the best approach to hernia repair since it was shown to reduce recurrence rates [1]. Our group recently published a large, multicenter randomized controlled trial which showed that heavyweight KP mesh had similar outcomes compared to mediumweight KP mesh in terms of wound morbidity, patient-reported quality of life, and patient perception of the prosthetic [2]. Given these results, coupled with the evidence of central mesh failure, our group started to routinely utilize heavyweight KP for most of our retromuscular hernia repairs.

In 2022, due to supply chain issues, our heavyweight KP mesh vendor was unable to provide this mesh, so this necessitated a change to a newer non-woven heavyweight polypropylene mesh (NWP), brand name SURGIMESH®. When compared with KP, which is typically a monofilament knitted scaffold, NWP mesh has some unique properties utilizing very small polypropylene fibers laid in place in random patterns [3]. Many commercially available knitted meshes are manufactured through a warp-knitting process by feeding multiple individual yarns from warp beams onto specialized knitting needles on a warp-knitting machine, where the yarns are interlocked in a specific pattern to create a mesh, using a medical-grade polymer like monofilament polypropylene. In contrast, non-woven meshes are manufactured through electrospinning, a spinning technique that uses electrostatic forces to produce fibrous scaffolds from biocompatible polymers, such as polypropylene. Electrospun non-wovens exhibit a high surface-to-volume ratio, porosity, pore interconnectivity, and other easy-tailorable properties. The ECM-like, three-dimensional architecture is thought to support cellular adhesion, spreading, and functions, while the intrinsic porosity and pore interconnectivity facilitate angiogenesis, ultimately promoting tissue homeostasis and repair [3]. Herein, we compare our initial experience using NWP heavyweight mesh in retromuscular abdominal wall reconstruction compared to heavyweight KP.

METHODS

After approval from the Institutional Review Board, the patients were identified using the Abdominal Core Health Quality Collaborative (ACHQC). This prospective, surgeon-entered quality improvement effort aims to improve outcomes through sharing transparent data and collaborative learning. The information is prospectively collected using standardized definitions for preoperative, operative, and post-operative phases of care. Details regarding the registry's design, implementation, and data quality assurance have been previously published [4].

The study population included all patients at our institution who underwent open ventral hernia repair with NWP or KP mesh from January 2014 until December 2023 and who had 30-day follow-up available at the outpatient clinic. We elected to study only open cases to minimize confounding factors. Similarly, the mesh size for inclusion in this comparison was limited to up to 30 cm by 30 cm for both arms because hernias repaired with larger-sized mesh are, by definition, more complex and could confound the results. A retrospective review of the prospectively collected data was then performed. The variables analyzed included patient demographics, comorbidities, and the operative technique, including mesh type, position, and postoperative outcomes. Our outcomes of interest were 30-day wound morbidities and post-operative wound events, including surgical site infection (SSI), surgical site occurrence (SSO), and SSO requiring procedural intervention (SSOPI) [5, 6]. SSI was classified as superficial, deep, or organ space according to the Centers for Disease Control and Prevention (CDC) standards. SSO included all SSI, in addition to wound cellulitis, non-healing incisional wound, fascial disruption, skin or soft tissue ischemia, skin or soft tissue necrosis, serous or purulent wound drainage, stitch abscess, seroma, hematoma, infected or exposed mesh, or development of an enterocutaneous fistula. Procedural interventions to be considered SSOPI included wound opening, wound debridement, suture excision, percutaneous drainage, partial mesh removal, and complete mesh removal. A propensity score model and matching algorithms were then implemented to address potential treatment-choice bias. Propensity score matches (PSM) were generated by matching patients receiving NWP mesh with patients receiving KP mesh. Two matched controls were selected for each case. A logistic regression model was used to estimate the propensity scores. The model included gender, BMI, COPD, smoking, immunosuppression, history of abdominal wall SSI, prior prosthetic mesh infection, hernia width, hernia length, wound status, hernia recurrent, and age. These variables were selected based on clinical considerations. Due to the low missing rate (<1%), only complete cases were included in the PSM analysis. Nearest neighbor matching without replacement was used to match the patients. No caliper was used to keep all of the NWP patients in the analysis. The standardized mean differences (SMD) were used to evaluate the balance between two mesh types pre- and post-matching [7]. The SMD less than 0.2 was considered acceptable however, values less than or around 0.1 indicate good balance. Two-sided p-values less than or equal to 0.05 were considered statistically significant. All analyses were performed using R 4.2 in addition to R packages: Hmisc, rms, MatchIt, tableone, and survey.

TABLE 1 | Patient and hernia characteristics for the unmatched cohort.

	NWP	KP	P-value
N	63	708	
Age (IQR)	61 (54–68)	59 (50–67)	0.12
Gender, N (%)			
Female	45 (71)	352 (50)	<0.001
BMI, kg/m^2, (IQR)	35 (29–36)	32 (29–36)	0.37
ASA, N (%)			<0.001
2	2 (3)	92 (13)	
3	55 (87)	604 (85)	
4	6 (10)	12 (2)	
Hypertension, N (%)	50 (79)	441 (62)	0.007
Diabetes Mellitus, N (%)	21 (33)	177 (25)	0.15
COPD, N (%)	8 (13)	61 (9)	0.28
Anti-coagulation medications, N (%)	7 (11)	50 (7)	0.24
Immunosuppressants, N (%)	6 (10)	53 (7)	0.56
Current smoking, N (%)	10 (16)	52 (7%)	0.017
History of open abdomen, N (%)	5 (8)	15 (2)	0.46
History of abdominal wall SSI, N (%)	16 (25)	105 (15)	0.027
Prior prosthetic mesh infection, N (%)	7 (11)	40 (6)	0.083
Wound classification, N (%)			<0.001
Clean	50 (79)	666 (94)	
Clean-contaminated	13 (21)	33 (5)	
Contaminated	0 (0)	8 (1)	
Dirty/Infected	0 (0)	1 (0)	
Hernia width, cm, (IQR)	14 (11–16)	14 (12–16)	0.51
Hernia length, cm, (IQR)	22 (18–25)	22 (18–25)	0.88
Recurrent, N (%)	42 (67)	397 (56)	0.1
Concomitant procedure performed, N (%)	13 (21)	58 (8)	0.001
Myofascial Release, N (%)	63 (100)	703 (99)	0.5

BMI, Body Mass Index; ASA, The American Society of Anesthesiologists Physical Status Classification System; COPD, Chronic Obstructive Pulmonary Disease; IQR, interquartile range.

RESULTS

A total of 771 patients were included in the study; 63 (8.2%) patients had their hernia repaired with NWP and 708 (91.2%) patients with KP mesh. Unmatched patient demographics for each group are presented in **Table 1**. The two groups had notable differences in the patient demographics and hernia characteristics. The NWP mesh group had more patients that were females, smokers, ASA class 4, and prior abdominal wall SSI. The NWP group also had more concomitant procedures and clean-contaminated cases. **Figure 1** shows the standardized mean difference (SMD) of several baseline covariates deemed to be important predictors of wound complications. The red line indicates the SMD of the cohort without adjustment, and the blue line indicates the SMD after adjustment. The SMD less than 0.2 was considered acceptable however, values less than or around 0.1 indicate good balance. Patient demographics, hernia characteristics and intraoperative details, post-match, revealed two well matched groups, 63 patients in the NWP group and 126 in the KP group which are shown in **Table 2**. After the match, the KP group had a lower rate of transfascial mesh fixation when compared to the KP group (4.8% vs. 44.4%, $p < 0.001$), representing a change in our practice based on a recently published randomized controlled trial [8]. All patients had a 30 cm long by 30 cm wide mesh placed, except one patient in the NWP group who had placement of a 15 cm long by 15 cm wide mesh.

Post-operative outcomes are shown in **Table 3**. At 30 days follow-up, there were no differences in readmission, reoperation, hernia recurrence, and overall SSI, SSO, and SSOPI. Notably, there were 16 SSI events during the study period (4 in the NWP group vs. 12 in the KP group, $p = 0.46$). The majority of SSI in the KP group were superficial (11/12 in the KP group vs. 1/4 in the NWP group, $p = 0.008$), whereas deep SSI comprised all the SSI in the NWP group and only 1/12 in the KP group ($p < 0.001$). With regards to the deep SSIs, three out of the four deep SSIs in the NWP group occurred in clean-contaminated cases. Three patients were managed with wet-to-dry packing, with the infection tracking to the anterior fascia but not involving the retromuscular prosthetic, and one patient required an image-guided drain placement for an infected hematoma in the retromuscular space around the prosthetic. All patients received oral antibiotics and the patient requiring drain placement also had IV antibiotics and antibiotic flushes through the drain. There were no mesh excisions, and all four patients completely resolved their infections without further interventions. The patient treated with percutaneous drainage had no signs of infection at 8 months follow up and has retained the mesh. In the KP group, there was one deep SSI. This patient required several takebacks to the operating room for washout, multiple mesh debridements in the office that led to a hernia recurrence, and ultimately underwent a redo abdominal wall reconstruction.

DISCUSSION

This study compared heavyweight non-woven polypropylene (NWP) mesh with heavyweight knitted polypropylene (KP) mesh in abdominal wall reconstruction. After propensity score matching, we found that at 30 days follow-up, when compared to KP mesh, NWP mesh had similar readmission, reoperation, hernia recurrence, and overall SSI and SSOPI rate. Of note, NWP had a higher rate of deep SSI, but all cases resolved with local wound care, and none required any mesh excision.

Our approach to hernia repair, particularly when it comes to mesh choice, has recently changed based on a multicenter randomized controlled trial published in 2021. When looking at the effect of mesh weight on postoperative outcomes in 350 patients, Krpata et al. showed that mediumweight KP mesh did not have any clinical benefits over heavyweight KP mesh [2]. Given evidence of medium-weight mesh fractures, which can be as high as 4.2%, our group switched to using primarily heavyweight polypropylene mesh for clean cases [9]. It must be highlighted that in the study by Krpata et al, all cases were clean, and the rate of SSI were 4.8% in the heavyweight KP mesh group and 5.5% in the mediumweight KP mesh group. In our series, 20% of the cases were clean contaminated, which certainly confounds the results, as indicated by the higher rate of SSI in the current study. We must highlight that this represents a change in our practice overtime as we gained more experience with using heavyweight mesh in clean contaminated cases. The higher rate of SSI in our series remained present when comparing

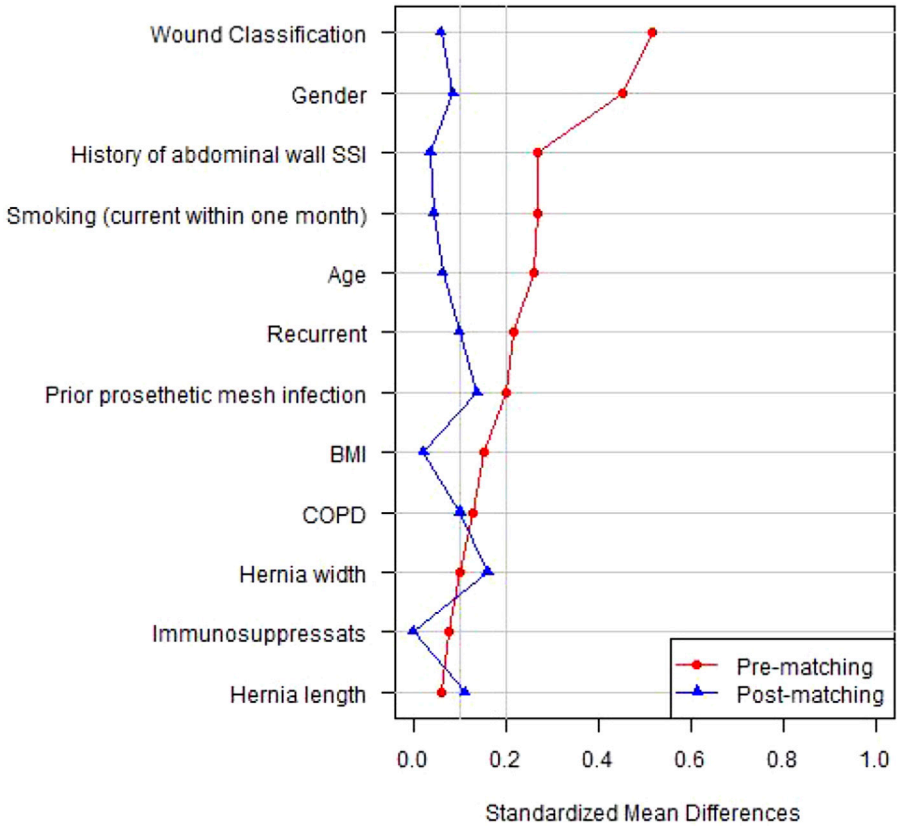

FIGURE 1 | Standardized mean difference (SMD) of several baseline covariates deemed to be important predictors of wound complications.

superficial and deep SSIs. There were no organ space infections in either study. Notably, using heavyweight mesh in clean contaminated cases remains controversial and should be further studied with a randomized controlled trial.

There are several unique features of NWP mesh that, at least theoretically, might provide some advantage over KP mesh. To form the NWP mesh, very small (0.02 mm in diameter) polypropylene fibers are randomly oriented and laid in place. Histological evaluations of NWP mesh implanted in animal models have shown planar deposition of connective tissue leading to the formation of collagen, which is primarily oriented in the plane of the surgical mesh and with minimal disruptions in the connective tissue and collagen. In contrast, KP meshes are formed with larger fibers (0.1–0.34 mm in diameter) and have a greater distance between each fiber which leads to connective tissue disruptions. When compared to non-barrier KP in histopathology birefringence analysis, non-barrier NWP had significantly less connective tissue disruptions (0.5% vs. 12.7%, $p < 0.0001$) [3]. The lower percentage of connective tissue disruptions, coupled with a planar connective tissue orientation, have been theorized as a better approach in mesh design as it may prevent mechanical mesh failures. While we did not notice any significant differences in early performance between NWP and KP, these patients undergo continued surveillance, and eventually, we will evaluate the long-term outcomes of hernia recurrence and patient-reported quality of life.

The difference in deep SSI rates deserves further consideration, particularly regarding whether it was a result of the complexity of the cases or the prosthetic itself. Given the retrospective nature of this study, it is impossible to establish causation. First, 3/4 of cases in the NWP group that had deep SSI were in clean-contaminated cases. Second, according to the CDC guidelines, our definition of deep SSI includes an infection involving the anterior fascia. In 3/4 of the deep SSI, the anterior fascia was exposed but the prosthetic in the retromuscular space was not involved. In the one case involving the prosthetic, a retromuscular hematoma became infected in a patient with a prior MRSA mesh infection who was actively smoking. After percutaneous drainage and antibiotic irrigation as described by Trunzo et al. [10], we were able to salvage the mesh, and the patient remains hernia-free with no signs of mesh infection at 8 months follow-up. In comparison, the only deep SSI in the KP group required several takebacks to the operating room for washout, multiple mesh debridements in the office that led to a hernia recurrence, and ultimately underwent a redo abdominal wall reconstruction. These are a small number of events in relatively small groups, so it is difficult to draw any conclusions. However, the safety and efficacy of heavyweight polypropylene mesh in non-clean cases should be evaluated in a prospective trial.

Although outside the scope of this study, there are other potential advantages to using NWP mesh as it is the only

TABLE 2 | Patient demographics and hernia characteristics after propensity score matching.

	NWP	KP	P-value
N	63	126	
Age, (IQR)	61 (54–68)	63 (53–70)	0.74
Gender, N (%)			1
Female	45 (71)	90 (71)	
BMI, kg/m^2, (IQR)	35 (29–36)	33 (29–37)	0.71
COPD, N (%)	8 (13)	17 (13)	0.88
Current smoking, N (%)	10 (16)	20 (16)	1
Immunosuppressants, N (%)	6 (10)	9 (7)	0.57
History of abdominal wall SSI, N (%)	16 (25)	31 (25)	0.90
Prior prosthetic mesh infection, N (%)	7 (11)	11 (9)	0.6
Recurrent, N (%)	42 (67)	81 (64)	0.75
Wound classification, N (%)			0.5
Clean	50 (79)	105 (83)	
Clean-contaminated	13 (21)	21 (17)	
Contaminated	0 (0)	0 (0)	
Dirty/Infected	0 (0)	0 (0)	
Hernia width, cm, (IQR)	14 (11–15.5)	14 (12–15)	0.94
Hernia length, cm, (IQR)	22 (17.5–25)	23 (22–25)	0.3
Mesh location, N (%)			0.16
Onlay	0	0	
Inlay	0	0	
Sublay	63	126	
Myofascial Release, N (%)			0.48
Yes	63 (100)	125 (99.2)	
No	0	1 (0.8)	
Transversus abdominis release, N (%)			0.48
Yes	63 (100)	124 (99.2)	
No	0	1 (0.8)	
Fixation used, N (%)			<0.001
Yes	3 (4.8)	56 (44.4)	
No	60 (95.2)	70 (55.6)	
Anterior fascial closure	63 (100)	123 (98%)	0.2

BMI, Body Mass Index; COPD, Chronic Obstructive Pulmonary Disease; IQR, interquartile range.

TABLE 3 | 30-day outcomes.

	NWP	KP	P-value
N	63	126	
Readmission, N (%)	4 (6.3)	10 (7.9)	0.69
Readmission reason			
Wound complication	2 (3.1)	3 (2.4)	
Gastrointestinal complication	2 (3.1)	5 (3.9)	
Bleeding complication	0 (0)	1 (0.8)	
Reoperation, N (%)	0 (0)	2 (1.6)	0.32
Reoperation reason, N (%)			
Major wound complication	0 (0)	1 (0.8)	
Unrelated intra-abdominal pathology	0 (0)	1 (0.8)	
Surgical Site Infection, N (%)	4 (6.3)	12 (9.5)	0.46
Superficial	1 (1.6)	11 (8.7)	0.008
Deep	4 (6.3)	1 (0.8)	<0.001
Organ space	0 (0)	0 (0)	
SSO requiring procedural intervention, N (%)	6 (9.5)	8 (6.3)	0.43
Pulmonary Embolism, N (%)	0 (0)	2 (5.6)	0.2
Urinary tract infection, N (%)	1 (3.4)	2 (5.6)	0.69
Acute renal failure, N (%)	0 (0)	2 (5.6)	0.2
Pneumonia, N (%)	4 (14)	4 (11)	0.74
Respiratory failure requiring intubation, N (%)	1 (3.4)	0 (0)	0.26
Post op bleeding requiring transfusion, N (%)	7 (24)	6 (17)	0.45

SSO, Surgical site occurrence.

commercially available heavyweight polypropylene mesh that has large mesh sizes, including up to 50 cm × 50 cm. At our institution, the biggest available size of heavyweight KP meshes are 30 cm long by 30 cm wide. These meshes do not provide adequate overlap when dealing with large incisional defects, so several pieces must be sewn together. The concern with this technique was the multitude of permanent sutures needed since these types of sutures have been linked to suture sinus formation [11]. The risk for mesh infection with sewn-together heavyweight KP was often balanced with the risk of mesh fracture if the mediumweight mesh was used, which comes in sizes up to 50 cm long by 50 cm wide. The mesh choice was even more difficult in clinical scenarios when the anterior fascia could not be closed completely, leading to a bridged repair. We know that this challenging cohort has a higher risk for wound morbidity [12], which makes paneled mesh less ideal. Additionally, this group also has a much higher risk for mesh fracture than those who are able to undergo reapproximation of the fascia, up to 30%, when medium-weight KP is used [9]. The long-term outcomes of these newer NWP mesh will need to be evaluated to determine the risk of mesh fracture in these challenging bridging situations.

This study is not without limitations. First, this is a retrospective review of prospectively collected data, so there may be biases associated with this type of study. Second, we limited the mesh sizes to 30 cm wide by 30 cm long in both groups. The reason for this is that the complexity of hernias increases when bigger pieces of mesh are used and that there are no KP meshes bigger than 30 cm wide by 30 cm long available at our institution. As such, the results are not generalizable to bigger mesh sizes. Third, this study looked at short-term outcomes, so we do not know how the NWP mesh compares to KP mesh long-term, especially with regards to hernia recurrence and patient-reported outcomes, so longer follow-up is needed. Finally, there was a statistically significant difference in mesh fixation rates between the two groups, higher rate for the KP group, which could have affected the results. However, this difference is due to our practice change after our randomized controlled trial looking at transfascial mesh fixation for open abdominal wall reconstruction which found that no transfascial fixation was non inferior to transfascial fixation [8]. Importantly, there were no differences in the rates of overall SSI between the two groups or mesh infections requiring mesh removal. As such, we do not believe mesh fixation has any effect on wound infection.

CONCLUSION

When compared to heavyweight KP mesh, heavyweight NWP mesh group had no differences in readmission, reoperation, hernia recurrence, and overall SSI, SSO and SSOPI. There were significantly more deep SSIs in the NWP group; however, in all cases, the mesh was salvaged with local wound care, and all patients made a complete recovery. In the short-term, the use of NWP mesh appears to be safe with outcomes comparable to KP mesh for meshes up to 30 by 30 cm. Long-term data are needed to evaluate the use of NWP mesh further. Finally, the use of either mesh

in non-clean cases remains experimental, requiring carefully selected patients, and our experience is not generalizable.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: The ACHQC data is available to the ACHQC statisticians who provided the analysis. Requests to access these datasets should be directed to http://.achqc.org.

ETHICS STATEMENT

The studies involving humans were approved by Cleveland Clinic institutional review board. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

AUTHOR CONTRIBUTIONS

L-CH provided the statistical analysis. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

SM accepted a Resident Research Grant from the Abdominal Core Health Quality Collaborative. BM received a research grant from the American Hernia Society and research funding for his institution from Integra. CP serves as an Advanced Medical Solutions, Bard-Davol, and Surgimatix Consultant, and has received research grants from the American Hernia Society, the Central Surgical Association, and the Society of American Gastrointestinal and Endoscopic Surgeons. AP is on the advisory board for Surgimatix and CMR Surgical. MR serves as the medical director of the ACHQC and receives salary for this position, received a grant to his institution for research from Telabio and has stock options with Ariste.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

GENERATIVE AI STATEMENT

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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ORIGINAL RESEARCH
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Development of Multicenter Deep Learning Models for Predicting Surgical Complexity and Surgical Site Infection in Abdominal Wall Reconstruction, a Pilot Study

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Objective: Hernia recurrence and surgical site infection (SSI) are grave complications in Abdominal Wall Reconstruction (AWR). This study aimed to develop multicenter deep learning models (DLMs) developed for predicting surgical complexity, using Component Separation Technique (CST) as a surrogate, and the risk of surgical site infections (SSI) in AWR, using preoperative computed tomography (CT) images.

Methods: Multicenter models were created using deidentified CT images from two tertiary AWR centers. The models were developed with ResNet-18 architecture. Model performance was reported as accuracy and AUC.

Results: The CST model underperformed with an AUC of 0.569, while the SSI model exhibited strong performance with an AUC of 0.898.

Conclusion: The study demonstrated the successful development of a multicenter DLM for SSI prediction in AWR, highlighting the impact of patient factors over surgical practice variability in predicting SSIs with DLMs. The CST model's prediction remained challenging, which we hypothesize reflects the subjective nature of surgical decisions and varying institutional practices. Our findings underscore the potential of AI-enhanced surgical risk calculators to risk stratify patients and potentially improve patient outcomes.

Keywords: artificial intelligence, ventral hernia repair, quality improvement, prediction model, component separation, deep learning model

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INTRODUCTION

Recent advances in artificial intelligence (AI) have demonstrated remarkable capabilities in the diagnosis and characterization of pathologies through computed tomography (CT) images, underscoring its potential as an indispensable tool in the surgical decision-making process [1–4]. Particularly in abdominal wall reconstruction (AWR), AI's predictive power promises to enhance operative planning and patient counseling, thus potentially improving the overall quality of care. In

prior research on AWR, our team successfully developed and internally validated image-based deep learning models (DLMs) designed to anticipate the level of surgical complexity and the risk of surgical site infections (SSI) [5]. This innovation was the first of its kind, utilizing preoperative CT imaging to foresee the likelihood of requiring a component separation technique (CST), which is a proxy for operative complexity, and predicting surgical site infection (SSI).

The AI model's proficiency in drawing from preoperative imaging to predict intraoperative events and postoperative outcomes signals a leap toward personalized surgical risk assessment and precision medicine that has been lacking in the field [1, 2, 6, 7]. First, AI in AWR will help surgeons identify patients who are at risk for a complex surgical operation in addition to postoperative complications. Successful implementation of such a model will allow appropriate triage of the patient to the proper surgeon, whether that is local to them, or at a tertiary hernia center. Additionally, the surgeon will be able to evaluate each patient's preoperative risk of complications, including SSI, and therefore be better able to counsel patients, obtain preoperative optimization, and prepare for intraoperative decision making. Particularly in AWR, this means accomplishing a low recurrence rate and low rate of postoperative surgical site occurences. Achieving these outcomes not only benefits the patient but also the hospital system as a whole [8]. The financial cost of complications in AWR is staggering, and reducing recurrence rates by 1% was estimated to save $139.9 million annually [8–10]. Given the annual incidence of around 611,000 AWR cases, optimization of outcomes has the potential to greatly reduce hospital resource utilization in the United States [9–12]. As previously discussed, the push for establishing AWR tertiary centers is ongoing [13–16], but empowering community general surgeons and equipping specialists alike with tools to optimize outcomes will have far reaching benefits.

The true test of any AI-based model's utility and generalizability lies in its ability to obtain external validity [17]. This is the foundation to evaluate the transferability and reliability of the DLMs predictions to external cohorts and ensures that the models perform well when confronted with the variability inherent to different surgical practices and patient populations [7]. Therefore, the aim of the current study was to construct a multicenter model and test its performance.

METHODS

Study Design

Study design and result reporting were based on the Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis (TRIPOD) reporting guidelines [18]. With institutional review board approval and a joint data sharing agreement, a multicenter DLM was developed. One center used the original CST and SSI images employed by Elhage et al [5] in the development of an internally validated model. The other center's images were obtained from a cohort of 75 patients, who were treated by an AWR specialist at a tertiary center in a different region of the United States. Both patient groups underwent preoptimization including smoking cessation for a minimum of 4 weeks, preoperative weight-loss, and reduction of HgbA1c to less than 7.2 mg/dL [19, 20]. Patients whose CT scans with scatter (secondary to orthopedic prosthetics, for example,) that limited the algorithm's interpretation of the image were excluded from model training. Additionally, those who had a chemical component relaxation with botulinum toxin A injection were excluded, as this would alter the rate of CST performed on large, loss of domain, hernias. A CST was either an anterior or poster myofascial release that was either unilateral or bilateral. CST technique and algorithm varied between institutions [21, 22]. Both institutions perform a step-up approach of an anterior or posterior CST. The patients were reported as having a CST if any portion of the CST procedure was performed, even if a full musculofascial release was not performed. SSI was defined as a deep or superficial wound infection. A deep infection included a deep space or mesh infection, whereas a superficial infection included a subcutaneous infection or cellulitis [23].

Development and Validation of DLM

CST and SSI prediction models were built from the original internal dataset with the established ResNet-18 architecture using PyTorch software version 1.13.1 [24]. The model architecture is comprised of 18 unique layers that include the initial convolutional layer, four sets of four convolutional layers of similar filter size, and finally a fully connected layer. ResNet-18 architecture uses the stochastic gradient descent optimizer and the sparse binary cross-entropy loss function for model training [25]. Finally, transfer learning was performed using pretrained model weights for ResNet-18 on the ImageNet database.

Model consistency was assessed using Leave-One-Out Cross-Validation (LOOCV) and k-fold cross-validation across multiple training runs, which provides less biased assessment than the traditional test:train split [26]. Specifically, LOOCV involves a series of training runs that equals the number of events. The model sequentially leaves one event out, trains the model on the other events, and tests the newly trained model on the left-out event. This is repeated until all events are tested. The results of the predictions are then averaged. This was performed for the CST and SSI models separately.

DLM Predictions and Evaluation

Statistical analysis was performed using Python version 3.7.1 by a data scientist. For internal validation, an 80:20 train:validation split was used. The models were assessed for discernibility and compared by training and validation accuracy, as well as the validation AUC score, across five training runs [27].

RESULTS

Cohort Description

The internal CST sample had 297 patients (97 underwent CST). The internal SSI sample had 362 patients (77 with an SSI). The

TABLE 1 | Cohort data.

	Overal	Internal Patients	External Patients
CST Sample	297	237 (79.8%)	60 (20.2%)
CST Yes[a]	115	77 (67.0%)	38 (33.0%)
SSI Sample	362	300 (82.9%)	62 (17.1%)
SSI Yes[a]	75	64 (85.3%)	11 (14.7%)

[a]*Patients who required CST or developed SSI of the entire cohort of images reviewed. Note: CST, component separation technique; SSI: surgical site infection. Data are presented as n(%).*

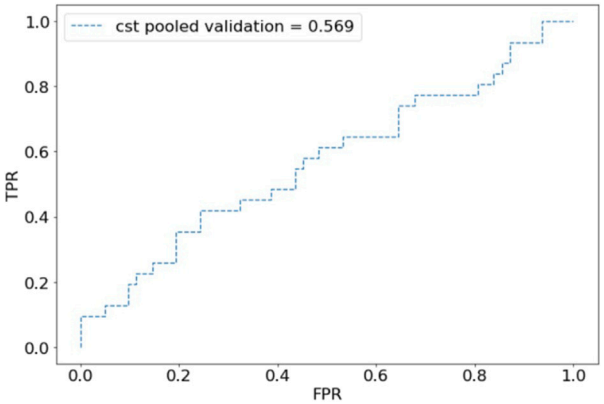

FIGURE 1 | Receiver operating characteristic (ROC) plot for component separation technique (CST) predictions of pooled validation group.

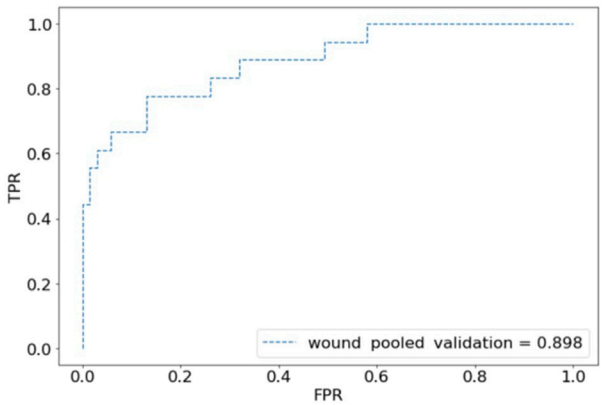

FIGURE 2 | Receiver operating characteristic (ROC) plot for wound complications predictions of pooled validation group.

external cohort had 75 patients. Of which, 48 patients underwent CST, and 13 patients developed an SSI.

Leave-One-Out Cross-Validation

To build the DLMs with the ResNet-18 Architecture, the patients were divided into cohorts CST and SSI as described. LOOCV revealed that both models showed good performance. The CST model had an overall classification accuracy of 75% of cases. SSI performed better with 94.65% accuracy across the dataset.

Pooled Multicenter Cross-Validation

The internal and external combined cohort had 297 patients in the CST model and 362 patients in the SSI model. The CST model consisted of 237 internal patients and 60 external patients, with 77 and 38 CSTs in each group, respectively. The SSI model consisted of 300 internal patients and 62 external patients, with 64 and 11 SSIs in each group, respectively (**Table 1**).

For internal validation, after an 80:20 train:test split, the CST pooled cohort had training accuracy of 91.26%, validation accuracy of 39.53%, and an AUC of 0.569 (**Figure 1**). the sensitivity was 41.94% and specificity of 67.77%. The SSI performed better with training accuracy of 97.92%, validation accuracy of 88.61%, AUC of 0.898 (**Figure 2**), sensitivity of 55.56%, and specificity of 95.65%.

DISCUSSION

This study describes the first known efforts to create and validate multicenter DLMs using AI to predict surgical complexity and postoperative outcomes. The results show proof of concept for multicenter development of image-based DLMs. While we have previously developed and demonstrated DLMs' ability to predict intraoperative and postoperative outcomes, external validation has not been performed [5, 28]. A multicenter model was developed to evaluate whether pooled training and analysis would improve the models' performance. While the CST model showed poor performance with a validation accuracy of 39.53% and an AUC of 0.568, the SSI model was more promising with a validation accuracy of 88.61% and an AUC of 0.879.

In general, external validation of predictive models is rarely described in the literature with only 5% of the approximately 85,000 prediction model publications on PubMed including some form of external validation [17, 29]. Specifically, many commonly used AWR risk stratification tools lack external validation [7]. To temper the recent excitement of using AI in surgical decision-making, Loftus et al recently called for more rigorous external validation, especially for AI prediction models [1]. This study was conducted to help address this evident gap in the literature.

Creating an externally validated DLM has many benefits, namely, its ability to become an advanced surgical risk calculator to provide personalized and informed patient counseling. There are currently several surgical risk calculators for AWR [7, 30]. The group at Carolinas Medical Center has previously published work aimed at predicting outcomes and patient centered care through the Carolinas Equation for Determining Associated Risk (CeDAR) application, which identifies patients that are at risk of wound complications after AWR along with their predicted costs [7, 31]. Unlike DLMs, this app requires human input to estimate risk [31]. Our group has also used volumetric assessment of CT scans to estimate surgical risk [32, 33]. The limitation to this method is the time and labor involved, as well as the subjectivity in data collection. DLMs can improve a surgeon's predictive ability and aid in surgical planning and patient counseling [1, 3]. The end goal of DLMs is not to replace a surgeon's clinical judgment, but rather augment it [1, 2].

The CST model performed poorly. While achieving fascial closure is the goal in AWR, techniques to achieve this vary [21, 34, 35]. The decision to perform a CST is complex and subjective, and practices often differ from institution to institution as well as patient to patient [21, 34]. There is a difference in practice and patient population, between the institutions, which is evident in the frequency of CST in each cohort [21]. While the authors attempted to propensity match the internal and external groups, this further limited the sample size. Therefore, the decision was made to continue without propensity matching. As a result though, differences in patient factors, such as hernia size or BMI, could contribute to the differences in rate of component separation. Another potential contributor to the poor performance of the CST model is the inability to predict tissue compliance. Past medical history and imaging do not capture compliance, as it is a difficult component to measure, but we suspect this too played a role in the model's performance.

Additionally, CST is a broad term that can be used for many specific procedures. While some surgeons may choose to do a posterior component separation, or Transversus Abdominus Release (TAR), others may choose an anterior approach. While both techniques have their advantages, individual patient differences may lead a surgeon to perform one technique over the other [21, 22, 34]. The surgeons of the internal cohort choose to perform an anterior or posterior CST based on defect size [21]. The surgeon of the external cohort also performs both anterior and posterior CST, but typically performs anterior CST for larger defects. Given the varied practice patterns, it is difficult to train a reliable and predictive model that will perform on external data [17, 29]. Even with pooled training and analysis the poor performance of the model is likely explained by the nuanced practice difference between AWR centers.

On the other hand, the SSI model was found to have excellent predictive ability. An explanation for this finding may be that patient factors such as obesity and predisposing comorbidities, rather than institutional differences in surgical practice, are more likely determinants of developing SSIs [8, 9, 20, 36, 37]. Factors such as the amount of subcutaneous adipose tissue, as a surrogate for BMI, are evident on the CT scans and may contribute to the model's ability to predict outcomes [32, 33, 38–42]. Predicting and preventing SSIs is vital for successful AWR. SSIs have been shown to increase a patient's risk of developing a hernia recurrence by three to five times [8, 43, 44]. Additionally, superficial wound complications increase a patient's likelihood of a mesh infection, which is a feared complication of AWR, that will likely lead to further operations in the future [43, 45].

Not only are SSIs responsible for poor patient outcomes, but also for increased healthcare spending [8, 9, 11]. The cost of complications has been explored in prior work [9]. The difference in outpatient charges between patients with and without a complication is \$6,200 ± 13,800 and \$1,400 ± 7,900, respectively, with more than four more office visits [9]. Determining which patients are at an increased risk for postoperative wound complications allows surgeons to intervene and decrease the risk of complications. Optimization of patients' outcomes could either be preoperative, in the form of preoptimization, intraoperative, or postoperative. Intraoperatively, maintaining strict sterility, judicious handling of the skin and soft tissues, as well as electing to use closing protocols can decrease the rate of SSI [20, 37, 46]. Postoperative options include the decision to perform a delayed primary closure (DPC) or apply a closed incision negative pressure wound therapy vacuum [19, 47, 48].

This study is not without limitations. A pooled multicenter analysis was performed, yet again, the CST model did not perform well. An explanation for the initial model's poor performance is the skewed nature of the datasets. The external cohort was limited with 75 patients. The external cohort also had different proportions of CST procedures performed. This is due to different AWR practice models. The internal group often uses botulinum toxin injections as a means to prevent the need for CST. This may differ from the practice algorithm of the external validation group or even other practices that may use techniques such as progressive pneumoperitoneum. This inherently is a limitation with comparing different medical centers and practices and may make our study less generalizable. Further, models developed with ResNet-18 are known to perform better with skewed data sets, like this study. Knowing the skewed nature of the datasets allows the model to be scaled appropriately. While training and validating a model based on pooled data seems promising, it is likely that a multi-institution model would need to be developed to account for the vast difference in practice patterns in CST among AWR surgeons.

This study is the first of its kind demonstrating techniques to externally validate a predictive surgical model. We demonstrated that while CST is challenging to predict, the SSI model performed well in a multicenter setting. This study indicates that models can predict outcomes where patient factors are readily evident in the data but are limited where there is subjectivity in surgical management. Future directions for study should look to train AI models on large multicenter databases to account for variations in surgical practice.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving humans were approved by Carolinas Medical Center and Ohio State University Medical Center institutional review boards. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors participated in the design, interpretation of the studies, and analysis of the data; SK, HW, SA, and BM performed and oversaw data collection; BS, KM, and GS led the computer science and statistical analysis; WL, AH, BS, BH, and JJ wrote the manuscript and participated in review of the

manuscript; BH and JJ oversaw the entire project. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

GENERATIVE AI STATEMENT

The authors declare that no Generative AI was used in the creation of this manuscript.

PUBLISHER'S NOTE

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Innovations for Incisional Hernia Prevention

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Incisional hernias are the most frequent long-term complication of abdominal surgery, resulting in considerable patient morbidity and increased health care costs. These hernias frequently result from excessive tension concentrated at points along the suture line of the abdominal closure. While ample research is focused on developing improved repair materials, the optimal solution to the problem of incisional hernias is prevention. Accordingly, some investigators have postulated that incisional hernias can be prevented by distributing tension more evenly along the fascial closure. Herein we describe two novel and ingenious strategies for the improved distribution of tension when closing abdomens (T-Line® Hernia Mesh and the REBUILD Bioabsorbable™) that were conceived of and developed by surgeons.

Keywords: incisional hernia, prevention, invention, tension, fascial closure

Dear Editors,

Incisional hernias are the most frequent long-term complication of abdominal surgery, resulting in considerable patient morbidity and increased health care costs. There are 4–5 million abdominal incisions (laparotomies) performed annually in the United States with hernias resulting after approximately 25% of these procedures (1–3). Importantly, incisional hernias result in severe morbidity beyond the cosmetic deformity of a visible bulge in the anterior abdominal wall, including intestinal obstruction, bowel ischemia, enterocutaneous fistula and significant limits on a patient's physical activity and gainful employment. Consequently, there are over 400,000 incisional hernia repairs performed each year in the United States making it one of the five most common procedures performed by general surgeons. The increase in US health care costs due to incisional hernia repair is estimated to currently exceed eight billion dollars per year, not including the cost of unemployment benefits for this moderately young patient population. Research and clinical experience indicate that incisional hernias frequently result from excessive tension concentrated at points along the suture line of the abdominal closure. These zones of excessive tension produce focal areas of tissue ischemia, decreased wound healing, and "cheese wiring"—sites of anchor point failure where sutures can tear or pull through myofascial tissue (**Figure 1**). Suture cheese wiring can occur at 6–14 N/cm, pressures that are routinely exceeded since peak abdominal pressures when coughing, sneezing, or vomiting are often greater than 32 N/cm.

Despite the magnitude and significance of incisional hernias, research focused on their prevention is sparse. While many studies and current research efforts are focused on improved repair materials, the optimal solution to the problem of incisional hernias is prevention. Notably, some investigators have postulated that incisional hernias can be prevented by more evenly distributing tension along the fascial closure. Support for this simple hypothesis comes from the well-known observation that closing laparotomies using a continuous suturing technique is associated with a decreased incisional hernia rate as compared to an interrupted suture closure (4). Herein we describe two novel and ingenious strategies to distribute tension more evenly

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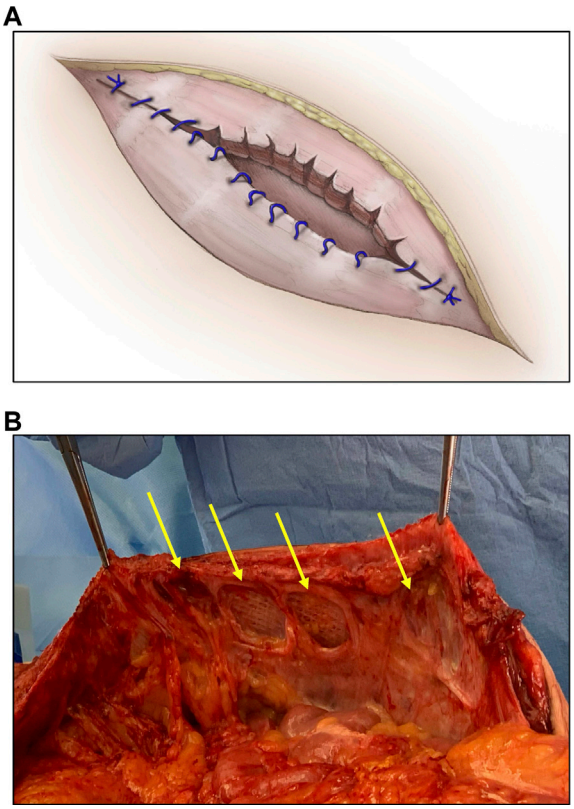

FIGURE 1 | Diagram **(A)** and photograph **(B)** depicting a form of anchor point failure termed cheese wiring wherein sutures tear or cut through tissue at a focal point of attachment and increased tension (arrows).

when closing abdomens that were conceived of and developed by surgeons. T-Line® Hernia Mesh (Deep Blue Medical Advances, Inc., Durham, NC) and the REBUILD Bioabsorbable™ System (AbSolutions Med, Inc., Mountain View, CA) represent deep insights born of clinical experience as the foundation for unique solutions to a common problem, further highlighting the tradition of the surgeon-inventor.

T-LINE® HERNIA MESH

T-Line Hernia Mesh is a standard weight (89 g/m^2), super macroporous (>2.6 mm^2), polypropylene (prolene) mesh with integrated mesh extensions located at 2-cm intervals along the lateral borders of the prosthetic (**Figure 2**). Invented by a plastic surgeon, Howard Levinson sought to combine how he was taught to repair tendons in the hand with nature's strategy for stabilizing tall trees (**Figure 3**) Similar to the roots of a tree, the T-Line Hernia Mesh extensions increase the surface area across which the prosthetic is anchored. Consequently, the mesh extensions serve to spread the tension and sheer forces over a larger area thereby significantly reducing focal anchor point stress and cheese wiring. While the T-Line Hernia Mesh achieves ~3-fold stronger anchoring strength than currently available meshes (5), the anchoring strength of the mesh extensions should increase over time as they incorporate with adjacent host tissue. When placed as an onlay, the mesh extensions can be sewn into the adjacent fascia using a quick, self-locking backstitch which secures the extensions and avoids the need for bulky suture knots (**Figure 4**). Mesh tension is set by sewing the contralateral extensions into tissue, thereby allowing the surgeon to control how tightly the mesh is stretched across the tissue. Notably, the prosthetic has the breaking strength of standard weight prolene mesh, but the handling characteristics of a lightweight mesh due to the specific way in which the mesh fibers are woven together.

An early clinical report involving 18 patients (12 women, mean age 57 years) indicates that the mesh is safe. The surgical site occurrence rate in this high-risk population was favorable with two seromas (11%) and one superficial surgical site infection (6%). While there were no early recurrences, longer follow-up is necessary to determine the product's effectiveness in terms of hernia prevention and the avoidance of chronic mesh infection.

In summary, T-Line® Hernia Mesh translates an observation from nature into a prosthetic design with three important features. First, the integrated mesh extensions effectively eliminate anchor point failure and cheese wiring, two common reasons hernia repairs fail. Second, the macroporous prosthetic material has the tensile strength of standard weight prolene mesh, yet the handling characteristics of a lightweight mesh, which render it easy to use and allow it to readily conform to any variations in the topography of the anterior abdominal wall fascia (**Figure 5**). Third, the option to remove and reposition the mesh extensions highlights the flexibility of the product, supporting the frequent need for surgeons to be creative when repairing complex ventral hernias. Accordingly, the inventor and Deep Blue Medical Advances, Inc. are expanding the potential applications of this novel technology by introducing a product combined with an adhesion barrier that will be suitable for placement within the peritoneal cavity, plus a biodegradable version for use when looking to avoid placing a permanent mesh.

REBUILD BIOABSORBABLE™

The REBUILD Bioabsorbable™ is a sterile, single-use implantable device designed for closure of midline abdominal incisions, also co-invented by a plastic surgeon. Dan Jacobs has long been fascinated by the anatomy and function of the anterior abdominal wall, and dubious of traditional teaching around how to best close laparotomy incisions. Convinced that there had to be a better way than conventional suture techniques, Jacobs drew inspiration from how we tie our

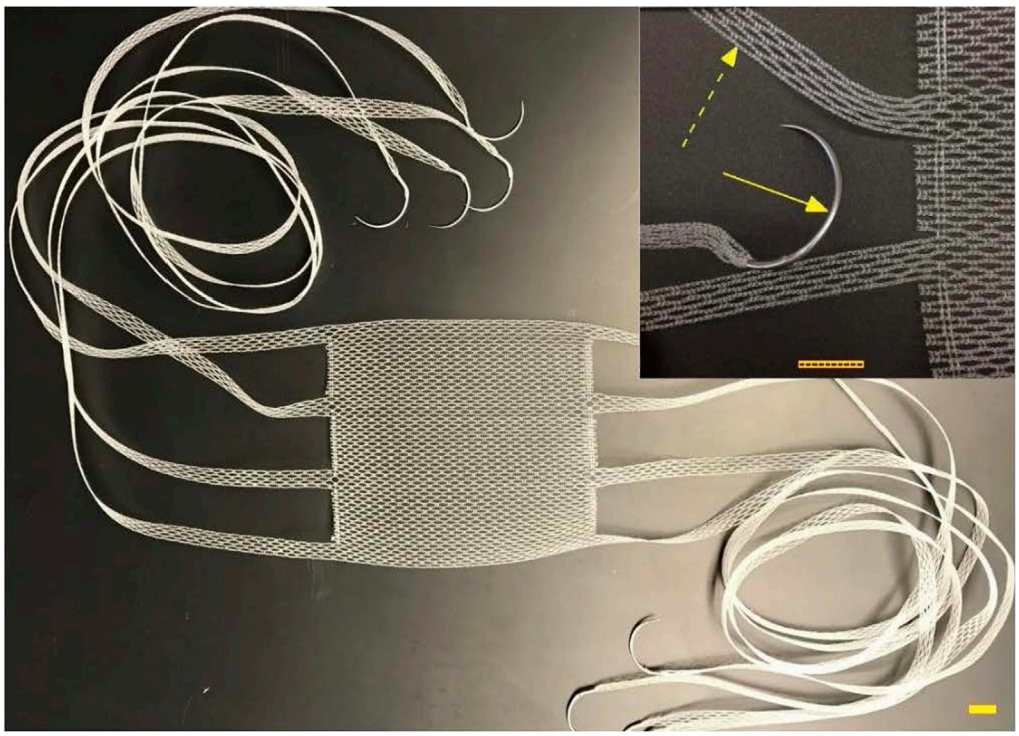

FIGURE 2 | T-line Hernia Mesh: 0.5 cm wide extensions emanating from body of textile with GS21 needles swaged on ends of extensions. Scale bar equals 1 cm; GS-21 needle (solid arrow); integrated mesh extension (dashed arrow). Photo used with permission from Deep Blue Medical Advances, Inc.

FIGURE 3 | Diagram illustrating the root system that provides anchor strength for the tree.

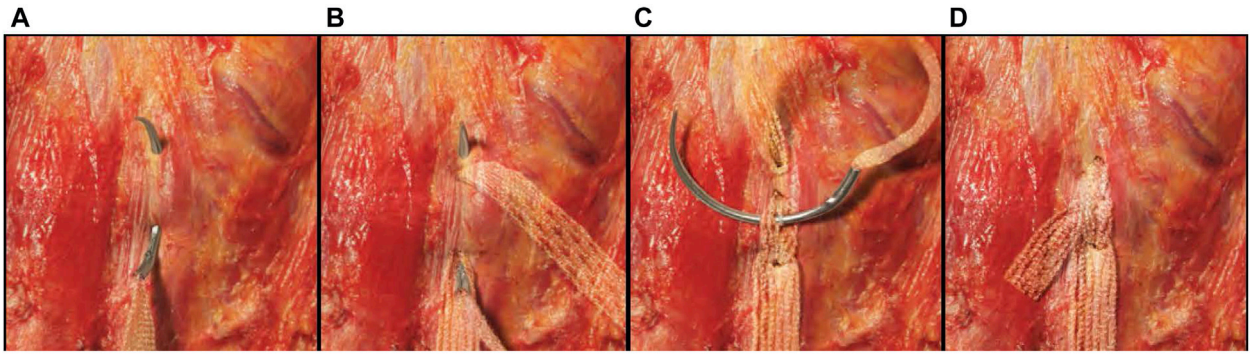

FIGURE 4 | Lock-stitch technique. **(A)** The first bite of the self-locking stitch can be a shallow bite lateral to the edge of the mesh. The extension would then be pulled to create the desired amount of tension on the mesh body. **(B)** The needle is then passed through a center portion of the extension where the first bite entered the fascia and placed slightly deeper through the tissue exiting just lateral to the exit of the first bite. **(C)** The second bite is pulled to create a snug loop around the fascia. The needle is then passed through a center pore of the extension where it exits on the first bite. **(D)** The extension is drawn snug to complete the self-locking stitch, and the excess extension is cut.

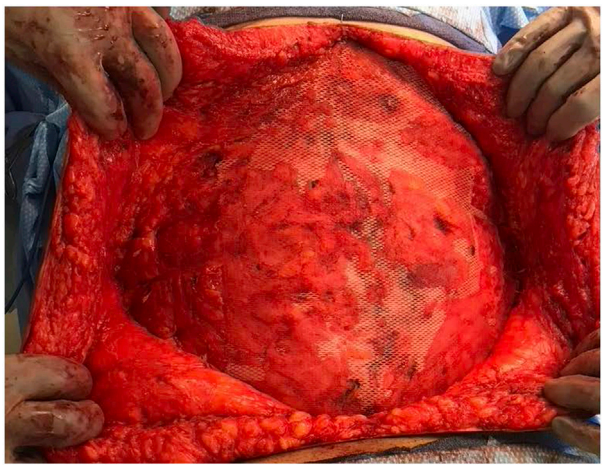

FIGURE 5 | Intraoperative photograph of an onlay mesh repair of a complex ventral hernia using T-Line® Hernia Mesh.

shoes! Or, more precisely, how reinforced eyelets prevent shoelaces from tearing through the shoe itself (**Figure 6**). Noting that reinforced eyelets effectively distribute the tension from tightly tied shoelaces, he sought to transfer this simple, yet elegant solution to closure of the abdominal wall. After several design iterations and prototypes, each REBUILD™ unit (think pair of opposing shoe eyelets) consists of two Anterior Tension Distribution (Anterior) Plates and two Posterior Tension Distribution (Posterior) Plates (**Figures 7A,B**). The Posterior Plate has one prong which is 26 mm tall and three 5.5-mm tines. The Anterior Plate also has five 5.5-mm tines. This suture tension distribution system provides 16-fold the tissue contact area compared to a standard 1 cm by 1 cm, USP #1 running suture closure. The Anterior and Posterior Plates are manufactured from poly-lactide-co-glycolide (PLGA), a biodegradable polymer that is physically strong, highly biocompatible, and whose building blocks are commonly used in suture material (Vicryl). PLGA undergoes bulk degradation by hydrolysis of its ester linkages, resulting in

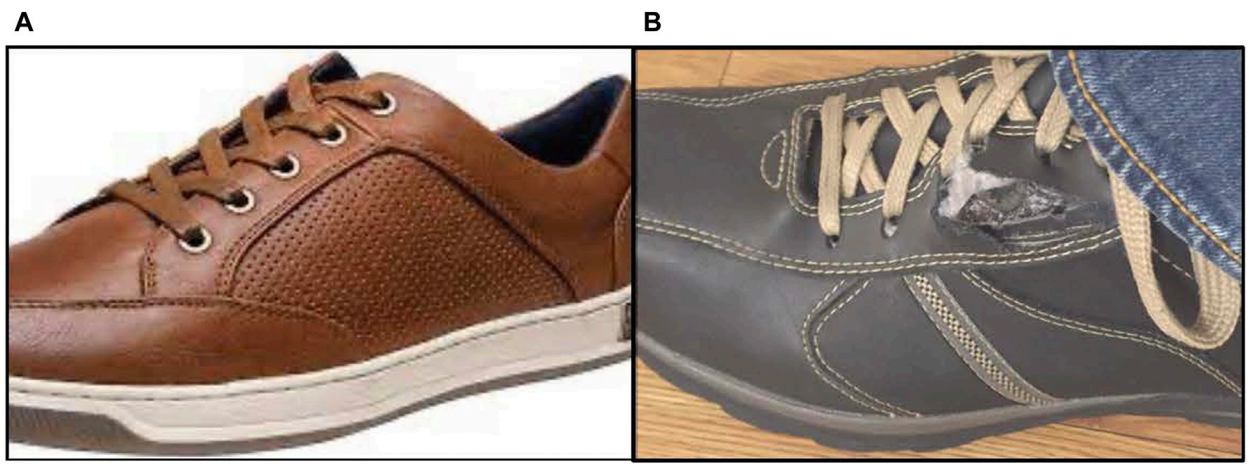

FIGURE 6 | Reinforced eyelets **(A)** prevent shoelaces from tearing through **(B)**.

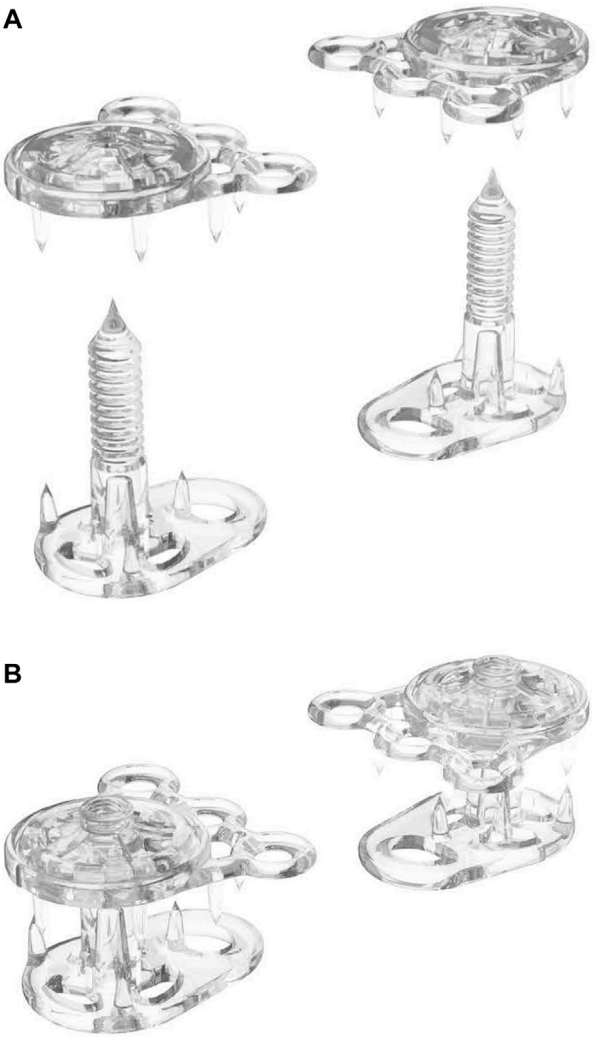

FIGURE 7 | A REBUILD™ pair consisting of two Anterior Plates **(A)** and two Posterior Plates **(B)** before being combined into single anchor units **(B)**.

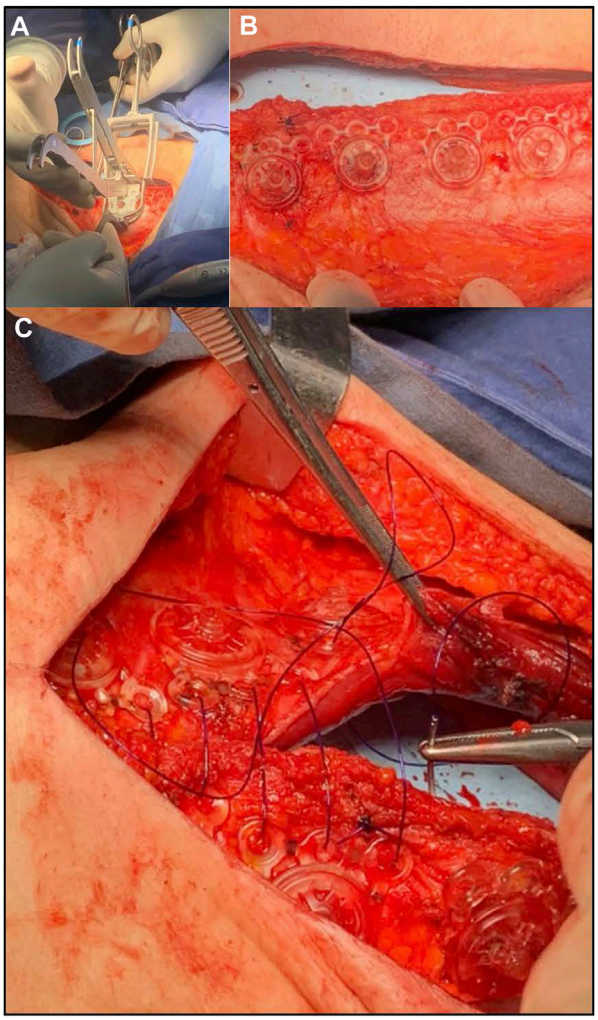

FIGURE 8 | Photographs of REBUILD™ use during surgery. A Posterior Plate with its central soft tissue fixation post is being inserted through the abdominal wall tissue **(A)**, with simultaneous ratchet fixation of an Anterior Plate on post of the Posterior Plate to create a module. A series of these modules are positioned along the midline incision **(B)**, the system is secured with suture placed through the anchor module eyelets, and the excess fixation posts trimmed **(C)**. The REBUILD™ system is provided with deployment tools made from stainless steel **(A)**.

the release of lactate and glycolate which are eliminated from the body after further metabolism.

A pair of Posterior Plates, with their central soft tissue fixation posts are inserted through the abdominal wall tissue directly opposite each other across the midline incision (**Figure 8A**). The Anterior Plates are simultaneously ratcheted to the fixation post of the Posterior Plate to create a single anchor. A series of these anchors are positioned along the midline incision (**Figure 8B**), the system is secured with suture placed through the device's eyelets (**Figure 8C**), and the excess fixation posts are trimmed (**Figure 8C**).

Porcine animal studies were conducted comparing REBUILD to standard suture technique, and although the number of animals is small (two REBUILD test animals and one suture control), the difference in midline integrity at 1 year is dramatic (**Figure 9**). MRI at 37 days in a separate pig demonstrates in vitro devices in the coronal view and contiguous rectus muscle without a gap at that midline in axial view (**Figure 10**). While this novel medical device is not FDA approved and thus not yet commercially available, clinical testing is underway with excellent early results.[1]

In summary, T-Line® Hernia Mesh and the REBUILD Bioabsorbable™ leverage simple but effective methods of dispersing force with the goal of mitigating myofascial tissue ischemia and injury, and thus preventing incisional hernias. Whereas the design strategies are very different, both are ingenious translations of common, everyday observations into clinically significant innovative tools that surgeons can use to

[1]Principal Investigator: Luis Palacios, MD: Surgical Oncology; Instituto de Cancerologia "Las Americas"—AUNA; Medellin, Columbia.

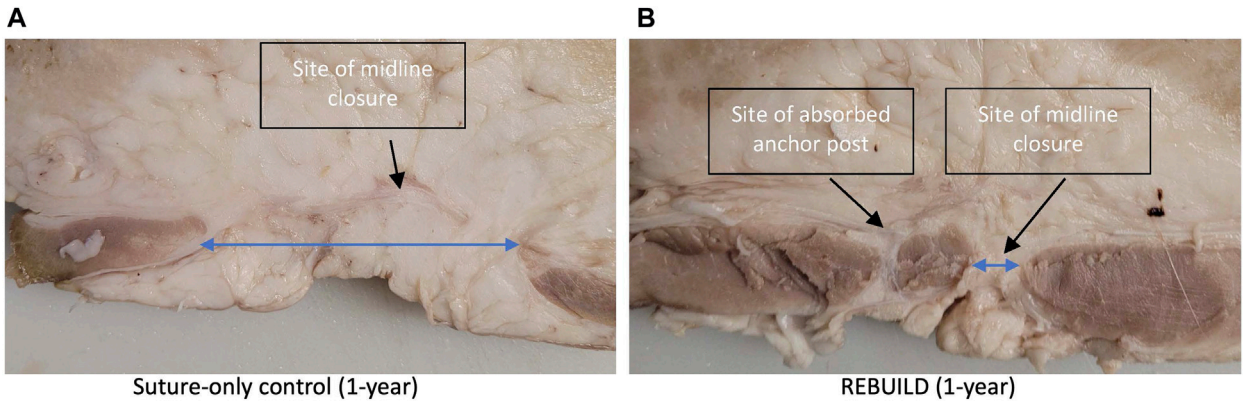

FIGURE 9 | Axial slices of the porcine abdominal walls one year after an animal was closed with standard running suture technique **(A)** compared to an animal closed with REBUILD plus suture **(B)**. Suture-only closure demonstrates a wide gap between the medial borders of the rectus muscles (long blue arrow) versus the narrow gap between the muscles present in the REBUILD-plus-suture closure (short blue arrow). Average gap measurements are 52.6 mm for running suture and 13.5 mm for REBUILD + suture.

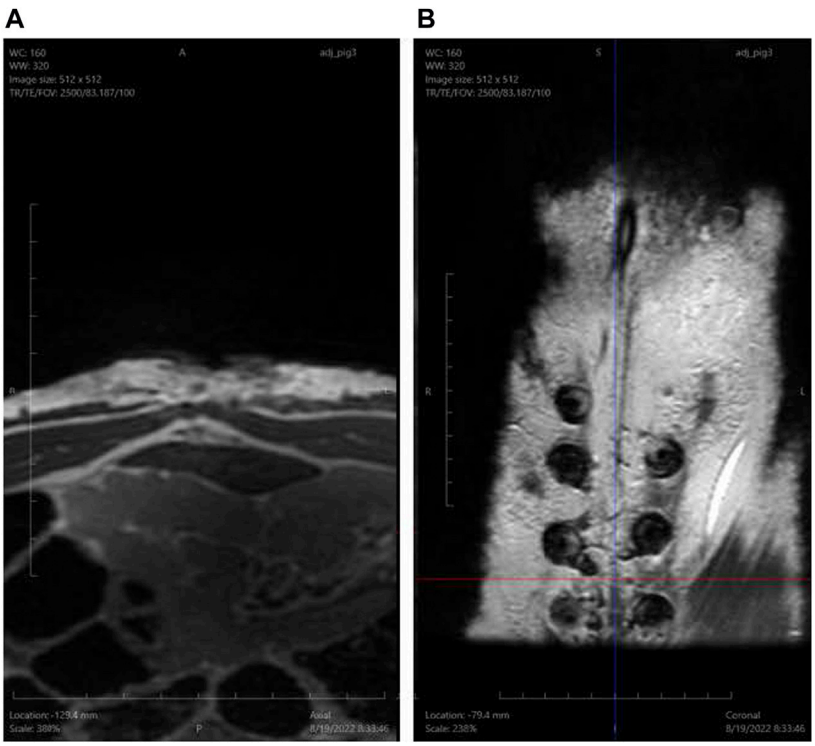

FIGURE 10 | MRI images of the abdomen 37 days after REBUILD-plus-suture closure of the abdominal wall in a porcine model. **(A)** Cross-sectional view demonstrates contiguous rectus muscle without a gap between the medial borders of the rectus muscles. **(B)** Coronal view demonstrates *in vivo* placement of REBUILD Anterior Plates in the subcutaneous (prefascial) plane.

improve outcomes for patients having abdominal surgery. Furthermore, these devices harken echoes of Theodor Kocher, Alexis Carrel, Michael DeBakey, Patricia Bath, Thomas Fogarty, and numerous other surgeon inventors whose commitment, determination, focus, imagination, and creative spirit benefit us daily.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of California, San Francisco and NYU Langone Medical Center. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

The entire manuscript was written by HH.

CONFLICT OF INTEREST

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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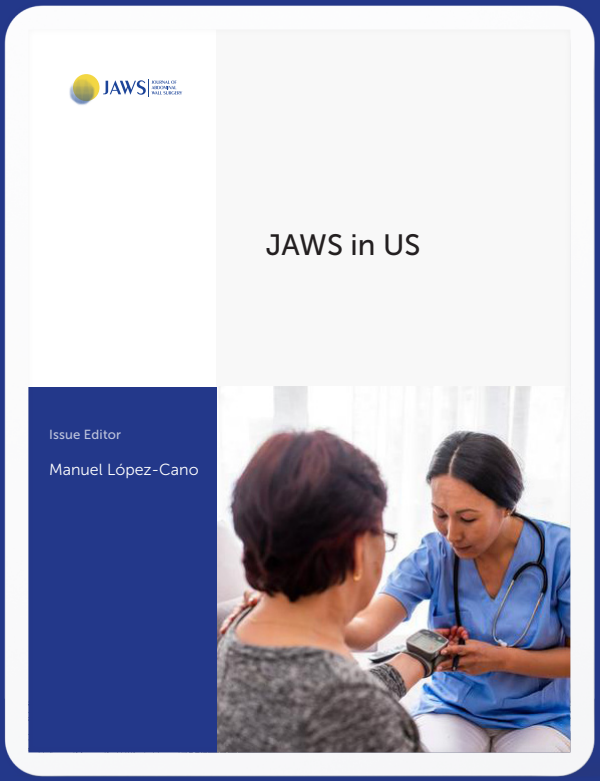

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