

Evaluation of antibiotic pressurized pulse lavage for contaminated retromuscular abdominal wall reconstruction

Arnab Majumder¹ · Heidi J. Miller¹ · Parita Patel¹ · Yuhsin V. Wu¹ · Heidi L. Elliott¹ · Yuri W. Novitsky¹

Received: 9 June 2016 / Accepted: 4 October 2016 / Published online: 31 October 2016
© Springer Science+Business Media New York 2016

Abstract

Background Despite patient risk factors such as diabetes and obesity, contamination during surgery remains a significant cause of infections and subsequent wound morbidity. Pressurized pulse lavage (PPL) has been utilized as a method to reduce bacterial bioburden with promising results in many fields. Although existing methods of lavage have been utilized during abdominal operations, no studies have examined the use of PPL during complex hernia repair.

Methods Patients undergoing abdominal wall reconstruction (AWR) in clean-contaminated or contaminated fields with antibiotic PPL, from January 2012 to May 2013, were prospectively evaluated. Primary outcome measures studied were conversion of retrorectus space culture from positive to negative after PPL and 30-day surgical site infection (SSI) rate.

Results A total of 56 patients underwent AWR, with 44 patients (78.6 %) having clean-contaminated fields and 12 patients (21.4 %) having contaminated ones. Twenty-two patients (39.3 %) had positive pre-PPL cultures, 18 of which (81.8 %) converted to negative cultures after PPL. Eleven patients (19.6 %) developed SSIs. Those with persistently positive cultures after PPL had the highest rate of SSI, where two out of four patients (50.0 %) developed an SSI. Contrastingly, only 5 of 18 patients (27.8 %) who converted from a positive to negative culture after PPL developed an SSI.

Conclusion Our findings demonstrate that antibiotic PPL is an effective method to reduce bacterial bioburden during AWR in clean-contaminated and contaminated fields. While complete conversion and eradication of SSI were not achieved, we believe that PPL may be a useful adjunct to standard operative asepsis in preventing prosthetic contamination during contaminated AWR.

Keywords Abdominal wall reconstruction · Ventral hernia repair · Retromuscular · Surgical site infection · Pulse lavage · Contaminated

Abdominal wall hernia repair remains one of the most common procedures performed by general surgeons. Although more than 300,000 repairs occur annually, surgeons are still faced with high rates of surgical site infections, varying between 4 and 16 % [1]. Patient factors, including age along with comorbidities such as diabetes, obesity, and smoking, play a large role in the rate of infectious complications. However, contamination at the time of operation may also play a significant role in addition to the aforementioned patient factors. Although generally a clean procedure, when repair of abdominal wall hernia is compared to other clean procedures, infection rates are found to be higher [1]. As the complexity of the repair increases, such as cases requiring components separation, the surgical site infection (SSI) rate may be as high as 40 % [2, 3]. Furthermore, complex hernia repair scenarios involving bowel resection, or other forms of potential contamination, may create additional avenues for wound morbidity. The development of SSIs predisposes patients to subsequent detrimental processes such as hernia recurrence and mesh infection [4–6]. Many of these infective processes require prolonged treatment and

✉ Yuri W. Novitsky
yuri.novitsky@uhhospitals.org

¹ Department of Surgery, UH Comprehensive Hernia Center, University Hospitals Cleveland Medical Center, 11100 Euclid Avenue, Cleveland, OH 44106, USA

increase the financial burden due to utilization of pharmacologic and healthcare resources [7, 8]. To address these concerns, both the Center for Disease Control (CDC) and the Ventral Hernia Working Group (VHWG) have made recommendations for prevention of SSIs [1, 9]. One such recommendation is the intraoperative reduction in wound bioburden [9].

Classically, decreasing the bioburden of infected wounds involves sharp debridement of necrotic and/or infected tissue along with subsequent irrigation to decrease the bacterial load. Irrigation can be performed with direct saline lavage with or without manual syringe irrigation and more recently pressurized pulse lavage (PPL). PPL allows delivery of high volumes of irrigation under variable, but higher, pressure than traditional lavage techniques. It is thought that the higher pressure of PPL offers faster, and more effective, clearance of bacteria compared to simple lavage [10–12]. PPL is almost routinely utilized by orthopedic surgeons during total knee arthroplasties and hip hemiarthroplasties [13, 14]. Although direct lavage of an infected field may be a common practice during hernia repairs, the benefit of irrigation during elective contaminated and clean-contaminated hernia cases is not well described. With regard to abdominal operations, irrigation has been utilized to remove debris, clot, and contaminants during colorectal surgeries and appendectomies with successful reduction in wound infection rates [15, 16]. However, the use of the PPL for complex abdominal wall reconstruction (AWR) has not been investigated to date. We hypothesized that using antibiotic laden PPL in the retromuscular space prior to mesh implantation would effectively decrease bacterial bioburden in clean-contaminated and contaminated cases.

Methods

Patient population

Consecutive patients undergoing AWR in clean-contaminated or contaminated operative fields along with PPL irrigation between January 2012 and May 2013 were evaluated. The use of PPL during hernia repair was part of a Continuous Quality Improvement (CQI) project in our hernia center, focused on reducing postoperative wound morbidity. We aimed to evaluate the effectiveness of PPL through a prospective study, following institutional review board approval. The use of PPL as an alternative to manual irrigation was considered part of a standard AWR at our institution; by definition, all patients were consented to potential use of PPL during their repair. Pertinent

demographics, including age, gender, American Society of Anesthesiologists Classification (ASA), body mass index (BMI), and comorbidities, were analyzed. We also evaluated history of prior abdominal operations and hernia repairs along with history of previous infections. Furthermore, CDC wound classification [9], type of mesh utilized, pre- and post-PPL culture results, and postoperative wound morbidity were also included.

Operative procedure

All patients received appropriate prophylactic antibiotics according to Surgical Care Improvement Project (SCIP) protocols [9]. Additionally, according to our protocol, patients with a history of methicillin-resistant *Staphylococcus aureus* (MRSA) infection also received an additional dose of intravenous vancomycin within 1 h of incision. The skin was prepped and draped with iodophor-impregnated drape (Ioban, 3 M™, St Paul, MN). Stomas, if present, were sutured closed prior to skin prep.

All patients underwent abdominal wall reconstructions by way of retromuscular hernia repair with posterior component separation via transversus abdominis release (TAR), as we have previously described [17]. Briefly, the retrorectus space is developed by release of the posterior rectus sheaths bilaterally. Once complete, the ventral aspect of the posterior sheath is incised, exposing the transversus abdominis, which is carefully isolated and divided. Once complete, the muscle is reflected away from the underlying transversalis fascia and/or peritoneum and the dissection is taken laterally to the retroperitoneum, superiorly into the subxiphoid space, and inferiorly into the space of Retzius. Once the dissection is complete, the posterior rectus sheaths are re-approximated at the midline, thus reconstituting the visceral sac and creating an extraperitoneal retrorectus space.

Wound irrigation and culture technique

Two sets of aerobic and anaerobic cultures were obtained from the retrorectus space and subcutaneous tissue prior to PPL (pre-PPL cultures). After obtaining the pre-PPL cultures, the retrorectus space and subcutaneous tissue were vigorously irrigated using a pulse irrigator (Simpulse™ Irrigator, C.R. Bard, Warwick, RI) with 3 L of room-temperature normal saline plus 3 g of cefazolin, 240 mg of gentamicin, and 50,000 U of bacitracin. All excess irrigation fluid was suctioned, and a second set of bacterial cultures were then obtained from the retrorectus space/exposed soft tissue (post-PPL cultures). Routine microbiologic analysis was performed on the cultures. Any detected bacterial growth was defined as a positive culture.

Bacterial burden was considered “cleared” for any patient in whom the pre-PPL culture was positive and the post-PPL culture was negative. All culture results were finalized postoperatively.

Mesh implantation

Following PPL, mesh was placed in the retrorectus space as a sublay. Three different types of mesh were used: a macroporous midweight polypropylene mesh (SoftMesh, C.R. Bard, Warwick, RI), a heavyweight polypropylene mesh (BARD™ Mesh, C.R. Bard (Davol), Warwick, RI), or a biologic mesh (Strattice™, LifeCell, Branchburg, NJ). Mesh choice was either randomized, as part of a randomized trial comparing a biologic versus synthetic mesh, or at the discretion of the surgeon. Drains were routinely placed in the retrorectus space overlying the mesh, and the anterior fascia was closed ventral to the mesh. The skin was typically closed with staples.

Postoperative management

All patients received standard postoperative care including 24 h of perioperative antibiotics. As per our protocol, patients with a history of MRSA wound or mesh infections were continued on intravenous vancomycin during their hospitalization. Drains were removed when there was <30 mL/day of output from each drain.

Determination of wound infection/outcomes

The primary outcome measure for this study was retrorectus space culture conversion rate from positive to negative. The incidences of 30-day SSI, whether superficial, deep, or organ space, were also documented. A culture was considered positive if there was any detected bacterial growth in either of the two cultures, and no cultures were excluded or regarded as contaminants. SSIs were classified as either superficial, deep, or organ/space, with standard definitions set forth by the Center for Disease Control.

Statistics

Statistical significance for SSI rates for each type of mesh was determined by utilizing cross-tabulation in SPSS, using SSI as the dependent variable. Chi-square correlation was then performed for SSIs, superficial infections, and deep infections. To determine the similarity of patient characteristics within the biologic mesh versus synthetic mesh groups, Student’s *t* test (numerical data) and Chi-square tests (categorical data) were employed, with $p < 0.05$ considered significant.

Results

Patient and operative characteristics

A total of 56 consecutive patients undergoing AWR with PPL in clean-contaminated and contaminated settings and were analyzed (Table 1). Average age was 57 with a mean BMI of 37.6. Fifty-five percent of patients were male. Comorbidities included diabetes (21.4 %), chronic obstructive pulmonary disease (COPD) (19.6 %), and recent smoking, defined as within 3 months of repair (21.4 %). Seventy-one percent had recurrent hernias with an average of two previous hernia repairs. Twenty-four patients (42.9 %) had a history of wound infections, 13 (23.2 %) of which were MRSA infections. The vast majority of patients had midline hernias, with 44 patients (78.6 %) having clean-contaminated fields and 12 patients (21.4 %) having contaminated ones. The contaminated patient group included unplanned violation of the GI tract with spillage and patients with chronic draining (nonpurulent) sinuses. Patients undergoing concomitant urologic,

Table 1 Patient characteristics: 56 patients with clean-contaminated and contaminated operative fields

Age (years)	57 (range 31–88)
Gender	
BMI	37.6 ± 14.7
Male	31 (55.4 %)
Female	25 (44.6 %)
ASA classification	3 (range 1–3)
Diabetes	12 (21.4 %)
COPD	11 (19.6 %)
Recent smoking (within 3 months of repair)	12 (21.4 %)
Prior abdominal surgery	4.5 ± 2.3
Recurrent hernia	
Yes	40 (71.4 %)
No	16 (28.6 %)
Prior hernia repairs	2.0 ± 2.1
History of wound infection	
Yes	24 (42.9 %)
MSSA	6 (10.7 %)
MRSA	13 (23.2 %)
<i>E. Coli</i>	4 (7.1 %)
Other	2 (3.6 %)
No	32 (57.1 %)
Wound classification	
Clean-contaminated	24 (42.9 %)
Contaminated	32 (57.1 %)

Values represented as number (percentage) or mean [range/standard deviation (SD)]

ASA American Society of Anesthesiologists, BMI body mass index, COPD chronic obstructive pulmonary disease

gynecologic, biliary procedures, as well as those with unplanned enterotomies without spillage or undergoing ostomy reversals/manipulations, were counted in the clean-contaminated category. The presence of mesh infections is typically a contraindication to definitive repair, and those patients were not a part of this study.

Culture results

A total of 34 patients (60.7 %) had negative retrorectus cultures prior to any PPL, which all remained negative following PPL (Table 2). Of the 22 patients (39.3 %) who had positive pre-PPL cultures, 18 (81.8 %) converted to negative cultures post-PPL. *Enterococcus faecalis* was the most common organism isolated in the pre-PPL positive cultures. Four patients (18.2 %) had persistently positive cultures, despite the lavage intervention. Of the four patients with positive pre-PPL cultures, three had post-PPL cultures consistent with pre-PPL cultures, including *Bacteroides*, *Enterococcus*, or *Clostridium* species as the predominant organism. Overall, the utilization of the retromuscular repair and antibiotic PPL allowed for mesh implantation in the culture negative field in 92.9 % of our patients undergoing clean-contaminated and contaminated filed repairs.

SSI rates

Of the 56 total patients, 11 patients (19.6 %) developed SSIs (Table 3). Patients with persistently positive cultures after PPL had the highest rate of SSIs, where two of the four (50.0 %) patients developed an SSI. In contrast, only 5 of the 18 patients (27.8 %) who converted from a positive culture to a negative culture developed an SSI. Although “converted” patients had a lower overall SSI rate, four of these five (80.0 %) patients did develop deep wound infections.

Upon subgroup analysis of SSIs, the rate of deep infection was significantly higher in patients with biologic versus synthetic mesh, despite similar patient

Table 2 Pre-PPL and post-PPL culture results: Of the 22 patients with patients with positive pre-PPL cultures, 18 (81.8 %) converted to negative post-PPL

Pre-PPL culture	Post-PPL culture	Number of patients (%)
Negative		34 (60.7 %)
	Negative	34 (100 %)
	Positive	0 (0.0 %)
Positive		22 (39.3 %)
	Negative	18 (81.8 %)
	Positive	4 (18.2 %)

PPL pressurized pulse lavage

Table 3 SSI rates with pre-PPL and post-PPL culture results

Pre-PPL culture/post-PPL culture		
Negative/negative ($n = 34$)	SSI	4 (11.8 %)
	Superficial	3 (75.0 %)
	Deep	1 (25.0 %)
Positive/negative ($n = 18$)	SSI	5 (27.8 %)
	Superficial	1 (20.0 %)
	Deep	4 (80.0 %)
Positive/positive ($n = 4$)	SSI	2 (50.0 %)
	Superficial	1 (50.0 %)
	Deep	1 (50.0 %)
Total ($n = 56$)	SSI	11 (19.6 %)
	Superficial	5 (45.0 %)
	Deep	6 (55.0 %)

PPL pressurized pulse lavage

characteristics between these two groups (Table 4). The breakdown of SSIs for biologic and synthetic groups is summarized in Table 5. Although the overall rate of SSIs (24.1 vs. 11.1 %, $p = 0.29$) and overall rate of superficial infections (3.4 vs. 11.1 %, $p = 0.34$) between the two mesh types were not significantly, 6 of the 29 (21.4 %) patients with biologic mesh had deep infections, whereas none of 27 patients with synthetic mesh had a deep infection ($p = 0.02$). Specifically, four of nine patients (44.4 %) with converted post-PPL cultures (pre-PPL positive to post-PPL negative) developed deep infections when a biologic mesh was utilized compared to none in the synthetic group ($p = 0.04$). Fifty percent of patients (2 of 4) with persistently positive cultures (pre-PPL and post-PPL positive) developed SSIs, all of whom had a biologic mesh implanted. Finally, of the 27 patients with synthetic meshes, three patients (11.1 %) developed an SSI, all of which were superficial SSIs only. Biologic mesh was the only independent predictor of an SSI on a multivariate analysis ($p = 0.02$). There was no difference in outcomes between clean-contaminated and contaminated groups.

Discussion

Ventral hernia repair presents a unique set of surgical challenges to practicing surgeons. Recently, there has been a focus on preoperative optimization to improve patient outcomes such as wound morbidity; however, this remains a multifaceted problem. Bacterial contamination during hernia repair remains a concern during complex cases as it can lead to significant postoperative morbidity. Although implementation of modern guidelines regarding preoperative skin preparation, draping, sterilization, and

Table 4 Patient characteristics for biologic versus synthetic mesh: There were no statistically significant differences detected between the two groups

	Biologic (<i>n</i> = 29)	Synthetic (<i>n</i> = 27)	<i>p</i>
Male/female	14/15	16/11	0.42
Age (years)	56.4 ± 10.8	58.4 ± 12.8	0.53
BMI (kg/m ²)	35.4 ± 8.9	39.5 ± 33.4	0.51
Prior hernia repair (<i>n</i>)	1.9 ± 2.1	2.0 ± 1.9	1
Recurrent hernia	21 (72.4 %)	20 (74.1 %)	1
History of wound infection	13 (44.8 %)	11 (40.7 %)	0.8
Wound class			
Clean-contaminated	10 (34.4 %)	12 (44.4 %)	0.18
Contaminated	19 (65.6 %)	15 (55.6 %)	0.20
Stoma manipulation	12	12	1
Diabetes	4	8	0.33
COPD	5	6	1
Pre-PPL positive	14 (48.2 %)	10 (37.0 %)	0.28

Values represented as number (percentage) or mean [standard deviation (SD)]

BMI body mass index, *COPD* chronic obstructive pulmonary disease, *PPL* pressurized pulse lavage

Table 5 Surgical site infections (SSIs) in biologic versus synthetic mesh groups: There was a significantly higher deep SSI rate found in the positive to negative conversion group when comparing biologic versus synthetic groups along with deep SSI rate for biologics when considering all patients pre- and post-PPL

Pre-/Post-PPL cultures	Biologic (<i>n</i>)	Synthetic (<i>n</i>)		<i>p</i>			
(−/−) 34	16	SSI	1 (6.2 %)	18	SSI	2 (11.1 %)	1.00
		Superficial	0		Superficial	2	0.48
		Deep	1		Deep	0	0.47
(+/−) 18	9	SSI	4 (44.4 %)	9	SSI	1 (11.1 %)	0.29
		Superficial	0		Superficial	1	1.00
		Deep	4		Deep	0	<i>0.04</i>
(+/+) 4	4	SSI	2 (50.0 %)	0	SSI	0 (0.0 %)	NA
		Superficial	1		Superficial	0	NA
		Deep	1		Deep	0	NA
All	29	SSI	7 (24.1 %)	27	SSI	3 (11.1 %)	0.29
		Superficial	1		Superficial	3	0.34
		Deep	6		Deep	0	<i>0.02</i>

p-values in italics are statistically significant

PPL pressurized pulse lavage, *NA* not applicable

preoperative antibiotics has resulted in a reduction in infection rates, wound morbidity remains a significant concern for patients undergoing hernia repairs. Although use of certain meshes in contaminated fields has shown the ability to overcome infections [18], prevention of this type of morbidity remains the definitive goal. Further strategies are thus needed to contend with reducing bacterial contamination intraoperatively. Ultimately, the creation of a “clean” cavity may allow for placement of a prosthetic mesh without significant concern for bacterial growth even in the face of contamination encountered during surgery. Sterility of the surgical field is certainly compromised during clean-contaminated and contaminated procedures, and very little convincing data exist on how to reduce the microbiological burden once wound contamination has occurred. Wound infection is largely influenced by two

factors: contamination by organisms that overwhelm the body’s immune system and the presence of debris within the wound that can potentially serve as a bacterial nidus [19, 20]. Logically, conversion of a culture positive cavity to a negative one may be an indicator of reduced bacterial burden and may alleviate some of the concerns with postoperative wound or mesh morbidity. In this study, we prospectively evaluated the efficacy of antibiotic pulse lavage of the retromuscular space during abdominal wall reconstructions in clean-contaminated and contaminated settings for the first time.

Most existing data regarding wound irrigation are limited to orthopedic procedures, which indicate that wound irrigation itself can decrease the bacterial bioburden. When combined with pressurized lavage, it can also remove loosely attached debris that could serve as a potential nidus

for future infection [21]. PPL uses an electrically powered pump to deliver a high volume of an irrigation solution under pressure. Studies involving fluid dynamics suggest that the higher the pressure used, the more efficient it becomes at removing loose debris and pathogens [20]. Rodeheaver et al. [10] determined that wound irrigation at 15 psi removed 84.8 % of contaminants compared to 48.6 % removal at 1 psi. It is important to note that a limit exists, beyond which too high pressure can cause tissue damage and impair the healing process [22]. Thus, it is recommended that 4–15 psi is needed to adequately remove debris and pathogens without causing wound trauma or bacteria to be driven deeper into the tissues [23]. PPL produces an average of 10 psi during the lavage process, which is greater than that produced with a standard bulb syringe or a small plunger syringe. Although the use of PPL in orthopedic procedures has never been shown to reduce infection rates in total joint replacement, PPL significantly reduced overall postoperative infection rates and reduced deep space infection rates in hip hemiarthroplasties [19]. During abdominal surgeries, infection rates as high as 40 % have been reported in cases of complicated appendicitis utilizing only prophylactic antibiotics prior to surgery. With PPL, infection rates have been decreased to 17 % in these cases [16]. Similarly, PPL has reduced wound infections (19–6 %) in hepatobiliary and pancreatic surgeries longer than 2 h [21]. These findings suggest that there is a role for PPL in decreasing bioburden in clean-contaminated and contaminated general surgery cases. Therefore, as part of CQI efforts, we implemented antibiotic PPL in our hernia patients with clean-contaminated or contaminated surgical wounds along with prospective data collection to evaluate the efficacy of the practice.

In the review of our experience, presented herein, we discovered that PPL converted 82 % of ventral hernia repair cases from positive pre-PPL cultures to negative post-PPL cultures. Because this was an observational study and post-PPL cultures were taken immediately after cleansing, it is very likely that the high conversion was caused by the intervention. Although we were able to reduce bacterial burden, PPL was not able to eliminate SSIs altogether. This is not entirely surprising, as many patients undergoing major surgical procedures, especially those with clean-contaminated and contaminated wounds, develop wound complications despite physician's best efforts. However, the vast reduction in the bioburden of the retromuscular space prior to mesh implantation, demonstrated in this series, indicates that antibiotic PPL is an efficacious method and it has become standard practice for all of our patients undergoing repairs in clean-contaminated and contaminated settings.

Mesh choice also remains an actively debated topic in the hernia world. Biologic meshes have been touted to be

superior to synthetics in contaminated fields in their ability to prevent significant wound morbidity when compared to synthetic mesh. As a result, many surgeons continue to utilize biologic mesh for hernia repairs, particularly in contaminated settings. However, despite the purported benefits, repairs with biologic mesh have been shown to have SSI rates up to 60 % [24]. The findings of this study may uncover a phenomenon of unclear causality. Some of our patients, 6 of 56 (10.7 %), who developed SSIs had deep infections. Interestingly, we found that all of those patients had repairs with a biologic mesh. Although there is concern for some selection bias as this was not a randomized study, we demonstrated that the two groups (synthetic vs. biologic) were similar in terms of patient, wound, and hernia characteristics. In our analysis, we discovered that biologic mesh was an independent predictor of the deep SSI. In other words, it appears that post-operative SSIs in patients undergoing biologic mesh repairs may not serve as a retrospective "justification" of their use, but may in fact be part of the cause of a given SSI. A mechanism for this seemingly paradoxical observation may be elucidated as follows. Existing literature has suggested that the pores of synthetic mesh allow for incorporation into the patients' native tissue more effectively than non-porous biologics [18]. The resultant lack of integration likely leads to the development of dead space/seromas in the retromuscular plane in the early postoperative period. Such delayed biologic mesh integration as compared to synthetics, combined with more pronounced seroma formation, may favor bacterial proliferation (particularly in contaminated settings), which may, in turn, lead to a higher rate of deep infections. Although this study was not designed to detect superiority of a certain mesh type, we believe that our findings add to the discussion of various mesh types utilized in contaminated fields.

The utility of pressured lavage system for abdominal wounds has not been uniformly accepted. Some may argue that simple manual irrigation, such as using a bulb syringe, would have achieved similar results to those noted in our cohort [13, 25]. Others have found significant bacterial clearance differences ranging from 50 % with bulb syringe to 70–87 % with pulse irrigation between the methods [12–14, 26]. In regard to the type of irrigation solution, several authors have reported that the addition of antibiotics to the irrigation fluid assists in decreasing immediate bacterial load. Parcels et al. [27] showed a significantly lower postoperative SSI rate after both perforated and nonperforated appendectomies with the use of imipenem in the irrigation solution. However, Anglen et al. [26] determined that the addition of antibiotic drugs to the irrigation solution had no significant effect on decreasing the bacterial count on *Staphylococcus*-coated steel screws. Furthermore, Owens et al. [28] demonstrated that some

antibiotic solutions did initially remove more bacteria during wound irrigation, but there was a rebound growth at 48 h in the mean bacterial count. We did not detect any deleterious effects of antibiotic laden PPL in any of our patients. Specifically, the vast majority did convert to negative cultures with no instances of allergic or adverse local reactions.

Although we feel our results provide an important contribution to hernia literature, this study has intrinsic limitations. The results also appear to be underpowered to make any definitive conclusions about the precise effect of antibiotic PPL on postoperative wound complications. With only 18 patients in the converted group compared to 34 in the persistently negative group, combined with a low overall rate of SSI, the beneficial association of PPL in reducing SSI rates was not statistically significant, possibly due to the type II error. However, it is important to note that superficial SSIs are common in clean-contaminated and contaminated cases. The fact that deep SSI was minimized, and even eliminated if the synthetic mesh was used, should not be overlooked. Additionally, although there were no significant differences detected between the biologic and synthetic groups, there may have been a component of selection bias as to which patients received biologic versus synthetic mesh; as a result, we have not made any recommendations on mesh selection in clean-contaminated or contaminated repairs. To address some of the above limitations, we plan to perform a prospective randomized trial comparing PPL with and without antibiotic solution to further evaluate the effects of the antibiotic irrigation itself.

Conclusion

The optimal method to perform a one-stage abdominal wall reconstruction in clean-contaminated and contaminated fields remains debatable. Our findings demonstrate that the retromuscular space has minimal intraoperative bioburden in the vast majority of patients, making it a desirable location for mesh placement if contamination is present. Furthermore, pressurized pulse irrigation of the retromuscular space with antibiotics prior to mesh implantation appears to be effective in further cleansing the wound and reduction in bacterial load in clean-contaminated and contaminated fields. We found that the use of PPL eliminated deep SSIs in patients undergoing synthetic mesh repairs. Overall, we believe our strategy of antibiotic pulse lavage of the extraperitoneal space may be an effective adjunct during major retromuscular abdominal wall repairs in clean-contaminated and contaminated settings.

Compliance with ethical standards

Disclosures Arnab Majumder, Heidi J. Miller, Parita Patel, Yuhsin V. Wu, and Heidi L. Elliott have no conflicts of interest or financial ties to disclose. Yuri W. Novitsky declares conflicts of interest [consultant for C.R. Bard (Davol) and Cooper Surgical, prior research support from C.R. Bard (Davol)] not directly related to the submitted work.

References

- Breuing K, Butler CE, Ferzoco S, Franz M, Hultman CS, Kilbridge JF, Rosen M, Silverman RP, Vargo D (2010) Incisional ventral hernias: review of the literature and recommendations regarding the grading and technique of repair. *Surgery* 148:544–558. doi:10.1016/j.surg.2010.01.008
- Koltz PF, Frey JD, Bell DE, Girotto JA, Christiano JG, Langstein HN (2013) Evolution of abdominal wall reconstruction: development of a unified algorithm with improved outcomes. *Ann Plast Surg* 71:554–560. doi:10.1097/SAP.0b013e3182a6367f
- Lowe JB, Lowe JB, Baty JD, Garza JR (2003) Risks associated with “components separation” for closure of complex abdominal wall defects. *Plast Reconstr Surg* 111:1276–1283. doi:10.1097/01.PRS.0000047021.36879.FD (quiz 1284–5; discussion 1286–8)
- Awad ZT, Puri V, LeBlanc K, Stoppa R, Fitzgibbons RJ, Iqbal A, Filipi CJ (2005) Mechanisms of ventral hernia recurrence after mesh repair and a new proposed classification. *J Am Coll Surg* 201:132–140. doi:10.1016/j.jamcollsurg.2005.02.035
- Luijendijk RW, Hop WC, van den Tol MP, de Lange DC, Braaksma MM, IJzermans JN, Boelhouwer RU, de Vries BC, Salu MK, Wereldsma JC, Bruijninx CM, Jeekel J (2000) A comparison of suture repair with mesh repair for incisional hernia. *N Engl J Med* 343:392–398. doi:10.1056/NEJM200008103430603
- Iqbal CW, Pham TH, Joseph A, Mai J, Thompson GB, Sarr MG (2007) Long-term outcome of 254 complex incisional hernia repairs using the modified Rives–Stoppa technique. *World J Surg* 31:2398–2404. doi:10.1007/s00268-007-9260-7
- Colavita PD, Zemlya AY, Tsirlin VB et al (2013) The expansive cost of wound complications following ventral hernia repair. In: American College of Surgeons meeting in Washington, DC
- Darouiche RO (2004) Treatment of infections associated with surgical implants. *N Engl J Med* 350:1422–1429. doi:10.1056/NEJMr035415
- Mangram AJ, Horan TC, Pearson ML, Silver LC, Jarvis WR (1999) Guideline for prevention of surgical site infection, 1999. Hospital Infection Control Practices Advisory Committee. *Infect Control Hosp Epidemiol* 20:250–278. doi:10.1086/501620 (quiz 279–80)
- Rodeheaver GT, Pettry D, Thacker JG, Edgerton MT, Edlich RF (1975) Wound cleansing by high pressure irrigation. *Surg Gynecol Obstet* 141:357–362
- Brown LL, Shelton HT, Bornside GH, Cohn I (1978) Evaluation of wound irrigation by pulsatile jet and conventional methods. *Ann Surg* 187:170–173
- Svoboda SJ, Bice TG, Gooden HA, Brooks DE, Thomas DB, Wenke JC (2006) Comparison of bulb syringe and pulsed lavage irrigation with use of a bioluminescent musculoskeletal wound model. *J Bone Joint Surg Am* 88:2167–2174. doi:10.2106/JBJS.E.00248
- Muñoz-Mahamud E, García S, Bori G, Martínez-Pastor JC, Zumbado JA, Riba J, Mensa J, Soriano A (2011) Comparison of a low-pressure and a high-pressure pulsatile lavage during

- debridement for orthopaedic implant infection. *Arch Orthop Trauma Surg* 131:1233–1238. doi:[10.1007/s00402-011-1291-8](https://doi.org/10.1007/s00402-011-1291-8)
14. Mote GA, Malay DS (2010) Efficacy of power-pulsed lavage in lower extremity wound infections: a prospective observational study. *J Foot Ankle Surg* 49:135–142. doi:[10.1053/j.jfas.2009.10.004](https://doi.org/10.1053/j.jfas.2009.10.004)
 15. Fry DE (2013) The prevention of surgical site infection in elective colon surgery. *Scientifica* 2013:896297. doi:[10.1155/2013/896297](https://doi.org/10.1155/2013/896297)
 16. Cervantes-Sánchez CR, Gutiérrez-Vega R, Vázquez-Carpizo JA, Clark P, Athié-Gutiérrez C (2000) Syringe pressure irrigation of subdermic tissue after appendectomy to decrease the incidence of postoperative wound infection. *World J Surg* 24:38–41
 17. Novitsky YW, Elliott HL, Orenstein SB, Rosen MJ (2012) Transversus abdominis muscle release: a novel approach to posterior component separation during complex abdominal wall reconstruction. *Am J Surg* 204:709–716. doi:[10.1016/j.amjsurg.2012.02.008](https://doi.org/10.1016/j.amjsurg.2012.02.008)
 18. Carbonell AM, Criss CN, Cobb WS, Novitsky YW, Rosen MJ (2013) Outcomes of synthetic mesh in contaminated ventral hernia repairs. *J Am Coll Surg* 217:991–998. doi:[10.1016/j.jamcollsurg.2013.07.382](https://doi.org/10.1016/j.jamcollsurg.2013.07.382)
 19. Hargrove R, Ridgeway S, Russell R, Norris M, Packham I, Levy B (2006) Does pulse lavage reduce hip hemiarthroplasty infection rates? *J Hosp Infect* 62:446–449. doi:[10.1016/j.jhin.2005.07.012](https://doi.org/10.1016/j.jhin.2005.07.012)
 20. Luedtke-Hoffmann KA, Schafer DS (2000) Pulsed lavage in wound cleansing. *Phys Ther* 80:292–300
 21. Nikfarjam M, Weinberg L, Fink MA, Muralidharan V, Starkey G, Jones R, Staveley-O'Carroll K, Christophi C (2014) Pressurized pulse irrigation with saline reduces surgical-site infections following major hepatobiliary and pancreatic surgery: randomized controlled trial. *World J Surg* 38:447–455. doi:[10.1007/s00268-013-2309-x](https://doi.org/10.1007/s00268-013-2309-x)
 22. Wheeler CB, Rodeheaver GT, Thacker JG, Edgerton MT, Edilich RF (1976) Side-effects of high pressure irrigation. *Surg Gynecol Obstet* 143:775–778
 23. Platell C, Papadimitriou JM, Hall JC (2000) The influence of lavage on peritonitis. *J Am Coll Surg* 191:672–680
 24. Primus FE, Harris HW (2013) A critical review of biologic mesh use in ventral hernia repairs under contaminated conditions. *Hernia* 17:21–30. doi:[10.1007/s10029-012-1037-8](https://doi.org/10.1007/s10029-012-1037-8)
 25. Bahrs C, Schnabel M, Frank T, Zapf C, Mutters R, von Garrel T (2003) Lavage of contaminated surfaces: an in vitro evaluation of the effectiveness of different systems. *J Surg Res* 112:26–30
 26. Anglen JO, Apostoles S, Christensen G, Gainor B (1994) The efficacy of various irrigation solutions in removing slime-producing *Staphylococcus*. *J Orthop Trauma* 8:390–396
 27. Parcels JP, Mileski JP, Gnagy FT, Haragan AF, Mileski WJ (2009) Using antimicrobial solution for irrigation in appendicitis to lower surgical site infection rates. *Am J Surg* 198:875–880. doi:[10.1016/j.amjsurg.2009.09.002](https://doi.org/10.1016/j.amjsurg.2009.09.002)
 28. Owens BD, White DW, Wenke JC (2009) Comparison of irrigation solutions and devices in a contaminated musculoskeletal wound survival model. *J Bone Joint Surg Am* 91:92–98. doi:[10.2106/JBJS.G.01566](https://doi.org/10.2106/JBJS.G.01566)