Langenbeck's Archives of Surgery
https://doi.org/10.1007/s00423-022-02625-2

ORIGINAL ARTICLE

The early outcomes of complex abdominal wall reconstruction with polyvinylidene (PVDF) mesh in the setting of active infection: a prospective series

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Received: 10 February 2022 / Accepted: 22 July 2022

Abstract

Purpose The use of synthetic mesh to repair infected abdominal wall defects remains controversial. Polyvinylidene fluoride (PVDF) mesh was introduced in 2002 as an alternative to polypropylene, with the advantages of improved biostability, lowered bending stiffness, and minimum tissue response. This study aimed to evaluate the short-term outcomes of using PVDF mesh to treat infected abdominal wall defects in the elective setting.

Methods This prospective clinical trial started in 2016 and was designed to evaluate the short- and mid-term outcomes of 38 patients submitted to abdominal wall reconstruction in the setting of active mesh infection and/or enteric fistulas (AI) when compared to a group of 38 patients submitted to clean ventral hernia repairs (CC). Patients were submitted to single-staged repairs, using onlay PVDF mesh (DynaMesh®—CICAT) reinforcement to treat their defects.

Results Groups had comparable demographic characteristics. The AI group had more previous abdominal operations and required a longer operative and anesthesia time. At 30 days, surgical site occurrences were observed in 16 (42.1%) AI vs. 17 (44.7%) CC, $p=0.817$; surgical site infection occurred in 4 (10.5%) AI vs. 6 (15.8%) CC, $p=0.497$; and a higher number of procedural interventions were required in the CC group, 15.8 AI vs. 28.9% CC, $p=0.169$. Both groups did not have chronic infections at 1 year of follow-up, and one hernia recurrence was observed in the AI group.

Conclusions The use of PVDF mesh in the infected setting presented favorable results with a low incidence of wound infection.

Keywords Ventral hernia · Incisional hernia · Mesh infection · Enteric fistula · Polyvinylidene mesh · DynaMesh® · CICAT mesh

Introduction

The use of mesh in repairing contaminated and infected abdominal wall defects remains controversial. The main aspects under discussion include mesh vs. suture repairs, single-stage vs. staged repairs, and the choice of biologic vs. synthetic vs. bio-absorbable mesh [1]. In previous reports, authors advocated using polypropylene mesh as a reliable alternative in elective repairs in the setting of contamination and active infection [2, 3]. Despite good outcomes, including low hernia recurrence rates and the cure of mesh infection following mesh replacement, polyvinylidene fluoride (PVDF) mesh is a newer generation material and a possible substitute for polypropylene in this scenario.

PVDF mesh was introduced in 2002, as an alternative to polypropylene, with the alleged advantages of an improved biostability, lowered bending stiffness, and a minimum tissue response [4, 5]. Ever since, it has been used in many clinical settings for the prevention of parastomal hernias [6], ventral hernias [7], cystocele [8], rectopexy [9], and emergency hernia repair [10].

This study aimed to evaluate the short- and mid-term outcomes of using PVDF mesh to treat infected abdominal wall defects in the elective setting and compare it with the results of clean repairs.

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Published online: 29 July 2022

Methods

From May 2016 to February 2021, 38 consecutive patients admitted with chronic mesh infection and/or enteric fistulas were enrolled in this prospective study. The active infection group (AI) was compared to a cohort of 38 patients submitted to clean ventral hernia repairs (CC) during the same period. The inclusion criteria in the AI group were the presence of active chronic mesh infection (non-healing sinus, exposed mesh, or mesh-related enteric fistulas) resulting from a previous repair, or the presence of an enteric/enteroatmospheric fistula, with or without an associated abdominal wall defect. The patients invited to participate as controls had a primary or recurrent ventral hernia without previous history of infection and were eligible for clean operations. The operations in the AI group were classified as class IV (dirty-infected), according to the CDC Wound Classifications [11], as adopted by the European registry for abdominal wall hernias [12]. All operations in both groups were elective.

The exclusion criteria were giant ventral hernias with a Tanaka index [13] higher than 25%, patients on immunosuppressive or corticosteroid therapy, patients with portal hypertension, Crohn's disease, acute postoperative mesh infection, chronic infections following inguinal hernia repair, a septic open-abdomen condition, and emergency operations.

Demographic data included age, gender, American Society of Anesthesiologists (ASA) score, body mass index (BMI), comorbidities, smoking status, cancer history, and the number of previous abdominal operations. Perioperative details included the list of associated procedures, the defect width, the extension of the pre-aponeurotic dissection, operative time, and anesthesia time. Further analysis in the AI group included the clinical presentation, the onset of symptoms, the type and position of the infected mesh, the possible causes for mesh infection, and the microbiology of mesh explants.

Patients were followed and operated on at a tertiary referral university center for abdominal wall and hernia surgery. Six surgeons on the team conducted the operations in both groups. The local ethics committee approved the study. Informed consent was obtained from all individual participants.

The manufacturer provided all the DynaMesh®- CICAT mesh samples (FEG Textiltechnik, Aachen, Germany) through their local dealer (BMR Medical, www.bmrmedical.com.br) at no cost. None of the authors or our institution received any financial support to undertake the study.

Preoperative workup

Patients were submitted to a routine preoperative medical evaluation. All AI patients underwent computed tomography (CT) scan of the abdominal wall. Whenever possible, cultures were obtained from patients presenting with draining sinuses or exposed mesh. The admissions commonly occurred five to 7 days before the operation. Preoperative antibiotics were administered, guided by the cultures obtained at the outpatient unit. Patients requiring enteric fistula take-down or bowel resection were submitted to bowel preparation. CC patients were admitted one or 2 days before the operation. CT scans were not requested routinely in this group. CC patients received prophylactic doses of cephazolin at the induction of the anesthesia.

Surgical procedure

Operations were performed through the previous surgical incision. The infected mesh was removed entirely, with all foreign material, fibrotic tissue, and sinus tracts for the AI patients. The abdominal cavity was entered in most patients, and associated or incidental procedures were made as required. The defect closure was done as anatomically as possible by muscle repositioning and primary fascial closure. We did not use component separation techniques or transverse abdominal releases in any case. A bilateral relaxing incision along the anterior rectus sheath was required to re-approximate the muscles in the midline in some patients. Patients with an intact abdominal wall below the infected mesh were submitted to mesh replacement following mesh removal. A previously used mesh was removed in CC patients with recurrent hernias, even when fully incorporated.

A 20 × 30 cm PVDF mesh (DynaMesh®- CICAT, www.dyna-mesh.com) was tailored to reinforce the repair at the onlay position with an extensive overlap necessary to cover the entire dissection area and extending beyond the relaxing incisions (Fig. 1). The mesh was fixed with absorbable polyglactin running sutures, placed over the borders of the mesh, in the midline, and along the relaxing incisions. The operative field was irrigated with 0.9% saline, and the subcutaneous was drained routinely with suction drains. The old scars and the exceeding skin flaps were resected. The subcutaneous tissue and the skin were closed with interrupted sutures. Fluids and samples of the explanted mesh were sent to cultures and microbiological analysis. The same repair technique was used in CC patients.

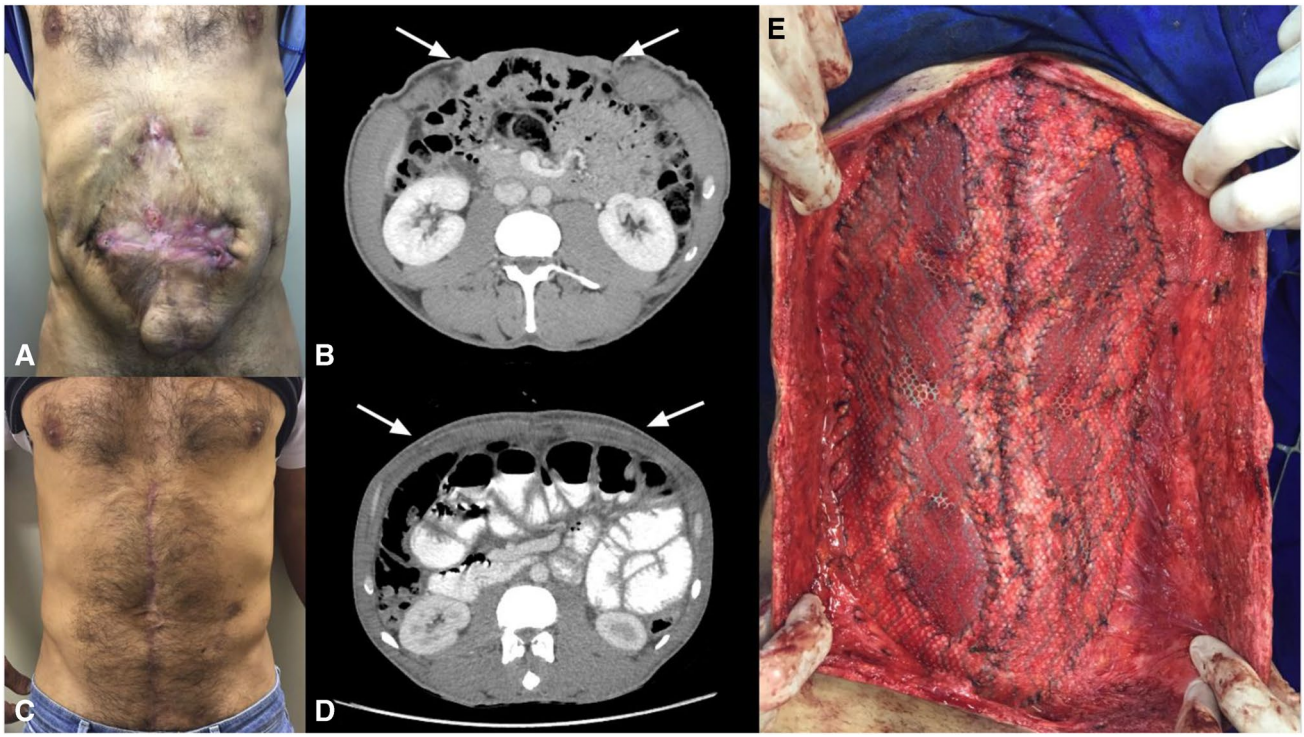

Fig. 1 Abdominal wall reconstruction with PVDF mesh. **A** Pre-operative view, peritoneostomy sequel with exposed mesh and sinus. **B** Pre-operative CT scan. Arrows point to the edges of the defect. **C** Post-operative result after 1 year. **D** Post-operative CT scan. Arrows point to the margins of the mesh. **E** Mesh placement, covering all the dissection area and relaxing incisions

Postoperative care

Patients fasted until bowel movements were present. All patients in the AI group received postoperative therapeutic antibiotics. The antimicrobial scheme was revalued when the intraoperative cultures from mesh explants became available; CC patients received postoperative antibiotics when necessary. Anti-thrombotic prophylaxis was used routinely.

The drains were removed when output was lower than 50 ml/day. Patients were encouraged to use an abdominal binder during the first postoperative month. After hospital discharge, the patients were examined on the tenth postoperative day and at one, three, and 6 months. After that, an annual follow-up was offered to all patients. Patients requiring wound dressings were reevaluated weekly until complete wound healing.

Outcome parameters

The primary outcomes were the presence of any surgical site occurrences (SSO) or surgical site infection (SSI) during the first 30 days after the operation. The secondary outcomes included developing hernia recurrence or the recurrence of mesh infection during a 12-month follow-up period. An SSI was defined as an infection occurring where the surgery took place and was further defined as superficial, deep, and organ space. An SSO was described as any surgical infection, wound breakdown, soft tissue ischemia, seroma, and hematoma formation. A surgical site occurrence requiring procedural intervention (SSOPI) was described as any wound event requiring the opening of the wound, wound debridement, suture excision, percutaneous drainage, hematoma evacuation, or mesh removal [14]. The Clavien-Dindo classification [15] was applied to all surgical complications. Physical examination and CT scan imaging determined suspected recurrences of a hernia or infection. Non-surgical complications, other operations, and deaths were recorded during the follow-up.

Statistical analysis

The statistical analysis was performed using the computer software Stata: version 16.0 (Stata Corp. 2019, Stata: Release 16, Statistical Software, College Station, TX, Stata Corp LLC). The frequency distribution was used by means to describe categorical variables (number of cases and relative percentage) and for continuous variables, measures of central tendency (median and mean), and variability (range and standard deviation). The nonparametric Mann–Whitney *U* test was applied for the statistical evaluation of the

association between groups and continuous variables. The Student *t* test was adopted when data normality was identified. Shapiro–Wilk test was applied to verify the normality of data. The association between categorical variables in contingency tables was analyzed using the frequency chi-square test and the Fisher exact test adopted in 2 × 2 tables whenever at least one expected frequency was less than five. The 5% significance level was considered for all statistical tests.

Results

Demographics

There were no significant differences between groups in age, gender, ASA score, BMI, smoking, or cancer history. More CC patients presented a diagnosis of hypothyroidism. The number of previous abdominal operations was significantly higher ($p < 0.001$) for AI patients (Table 1).

Chronic mesh infection presentation for AI patients (Table 2)

Mesh sinus alone or combined with a recurrent ventral hernia was observed in 23 (60.5%) patients. An exposed mesh was observed in 4 (10.5%) and a chronically infected seroma in two patients (5.3%). Nine patients (23.7%) had an enteric or entero-atmospheric fistula.

The onset of mesh infection symptoms ranged from less than 1 to 20 years after mesh placement. Polypropylene was the most common explanted material (35 patients, 97.2%). Meshes were removed from the onlay or bridged onlay position in 33 (86.8%) patients.

An unincorporated mesh was the primary cause of the maintenance of mesh infection in 31 (81.6%) cases. The finding of unincorporated mesh was frequently associated with mesh fixation with monofilament (25%) or multifilament non-absorbable sutures (16.7%) and mesh over mesh placement (13.2%). Mesh placement against the bowel caused enteric fistulas in 5 patients (13.2%).

Microbiology of mesh infection and antibiotic use

A positive culture was obtained in 37 out of 38 patients. Most of the cultures were polymicrobial. Methicillin-resistant (MRSA) and methicillin-sensitive *Staphylococcus aureus* (MSSA) were isolated in 21 (55.7%) cultures of mesh samples or fluids collected during the operation. Gram-negative species were isolated in 15 (39%) and included *Escherichia coli*, *Pseudomonas aeruginosa*, *Proteus mirabilis*, and *Klebsiella pneumoniae*. Anaerobes were isolated in 15 (39%), frequently associated with gram-negatives, and included *Bacteroides* sp., *Fusobacterium* sp., *Prevotella* sp., and *Veillonella parvula*. One patient presented growth of *Candida glabrata*.

Patients in the CC group received prophylactic antibiotics with cephazolin in 37 cases and clindamycin in one case. Six patients received therapeutic antibiotics along the postoperative course, including ciprofloxacin, clindamycin, and metronidazole or a combination of these drugs. Patients in the AI group received full-course antibiotics, starting 2 to 10 days before the operation and lasting for a minimum of 7 days or more. Most patients received vancomycin, methicillin, or a combination of ceftriaxone or ciprofloxacin and clindamycin during the preoperative period. Post-operatively, antibiotics were adjusted per the cultures obtained. While vancomycin and methicillin were frequently used as single drug

Table 1 Patient demographics

Variable	Active infection ($N = 38$)	Clean controls ($N = 38$)	*p*-value
Demographics			
Age (years)			
Median (range)	61 (25–80)	59.5 (37–86)	0.233
Mean (± SD)	57.2 (± 14.2)	60.8 (± 11.7)	
Gender (M/F) *n* (%)	15 (40)/23 (60)	13 (34)/25(66)	0.634 *
ASA			
Median (range)	2 (1–3)	2 (2–3)	0.802
Mean (± SD)	2.1 (± 0.5)	2.2 (± 0.4)	
BMI (kg/m^2)			
Median (range)	29.8 (11.7–41.1)	29.6 (15.6–45)	0.823
Mean (± SD)	29.6 (± 6.9)	30.0 (± 5.6)	
BMI > 30 N (%)	19 (50.0)	17 (44.7)	0.646 *
BMI > 40 *N* (%)	3 (7.9)	2 (5.3)	0.999 **
Comorbidities *N* (%)			
Hypertension	17 (44.7)	19 (50)	0.646 *
Diabetes mellitus	6 (15.8)	12 (31.6)	0.105 *
Smoking history	19 (50)	12 (31.6)	0.102 *
Hypothyroidism	2 (5.3)	10 (26.3)	**0.012 ***
Cancer history	6 (15.8)	7 (18.4)	0.761 *
COPD	8 (21.1)	7 (18.4)	0.773 *
Heart disease	6 (15.8)	1 (2.6)	0.108 *
HIV	1 (2.6)		
Previous abdominal operations			
Median (range)	4 (2–17)	2 (1–7)	**< 0.001*****
Mean (± SD)	5.3 (± 3.8)	2.4 (± 1.6)	

p-value obtained by Student *t* test

* *p*-value obtained by chi-square test

** *p*-value obtained by Fisher exact test

*** *p*-value obtained by Mann–Whitney *U* test

Table 2 Mesh infection and other details for AI patients

Variable	*N* (%)
Clinical presentation	
Ventral hernia and sinus	14 (36.8)
Mesh sinus	9 (23.7)
Ventral hernia, enteric fistula and sinus	3 (7.9)
Ventral hernia and infected seroma	2 (5.3)
Enteric fistula and sinus	3 (7.9)
Enteroatmospheric fistula	3 (7.9)
Exposed mesh	3 (7.9)
Peritoneostomy and exposed mesh	1 (2.6)
Onset of symptoms (years)	
Up to 1	2 (5.3)
> 1 a 3	14 (36.8)
> 3 a 5	10 (26.3)
> 5 a 10	8 (21.1)
> 10 a 20	4 (10.5)
Type of explanted mesh	
Polypropylene	35 (97.2)
Polyester	1 (2.6)
No mesh	2
Position of the explanted mesh	
Onlay	28 (77.8)
Bridged onlay	4 (11.1)
Intraperitoneal	1 (2.6)
Retromuscular	2 (5.3)
Onlay and retromuscular	1 (2.6)
Mesh infection findings	
Unincorporated polypropylene mesh	9 (25)
Unincorporated polyester mesh	1 (2.6)
Unincorporated mesh and Prolene sutures	9 (25)
Unincorporated mesh and multifilament sutures	6 (16.7)
Unincorporated mesh and silicone ring	1 (2.6)
Unincorporated mesh over mesh	5 (13.2)
Bowel erosion by mesh and Prolene sutures	4 (10.5)
Bowel erosion by mesh	1 (2.6)

regimens, most patients received a combination of drugs, with different schemes including ceftriaxone, metronidazole, ciprofloxacin, clindamycin, and tazobactam.

Operative details (Table 3)

The operations performed in the AI group included removing an infected mesh, except in two patients with enteroatmospheric fistulas (without mesh). Eleven patients had an intact abdominal wall below an infected mesh and were submitted to mesh replacement; four of them underwent associated procedures such as appendectomy and/or cholecystectomy. Gastrointestinal (GI) procedures were performed in 24 (63.2%). Commonly associated GI procedures included incidental appendectomy, cholecystectomy, and bowel resections. One patient required a biliary diversion. Adhesiolysis was needed in 24 (63.2%) and lipectomy in 9 (23.7%).

Six patients in the CC group were submitted to GI procedures, including appendectomy in three, cholecystectomy in one, and both procedures in two. GI procedures in the CC group were performed under controlled conditions to avoid spillage of fluids or contamination. Adhesiolysis (42.1%) and lipectomy (10.5%) were performed as required. In addition, four CC patients required the removal of a previously placed mesh.

A satisfactory fascial closure with anatomical reconstruction was achieved for all patients in both groups. The defect width and the subcutaneous dissection area were similar between groups. The operative and anesthesia times were significantly longer for the patients in the AI group.

30-day outcomes (Table 4)

All patients completed 30 days of follow-up.

In the AI group, SSO were observed in 16 (42.1%), including 4 SSI (10.5%). A procedural intervention was required in 6 (15.8%), including the open drainage of infected seromas in 4 (10.5%), minor skin debridement in 2 (5.3%), and needle aspiration of seroma in one. A partial wound breakdown was observed in 14 patients (36.8%). A reoperation was undertaken in one patient after presenting drainage of enteric fluids through the drain on the first PO-day. Intraoperative findings revealed an ischemic perforation of the small bowel caused by contact with the hard part of the drain itself. He was treated by enterectomy and primary anastomosis. To allow access to the abdominal cavity, the mesh was released and folded to one side, and re-attached at the end of the procedure. No wound events were reported for this patient.

Seventeen patients (44.7%) presented wound morbidity in the CC group. SSO included 6 (15.8%) surgical site infections, 8 (21.1%) non-infected seromas, and 8 (21.1%) wound breakdowns. Among the six patients with SSI, four developed an infected seroma, and three presented with skin cellulitis. Eleven patients required procedural intervention, including four open seroma drainages, minor debridement of skin in six cases, and needle aspiration of seroma in one.

One readmission was necessary for each group to treat infected seromas with antibiotics and open drainage at the bedside. Other wound events were treated at the outpatient unit. Most of the surgical complications in both groups were classified as Clavien-Dindo grade I. A few patients

Table 3 Operative details

Variable	Active infection ($N=38$)	Clean controls ($N=38$)	p-value
Gastrointestinal procedure N (%)	24 (63.2)	6 (15.8)	**< 0.001**
Appendectomy	3 (7.9)	3 (7.9)	0.999 *
Cholecystectomy	2 (5.3)	1 (2.6)	0.999 *
Enterotomy/Enterectomy	2 (5.3)	0	0.493 *
Cholecystectomy and enterectomy	4 (10.5)	0	0.115 *
Appendectomy and cholecystectomy	8 (21.1)	2 (5.3)	0.086 *
Appendectomy and enterectomy	1 (2.6)	0	NA
Appendectomy, enterectomy, and Roux en Y BD	1 (2.6)	0	NA
Appendectomy, cholecystectomy, and enterectomy	1 (2.6)	0	NA
Appendectomy, cholecystectomy, colostomy take-down	1 (2.6)	0	NA
Sigmoidectomy	1 (2.6)	0	NA
Another procedures N (%)			
Adhesiolysis	24 (63.2)	16 (42.1)	0.066
Mesh removal	36 (94.7)	4 (10.5)	**< 0.001**
Lipectomy	9 (23.7)	4 (10.5)	0.128
Defect characteristics			
Defect width N (%)			
W0 (no defect)	11 (28.9)	0	**0.003**
W1 (< 4 cm)	6 (15.8)	5 (13.2)	
W2 (4–10 cm)	13 (34.2)	21 (55.3)	
W3 (> 10 cm)	8 (21.1)	12 (31.6)	
Dissection area N(%)			
Anterior abdominal wall	32 (84.2)	28 (73.7)	NA
Supra umbilical	3 (7.9)	8 (21.1)	
Infra umbilical	2 (5.3)	2 (5.3)	
Lumbar	1 (2.6)	0	
Operative characteristics			
Operative time (min)			
Median (range)	390 (150–800)	257.5(135–420)	**< 0.001** **
Mean (± SD)	408.2 (± 155.6)	272.8 (± 75.3)	
Anesthesia time (min)			
Median (range)	480 (300–880)	360 (230–540)	**< 0.001** **
Mean (± SD)	525.1 (± 158.8)	367.5 (± 80.9)	

NA p-value calculation not applicable

p-value obtained by chi-square test

*p-value obtained by Fisher exact test

**p-value obtained by Mann–Whitney U test

presented reversible medical issues, including respiratory distress, acute renal failure, deep vein thrombosis, and GI bleeding.

There were no differences between groups in 30-day outcomes, including wound morbidity, SSI, SSOPI, and medical morbidity. The hospital stay was significantly longer in the AI group.

12-months outcomes (Table 5)

One CC patient died of lung cancer, undiagnosed by the date of the operation, after completing 5 months of follow-up. He presented no complaints about his hernia repair and had no clinical signs of infection or hernia recurrence at his death.

Table 4 Thirty-day outcomes

Variable	Active infection ($N=38$)	Clean controls ($N=38$)	p-value	All ($N=76$)
SSO N (%)	16 (42.1)	17 (44.7)	0.817	33 (43.4)
Surgical site infection	4 (10.5)	6 (15.8)	0.497	10 (13.2)
Seroma (non-infected)	4 (10.5)	8 (21.1)	0.208	12 (15.8)
Wound breakdown	14 (36.8)	8 (21.1)	0.129	22 (28.9)
Skin ischemia/necrosis	2 (5.3)	2 (5.3)	0.999 *	4 (5.3)
SSI N(%)	4 (10.5)	6 (15.8)	0.497	10 (13.2)
Infected seroma	4 (10.5)	4 (10.5)	0.999 *	8 (10.5)
Cellulitis	0	3 (7.9)	0.240 *	3 (3.9)
Organ space	0	0	NA	0
SSOPI N (%)	6 (15.8)	11 (28.9)	0.169	17 (22.4)
Open seroma drainage	4 (10.5)	4 (10.5)	0.999 *	8 (10.5)
Skin debridement	2 (5.3)	6 (15.8)	0.262 *	8 (10.5)
Needle aspiration	1 (2.6)	1 (2.6)	NA	1 (1.3)
Clavien-Dindo classification				
Grade I	11 (28.9)	10 (26.3)		
Grade II	4 (10.4)	6 (15.8)		
Grade IIIa	1 (2.6)	1 (2.6)		
Grade IIIb	1 (2.6)	0		
Medical morbidity N (%)	3 (7.9)	4 (10.5)	0.999 *	7 (9.2)
Respiratory distress	2 (5.3)	2 (5.3)	0.999 *	4 (5.3)
Acute renal failure	1 (2.6)	0	NA	1 (1.3)
Deep vein thrombosis	0	1 (2.6)	NA	1 (1.3)
GI bleeding	0	1 (2.6)	NA	1 (1.3)
Reoperations N (%)	1 (2.6)	0	NA	1 (1.3)
Bowel perforation	1 (2.6)	0	NA	1 (1.3)
Readmissions due to SSO/SSI	1 (2.6)	1 (2.6)		2 (2.6)
Infected seroma	1 (2.6)	1 (2.6)		
Hospital stay (days)				
Median (range)	8 (6–20)	6 (3–15)	**< 0.001****	
Mean (± SD)	9.9 (± 3.4)	6.2 (± 2.2)		

NA p-value calculation not applicable

p-value obtained by chi-square test

*p-value obtained by Fisher exact test

**p-value obtained by Mann–Whitney U test

Table 5 Twelve-month outcomes

Variable	Active infection ($N=38$)	Clean controls ($N=38$)	All ($N=76$)
12 months wound morbidity N (%)			
2nd intention wound healing	4 (10.5)	2 (5.3)	6 (7.9)
Infection recurrence	0	0	0
Readmissions due to SSO			
Seroma deroofing	1 (2.6)	1 (2.6)	2 (2.6)
Hernia recurrences	1 (2.6)	0	1 (1.3)
Reoperations N (%)	0	0	0
Deaths during FU			
Lung cancer PO 5 months	0	1 (2.6)	1 (1.3)

During the following months after the operation, 4 AI patients and 2 CC patients required wound dressings for longer than 1 month. After 6 months of follow-up, one patient in each group had an incomplete wound healing following earlier drainage of seromas. Both resolved subsequently after readmission for wound debridement under local anesthesia.

At the end of the 12-month follow-up, one hernia recurrence was reported in the AI group. There were no recurrences of mesh infection, and no mesh had to be removed. No reoperations were needed for both groups.

Analysis of variables associated with wound events

We analyzed several variables to identify associations with the occurrence of wound events and wound infection. Variables analyzed included demographics, comorbidities, number of previous operations, a preoperative positive culture, the association of GI procedures, the size of the defect, adhesiolysis, and operative and anesthesia time. A BMI higher than 30 kg/m^2 was the only variable associated with SSO development. None of the variables analyzed pointed to an increase in the occurrence of SSI.

Discussion

The search for an ideal mesh to be used in the reconstruction of contaminated and infected abdominal wall defects continues.

It seems consensual that the optimal management of infected hernias demands removing the infected mesh and all foreign material, the debridement of devitalized tissues, adhesiolysis, and GI procedures, including enterectomy or take-down of enterocutaneous fistulas [16].

A broader debate continues about how to proceed with the single-staged abdominal wall reconstruction in the setting of contamination and infection. Some authors advocate using last-generation biologic mesh despite increased costs and higher hernia recurrence rates, while others defend using the newest and cheaper biosynthetic mesh with its uncertain long-term results [17].

The safety of synthetic mesh in the setting of contamination has been recently reassured in clinical studies [18, 19], hernia database studies [17], systematic reviews [20–22], and expert consensus [23]. These publications demonstrate a continuous and favorable shift towards the benefits of permanent synthetic mesh since Carbonell's challenge in the early 2010s [24].

PVDF mesh fulfills all current requirements for an ideal mesh in such conditions, including its lighter weight and uniform monofilament material with larger interstices. Monofilament PVDF is a synthetic yarn made from polyvinylidene fluoride. Its diameter is between 0.0085 and 0.165 mm. The filament is tear and aging-resistant and presents suitably adapted elasticity. In 2002, PVDF was introduced as a new polymer for surgical meshes [4] with the advantages of being more resistant to hydrolysis and degradation than polyester and polypropylene [25].

The preliminary experimental studies by Conze [26] and Klink [5] with PVDF filament-made mesh reported excellent biocompatibility, low inflammation parameters, minor foreign body reaction, and similar cellular response compared to polypropylene. Other advantages of PVDF mesh include an optimal elasticity, a high tear propagation resistance, and the possibility of tailoring the mesh to the defect. Later experimental data by Kallinowski [27] classified DynaMesh® CICAT (the commercial brand of PVDF mesh) as DIS-Class A, due to its observed "sticky" effect, which prevents slippage of the mesh even under extended repeated dynamic intermittent strain (DIS) impacts. The research concluded that this type of mesh requires no or only little fixation to bridge a hernia, when placed underlay. Another peculiar property of DynaMesh® is that it may turn visible in diagnostic radiology by incorporating ferromagnetic micro pigments into the PVDF polymer. This unique characteristic, available in DynaMesh®—CICAT visible, allows the visualization and monitoring of the mesh in computed tomography and magnetic resonance scans.

With such advantages, it is natural that PVDF mesh emerges as an alternative to lightweight polypropylene (LWP). Lightweight polypropylene was associated with overall worse quality of life at 6 months and symptomatic pain at 1 year compared to heavy and midweight mesh in open ventral hernia repair [28]. In laparoscopic inguinal hernia repair, LWP presented an increased hernia recurrence risk and provided no benefits in the incidence of pain or foreign body sensation [26, 29]. Regarding its effectiveness in ventral hernia repair, Carbonell [24] reported a 7% recurrence rate using lightweight mesh in contaminated repairs with a mean follow-up of 10.8 ± 9.9 months, remarkably higher than our 4.2% recurrence rate in infected repairs using heavyweight polypropylene (HWP), after a follow-up of 50.2 ± 14.8 months [3].

During the last decade, a valuable experience in the repair of challenging defects with heavyweight polypropylene in the setting of contamination and infection was reported in elective operations [2, 3, 30] and emergencies [31]. While several commercial products are available in the USA and Europe, HWP is still widely used in emerging countries due to its cost-effectiveness and well-established results. Using the current currency conversion, one single 10,000 USD biologic mesh costs approximately the same as 500 standard HWP meshes in our country, enough to operate ventral hernias for almost 2 years in our facility. The choice to evaluate the efficacy of PVDF mesh in the infected setting happened

because it seems to be more appealing than HWP, stronger than LWP, and cheaper than the other bioabsorbable and biologic mesh alternatives.

We adopt standardized management in open ventral hernia repair. Our surgical technique includes removing foreign material used in previous operations, a complete inspection of the abdominal cavity and organs with adhesiolysis, tactical appendectomy, and cholecystectomy in selected cases, and further GI procedures when required. The reconstruction must be as anatomical as possible and involves tissue reinforcement by placement and fixation of mesh over the aponeurosis at the onlay position, using absorbable sutures.

We recruited patients with an infected abdominal wall condition, including an active chronic infection with positive cultures, enteric fistulas, or both, and compared the short-term results to a group submitted to clean operations. There might be some criticism since a few patients in the control group were submitted to appendectomy and cholecystectomy. Favoring these incidental procedures, Dilek [32] performed prophylactic appendectomy in patients with incisional hernias, arguing that, in the future, dense adhesions could lead to complicated appendectomy and found no adverse effect on perioperative complications. Newhall [33] reported incidental appendectomy to be cost-saving for patients undergoing elective laparoscopic abdominal procedures, using a decision model. And regarding cholecystectomy, a recent AHSQC analysis study noted that concomitant cholecystectomy did not increase the wound morbidity compared to uncomplicated, clean abdominal wall reconstruction alone [34]. Since mesh repairs create a certain shielding of the abdominal wall to further operations, we consider it reasonable to remove the appendix or gallbladder under elective and controlled conditions during open ventral hernia repair. In fact, our data showed that any simultaneous gastrointestinal procedures, including bowel resections, did not contribute to an increase in SSO or SSI.

Another controversial aspect of our study was the replacement of mesh in some patients not originally presenting a fascial defect. As stated by Arnold et al. [35], "*The excision of infected mesh with suture repair of the fascia is considered a multistaged repair due to the almost universal hernial recurrence after the first operation… In our experience, patients undergoing suture repair in a contaminated setting have a nearly 80% hernial recurrence, with most of those without recurrence having very short follow-up. Thus, patients undergoing suture repair alone after mesh excision are counseled on an essentially inevitable hernia recurrence with a plan for synthetic mesh repair in the future*." We share the same opinion, as it is a fact that removing infected mesh causes significant damage and weakening of the remaining fascia. Thus, replacement of mesh in such condition is essential to reinforce the abdominal wall, and to prevent hernia recurrence.

There was no difference in 30-day outcomes when we compared the incidence of SSO, SSI, and SSOP between groups. While the overall incidence of SSO was high (42.1% AI and 44.7% CC), the wound infection rate was remarkably lower in the AI group (10.5% AI and 15.8% CC) but non-significant between groups. In addition, we observed a higher incidence of seromas in the CC group. This condition was possibly associated with the fact that most CC patients had primary, non-recurrent defects, while most of the patients in the AI group had already been submitted to a previous dissection with the splitting of the subcutaneous tissue from the muscular layer. This maneuver determines devascularization of the subcutaneous tissue and is a common cause of seroma formation and skin ischemia following onlay repairs. Indeed, onlay repairs are frequently criticized due to a higher incidence of seroma formation, but this has long been our technical choice for ventral hernia repair. Despite the need for larger dissections in patients with larger defects, the size of the defect (smaller or larger than 4 cm) was not associated to an increase in the occurrence of SSO. Regarding the incidence of SSI in both groups, it should be noted that patients in the AI group received full-course, therapeutic antibiotics since they were considered as having an active infection. Patients in the CC group received prophylactic doses only.

Considering a high incidence of seromas and wound breakdown, it is necessary to mention that most wound events were classified as Clavien-Dindo grades I or II and managed at the outpatient unit by open drainage and local skin debridement. Mesh positioning closer to the surface makes dealing with SSO and infection easier, allowing drainage of infected seromas and minor debridement without readmissions, open reoperations, or radiology interventions.

Four AI patients presented an exposed mesh after skin necrosis debridement or wound breakdown. PVDF mesh was fully incorporated after a few days of placement, and the second intention of wound healing covered the mesh during the following weeks. The occurrence of infected seroma and skin cellulitis did not prevent mesh incorporation, and there was no need for mesh removal in any case. One patient in each group required early readmission for infected seroma drainage and antibiotics. None required negative-pressure therapy to treat wound events. The more extended hospital stay for AI patients was due to therapeutic antibiotics in this group.

The first 6 months of follow-up were uneventful for most of the patients. However, among patients returning to the outpatient unit to treat open wounds after seroma drainage, two required readmissions for debridement under local anesthesia. One recurrence was observed in a patient in the AI group shortly after completing 12 months of the operation.

Conclusions

The use of PVDF mesh in the infected setting presented favorable results with a low incidence of wound infection compared to clean ventral hernia repairs.

PVDF mesh showed an acceptable behavior with adequate tissue incorporation, even in patients presenting SSI and mesh exposure.

Our results showed that PVDF mesh has the necessary characteristics required to repair complex defects in the setting of contamination and infection.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00423-022-02625-2.

Authors' contributions Study conception and design: CB, EYT. Acquisition of data: CB, YET, JSM, AHM. Analysis and interpretation of data: CB, YET, EMU. Drafting of the manuscript: CB. Critical revision of the manuscript: SHBD, EMU.

Declarations

Mesh samples were provided by the manufacturer (FEG Textiltechnik, Aachen, Germany) at no cost.

Informed consent Informed consent was obtained from all individual participants included in the study.

Conflict of interest The authors declare no competing interests.

Study registration Plataforma Brasil (www.plataformabrasil.saude.gov.br/login.jsf), CAAE 52383615.0.0000.0068, Identifier 1.412.367

Clinical Trials, registration ID NCT05061264

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