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Six-year national study of damage control laparotomy and the effect of repeat re-exploration on rate of infectious complications

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ABSTRACT

Background Damage control laparotomy (DCL) is a life-saving procedure in patients with abdominal hemorrhage. After DCL, patients are sometimes left with an open abdomen (OA) so they may undergo multiple exploratory laparotomies (EXLAP), or re-explorations. Patients with OA are at increased risk of infectious complications (ICs). The association between number of re-explorations after DCL and the number of ICs is not clear. We hypothesized that each additional re-exploration increases the risk of developing IC.

Methods This 6-year retrospective cohort study included patients aged ≥16 years from the NTDB who had DCL defined as EXLAP within 2 hours of arrival (ICD-9: 54.11, 54.12, 54.19) with at least one re-exploration. The primary outcome was IC (ie, superficial surgical site infection (SSI), organ space SSI, deep SSI, sepsis, pneumonia, or catheter-related bloodstream infection), examined dichotomously (present/absent) and ordinally as the number of ICs. Multivariate Poisson regression was used to assess the association between number of re-explorations and number of ICs. Significance was assigned at $p<0.01$.

Results There were 7431 patients who underwent DCL; 2509 (34%) patients developed at least one IC. The rate of IC was lowest in patients who were closed during the first re-exploration (27%) and significantly increased with each re-exploration to 59% in patients who had five or more re-explorations (Cochran-Armitage trend $p<0.001$). After adjustment, there was 14% increased risk of an additional IC with each re-exploration ($p<0.001$).

Discussion For patients requiring DCL, each re-exploration of the abdomen is associated with increased rate of ICs.

Level of evidence III, retrospective epidemiological study.

BACKGROUND

Damage control laparotomy (DCL) is used for patients suffering major, life-threatening abdominal trauma. In comparison to the more traditional definitive exploratory laparotomy (EXLAP), during which the patient undergoes a single abdominal exploration with primary closure, DCL is characterized by a staged approach. The first phase of DCL is the initial EXLAP, where the primary goal is controlling abdominal hemorrhage while concomitantly limiting wound and organ space contamination. The second phase encompasses the resuscitation and stabilization of the patient—typically performed in the intensive care unit (ICU)—during which the abdomen is left open. The third, and final, phase is definitive treatment. During the third phase, the abdomen may be left open for future re-exploration, it may be partially closed, or the treating surgeon may be able to close the abdomen completely. The level of closure is dependent on the successful resuscitation of the patient and the state of the laparotomy wound. Due to the varying levels of abdominal closure, the third stage of DCL may last several days and may require repeat re-explorations before definitive abdominal closure occurs, leaving the patient with an open abdomen (OA) for an extended period.

In general, returning to the operating room (OR) multiple times increases a patient's risk of adverse outcomes. Wafaisade and colleagues queried a national trauma database of nearly 30 000 patients and found that trauma patients were more likely to become septic with more operative procedures.[1] This study included all operations and did not focus solely on abdominal procedures. Additional studies have narrowed the focus of study on EXLAP. Investigators at a Memorial Hermann hospital investigated complications in 222 patients who presented with life-threatening truncal hemorrhage. They reported that DCL, rather than primary closure at first EXLAP, increases risk of mortality, superficial surgical site infections (SSI), enteric suture line failure, and fascial dehiscence.[2] The authors concluded that DCL was overused among their trauma population and reducing the use of DCL may be associated with improved survival and fewer complications.

Delayed abdominal closure after DCL is also associated with adverse outcomes. Hatch *et al* reported a significantly greater risk of complications among patients whose abdomens remained open longer, with greater frequencies of abscesses, pneumonia, sepsis, and multiorgan failure.[3] This group did not examine infectious complications (ICs) such as SSIs and catheter-related bloodstream infections (CRBSIs). Smith *et al* showed that a closure delay of 9 days or more was closely associated with an increased risk of death.[4] Recent publications present a consensus about patients who undergo DCL: they should be closed as soon as physiologically possible.

Limited research has been completed on the association between number of re-explorations and corresponding rise in number of ICs; this investigation sought to quantify this association.

We hypothesized that each additional re-exploration in a DCL patient increases that patient's risk of developing an additional IC.

METHODS

Setting, study design, and patient population

This retrospective, observational cohort study was conceived by physicians at a level 1 trauma center in Colorado. Data for a 6-year period were obtained from the National Trauma Data Bank (NTDB), a publicly available data set that serves as the largest repository of trauma-related data in the USA.

The study population included patients captured in the NTDB between 2010 and 2015 who were admitted to the hospital for at least one International Classification of Diseases 9th Revision (ICD-9) procedure code indicating EXLAP (ICD-9: 54.11, 54.12, 54.19). Patients were excluded if they were younger than 16, did not have an initial EXLAP within 2 hours of arrival, or had definitive closure at initial EXLAP (no re-exploration). The NTDB transitioned from ICD-9 coding to ICD-10 coding beginning in 2016. The study period chosen used the six most recent years of ICD-9 coding, as only 2 years of NTDB data were available with ICD-10 coding. As NTDB data are publicly available and completely deidentified of protected health information, this study did not require institutional approval.

Study variables

The primary exposure variable was number of re-explorations, examined ordinally. The number of re-explorations was also assessed categorically, comparing patients closed after completion of the first re-exploration to those who underwent more than one re-exploration. The primary outcome was the development of an IC (ie, superficial SSI, organ space SSI, deep SSI, severe or systemic sepsis, pneumonia, or CRBSI) examined dichotomously (yes/no) as well as ordinally. Secondary outcomes were ventilator days, hospital length of stay (HLOS), ICULOS, and in-hospital mortality.

The following patient characteristics were analyzed for association with the exposure and primary variables: age, sex, race, ethnicity, insurance used, injury type (blunt vs. all others), interhospital transfer status, multiple comorbidities and pre-existing conditions, Injury Severity Score (ISS, <16 vs. ≥16), Glasgow Coma Scale score (GCS, 13–15 vs. 3–12), abnormal emergency department (ED) vital sign measures (oxygen saturation <95%, body temperature <36.4°C or >37.6°C, heart rate <60 or >100 beats per minute, systolic blood pressure (SBP) <90 mm Hg, respiratory rate <12 or >16 breaths per minute).

Statistical analyses

The associations of all variables with the categorical outcome (ie, development of an IC) and exposure (ie, multiple re-explorations) were measured using χ^2 or Fisher's exact tests, where appropriate. Results are presented as numbers and proportions (n, %).

Poisson regression was used to model the relationship between number of re-explorations and number of ICs, after adjustment for relevant covariates. Variables that were significantly associated with the outcome or exposure of interest in univariate analysis at the $p<0.01$ significance level were individually added to the Poisson model. Variables remained in the model when they were statistically significant at $p<0.01$ when adjusting for the other variables in the model. The final adjusted Poisson model was determined by a combination of statistically significant variables alongside the lowest possible Akaike information criterion. Results for Poisson analysis are presented as risk ratios, which were calculated from β estimates, and p values. The unadjusted association between number of re-explorations and developing an IC was also analyzed with a Cochran-Armitage trend test, with two-sided significance assigned at $p<0.01$. All analyses were completed using SAS software V.9.4 (SAS Institute).

RESULTS

A total of 7431 patients in the NTDB underwent DCL during the 6-year period of study. Most patients were male (n=5999, 81%), younger than 55 (n=6279, 85%), had a GCS score of 13–15 (n=4759, 64%), and had an ISS ≥16 (n=5985, 81%). The overall in-hospital mortality rate was 15% (n=1116).

The majority (n=4773; 64%) of patients had 1 re-exploration, 19% (n=1395) had 2 re-explorations, 7% (n=543) had 3 re-explorations, 4% (n=293) had 4 re-explorations, and 6% (n=427) had ≥5 re-explorations. The median (IQR) time from hospital arrival to initial DCL was 1 (1–2) hours. The time from arrival to last re-exploration was 37 (21–53) hours for patients with only one re-exploration but increased to 432 (278–619) hours for patients with ≥5 re-explorations.

Univariate associations: development of IC

Overall, 34% of patients developed an IC, and those patients were more likely to have multiple re-explorations than patients who did not develop an IC (49.4% vs. 28.8%, $p<0.001$). Patients who developed an IC also had a longer time from arrival to last re-exploration than patients who did not develop an IC (median: 88 hours vs. 41 hours).

As shown in table 1, patients who developed an IC were more likely to be ≥55 years old (17.4% vs. 14.6%, $p=0.001$), have a blunt injury (45.9% vs. 41.2%, $p<0.001$), have an ISS ≥16 (86.7% vs. 77.4%, $p<0.001$), and have a GCS score of <13 (38.5% vs. 34.7%, $p=0.001$). Patients who developed an IC were also more likely to have comorbidities of hypertension, a bleeding disorder, obesity, and be a smoker, and were also more likely to have abnormal oxygen saturation, body temperature, and heart rate in the ED (table 1). Patients who developed an IC were not different from those who did not develop an IC with regard to sex, interhospital transfer status, most studied comorbidities, abnormal ED SBP, or abnormal ED respiratory rate.

Patients who developed an IC also had worse in-hospital outcomes than patients who did not develop an IC; they were more likely to have stayed in the hospital longer than a week (98.4% vs. 79.5%, $p<0.001$), in the ICU longer than a week (82.2% vs. 43.5%, $p<0.001$), and on a ventilator for more than 5 days (74.2% vs. 34.6%, $p<0.001$). However, they were less likely to die in hospital than those patients who did not develop an IC (11.3% vs. 16.9%, $p<0.001$).

Univariate associations: closed at first re-exploration

Patients who were closed at first re-exploration were less likely to develop any IC (26.6% vs. 46.6%, $p<0.001$) than patients who were closed at later re-explorations. These patients were also more likely to have an ISS <16 (21.4% vs. 16.1%, $p<0.001$). With regard to abnormal ED vital signs, a smaller portion of patients who were closed at first re-exploration demonstrated abnormal oxygen saturation, abnormal body temperature, abnormal heart rate, and abnormal SBP than patients who had more than one re-exploration (table 2). Closure at first re-exploration was not associated with age, sex, mechanism, transfer status, any comorbidity or pre-existing condition, GCS, or abnormal ED respiratory rate.

Table 1 Associations of variables with developing an infectious complication

Variable, n (%)	No IC 4922 (66.2)	IC 2509 (33.8)	P value
Number of re-explorations			**<0.001**
1	3503 (71.2)	1270 (50.6)	
2	834 (16.9)	561 (22.4)	
3	278 (5.7)	265 (10.6)	
4	134 (2.7)	159 (6.3)	
≥5	173 (3.5)	254 (10.1)	
Age, ≥55 years	716 (14.6)	436 (17.4)	**0.001**
Male	3951 (80.3)	2048 (81.6)	0.172
Blunt mechanism	2023 (41.2)	1151 (45.9)	**<0.001**
Interhospital transfer	733 (14.9)	349 (13.9)	0.256
Comorbidities			
Hypertension	523 (10.6)	344 (13.7)	**<0.001**
Alcoholism	304 (6.2)	181 (7.2)	0.087
Respiratory disease	175 (3.6)	119 (4.7)	0.013
Bleeding disorder	90 (1.8)	74 (3.0)	**0.002**
Diabetes mellitus	216 (4.4)	132 (5.3)	0.092
Current smoker	812 (16.5)	481 (19.2)	**0.004**
Obesity	253 (5.1)	198 (7.9)	**<0.001**
Cirrhosis	84 (1.7)	27 (1.1)	0.034
Drug abuse or dependence	274 (5.6)	159 (6.3)	0.180
Injury Severity Score			**<0.001**
<16	1111 (22.6)	335 (13.3)	
≥16	3811 (77.4)	2174 (86.7)	
Glasgow Coma Scale score			**0.001**
13–15	3215 (65.3)	1544 (61.5)	
3–12	1707 (34.7)	965 (38.5)	
Abnormal ED vital signs			
Oxygen saturation <95%	714 (17.0)	444 (20.7)	**<0.001**
Temperature <36.4°C or >37.6°C	3560 (72.3)	1889 (75.3)	**0.006**
Pulse <60 or >100 beats/min	2864 (59.4)	1587 (64.4)	**<0.001**
SBP <90 mm Hg	1362 (27.7)	720 (28.7)	0.352
RR <12 or >16 breaths/min	3749 (80.6)	1947 (82.9)	0.020
In-hospital mortality	833 (16.9)	283 (11.3)	**<0.001**
HLOS (days)			**<0.001**
1–6	1011 (20.5)	40 (1.6)	
>7	3911 (79.5)	2469 (98.4)	
ICULOS (days)			**<0.001**
0	291 (5.9)	56 (2.2)	
1–6	2490 (50.6)	391 (15.6)	
>7	2141 (43.5)	2062 (82.2)	
Ventilator days			**<0.001**
0	771 (15.7)	172 (6.9)	
1–5	2446 (49.7)	474 (18.9)	
>5	1705 (34.6)	1863 (74.2)	

Bolded p values indicate statistical significance.
ED, emergency department; HLOS, hospital length of stay; IC, infectious complication; ICULOS, intensive care unit length of stay; RR, respiratory rate; SBP, systolic blood pressure.

Table 2 Associations of variables with multiple re-explorations

Variable, n (%)	1 re-exploration 4773 (64.2)	>1 re-exploration 2658 (35.8)	P value
Any infectious complications	1270 (26.6)	1239 (46.6)	**<0.001**
Age, ≥55 years	725 (15.2)	427 (16.1)	0.318
Male	3875 (81.2)	2124 (79.9)	0.170
Blunt mechanism	2017 (42.3)	1157 (43.6)	0.786
Interhospital transfer	709 (14.8)	373 (14.0)	0.336
Comorbidities			
Hypertension	542 (11.4)	325 (12.2)	0.262
Alcoholism	296 (6.2)	189 (7.1)	0.128
Respiratory disease	181 (3.8)	113 (4.2)	0.330
Bleeding disorder	100 (2.1)	64 (2.4)	0.379
Diabetes mellitus	214 (4.5)	134 (5.0)	0.275
Current smoker	863 (18.1)	430 (16.2)	0.038
Obesity	273 (5.7)	178 (6.7)	0.091
Cirrhosis	63 (1.3)	48 (1.8)	0.098
Drug abuse or dependence	279 (5.9)	154 (5.8)	0.928
Injury Severity Score			**<0.001**
<16	1019 (21.4)	427 (16.1)	
≥16	3754 (78.6)	2231 (83.9)	
Glasgow Coma Scale score			0.241
13–15	3080 (64.5)	1679 (63.2)	
3–12	1693 (35.5)	979 (36.8)	
Abnormal ED vital signs			
Oxygen saturation <95%	707 (17.2)	451 (20.1)	**0.005**
Temperature <36.4°C or >37.6°C	3440 (72.1)	2009 (75.6)	**0.001**
Pulse <60 or >100 beats/min	2765 (59.0)	1686 (64.8)	**<0.001**
SBP <90 mm Hg	1266 (26.5)	816 (30.7)	**<0.001**
RR <12 or >16 breaths/min	3641 (80.7)	2055 (82.7)	0.038
In-hospital mortality	382 (14.3)	434 (16.3)	0.018
HLOS (days)			**<0.001**
1–7	888 (18.6)	163 (6.1)	
>7	3885 (81.4)	2495 (93.9)	
ICULOS (days)			**<0.001**
0	294 (6.2)	53 (2.0)	
1–7	2358 (49.4)	523 (19.7)	
>7	2121 (44.4)	2082 (78.3)	
Ventilator days			**<0.001**
0	770 (16.1)	173 (6.5)	
1–5	2297 (48.1)	623 (23.4)	
>5	1706 (35.7)	1862 (70.1)	

Bolded p values indicate statistical significance.
ED, emergency department; HLOS, hospital length of stay; ; ICULOS, intensive care unit length of stay; RR, respiratory rate; SBP, systolic blood pressure.

Closure at first re-exploration was not significantly associated with a lower rate of in-hospital mortality. However, patients closed at first re-exploration were more likely to have an HLOS of 1–7 days (18.6% vs. 6.1%, p<0.001), and they were more likely to avoid the ICU (6.2% vs. 2.0%, p<0.001) and time on a ventilator (16.1% vs. 6.5%, p<0.001) than patients with multiple re-explorations.

Trends in infection rates with more laparotomies

Before adjustment, there was a significant association between developing an IC and the number of re-explorations (Cochran-Armitage trend p<0.001, figure 1). The rate of IC was lowest

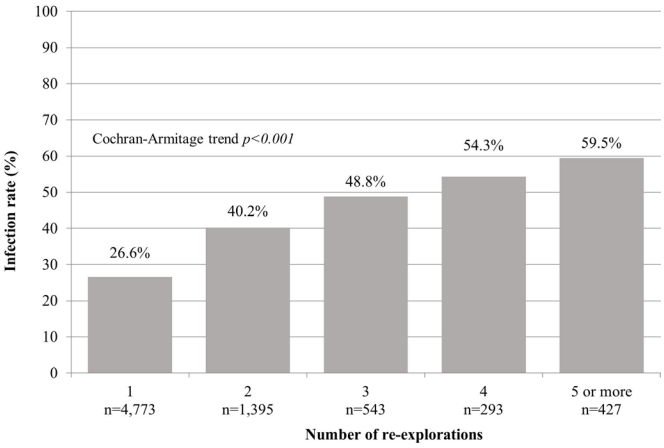

Figure 1 Histogram demonstrating rate (%) of an infectious complication by number of re-explorations.

in patients who were closed at the first re-exploration (27%) and more than doubled (59%) in patients who had ≥5 re-explorations.

Poisson regression

The association between number of ICs and number of re-explorations is shown in figure 2; as the number of re-explorations increased, the ordinal IC count increased. Based on significant associations of covariates with both the outcome and exposure of interest, the variables made available to Poisson regression included number of re-explorations, age, blunt mechanism, hypertension, bleeding disorder, current smoker status, obesity, ISS, GCS, abnormal ED oxygen saturation, abnormal ED body temperature, abnormal ED heart rate, and abnormal ED SBP. The final adjusted Poisson regression model included number of re-explorations, ISS, hypertension, bleeding disorder, obesity, and status as a current smoker.

After adjustment, each additional re-exploration increased a patient's risk of IC by 14% (table 3). The risk of another IC also independently increased by 19% among patients with hypertension, 23% for smokers, 24% among the obese, 43% among those with a bleeding disorder, and 56% among patients with an ISS ≥16.

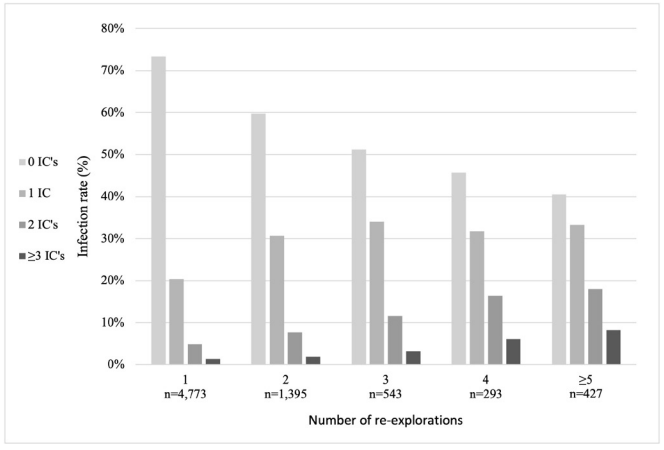

Figure 2 Histogram demonstrating number of infectious complications by number of re-explorations. IC, infectious complication.

DISCUSSION

The findings presented here demonstrate that, for patients who require DCL, each additional return to the OR for re-exploration of the abdomen is associated with increased rate of ICs. The overall rate of IC in our population (33.8%) aligns with a recent study by Gundel *et al*, who identified at least one infectious or respiratory complication in 24% of laparotomy patients.[5] It is understandable that our rate would be somewhat higher because our study population included DCL patients and excluded patients who had primary closure; that is, our study population included more severe, 'sicker' patients. The differences in rates of infections and re-explorations were consistent with recent literature as well. In one study of 517 OAs from 14 level 1 trauma centers during 1 year, patients who experienced complications (e.g., intra-abdominal sepsis or abscesses) after DCL had nearly twice as many abdominal explorations as those without complications, and investigators reported that an increasing number of explorations was an independent predictor of any complication.[6] These results align with our findings of increased numbers of infections with more re-explorations. However, our study adds considerable depth to the literature because it examined a population more than 10-fold larger, it focused specifically on ICs rather than any complications, and it demonstrated an association between rates of IC and numbers of re-explorations via Poisson regression.

Although the life-saving utility of DCL is clear, clinicians have intimated that DCL is overused and may contribute to needlessly high rates of iatrogenic morbidity and mortality.[7] One group reported that a decrease in DCL usage at their center did not result in a corresponding increase in rates of complications or death.[2] Their quality improvement project showed that DCL is sometimes implemented unnecessarily, and it is possible to reduce DCL usage without additionally harming severely injured trauma patients. However, despite efforts to reduce reliance on DCL, it remains an effective method of managing the severely injured, hemodynamically unstable trauma patient. Although leaving the abdomen open after the initial DCL and initial re-exploration may increase the patient's risk of infection and other complications, clinicians have shown the long-term survival benefit of DCL and resultant OA.[8]

Through our Poisson regression, we have shown that an increase in re-explorations is associated with a proportional increase in number of ICs. For optimal management of patients undergoing DCL, the World Society of Emergency Surgery (WSES) recommends that the primary goal should be to get the abdomen closed as soon as the patient can physiologically tolerate it.[9] Our finding that a greater rate of return to the OR for additional abdominal re-explorations is associated with a higher rate of IC supports this WSES recommendation.

Comorbidities of hypertension, smoking status, and obesity are recognized risk factors for poor outcome after surgery. After analyzing data from over 5 million operations across 855 hospitals and compiling decades of literature, the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) developed a Surgical Risk Calculator that incorporates several important risk factors to help guide clinicians in surgical decision-making and inform patients about risk during the informed consent process.[10] The calculator uses these predictors, along with the type of procedure, to assess the risk of developing 18 different poor outcomes within 30 days of surgery, including various types of SSI, pneumonia, urinary tract infection, venous thromboembolism, unplanned hospital readmission, and death. It was first built in 2013 and was recently updated in December

Table 3 Poisson regression model building—effect of covariates on number of infectious complications

Risk Ratio	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	
Number of re-explorations	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	
Age ≥55		1.21	1.18	1.15	1.14	1.12			
Blunt injury			1.06						
Hypertension				1.18	1.15	1.18	1.23	1.17	
Bleeding disorder									
Obesity					1.24	1.24	1.25	1.22	
Current smoker									
Injury Severity Score ≥16						1.55	1.55	1.49	
Glasgow Coma Scale score <13									
Oxygen saturation <95%								1.10	
Temperature <36.4°C or >37.6°C									
Pulse <60 or >100 beats/min									
SBP <90 mm Hg									
AIC	13181	13166	13165	13159	13150	13072	13075	11223	
Risk ratio	**Model 9**	**Model 10**	**Model 11**	**Model 12**	**Model 13**	**Model 14**	**Model 15**	**Model 16 (final)**	**P value**
Number of re-explorations	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	<0.001
Age ≥55							1.12		
Blunt injury									
Hypertension	1.24	1.23	1.23	1.24	1.23	1.19	1.15	1.19	<0.001
Bleeding disorder						1.43	1.37	1.43	<0.001
Obesity	1.24	1.25	1.24	1.25	1.24	1.24	1.24	1.24	0.001
Current smoker					1.23	1.23	1.24	1.23	<0.001
Injury Severity Score ≥16	1.53	1.56	1.54	1.53	1.56	1.56	1.55	1.56	<0.001
Glasgow Coma Scale score <13				1.06					
Oxygen saturation <95%									
Temperature <36.4°C or >37.6°C			1.08						
Pulse <60 or >100 beats/min	1.08								
SBP <90 mm Hg		0.99							
AIC	12829	13077	13073	13075	13056	13046	13042	13046	

AIC, Akaike information criterion; rr, remove from abbreviations list.; SBP, systolic blood pressure.

2020.[10 11] According to the calculator, a patient receiving an emergent laparotomy who suffers from hypertension, obesity, and is a current smoker is at 'above average' risk of SSI, while that patient's calculated risk of all other outcomes is calculated to be 'below average'. It is important to note that the ACS NSQIP Surgical Risk Calculator would not be used to calculate the risk of poor outcome in a DCL patient because the patient would likely be unable to give a complete and accurate medical history due to physiological or neurological derangement. However, we think that a discussion of this tool is relevant because it encompasses data from a large sample of patients who underwent both emergent and non-emergent laparotomies, including the patients in this study, and the risk factors for IC identified among the DCL patients in this study align with those used in the calculator.

One comorbidity identified as a predictor of ICs for our study, which is not included in the NSQIP risk calculator, was bleeding disorder. This class of comorbidity that encompasses disorders such as hemophilia, von Willebrand disease, and factor V Leiden thrombophilia is associated with bleeding and clotting complications but has also demonstrated a predictive ability for infectious outcomes. In a 2018 study of 6538 SSIs identified among patients at 136 Veterans Affairs hospitals, researchers demonstrated that a bleeding disorder was associated with elevated risk of postoperative SSI.[12] Other studies of orthopedic patients with hemophilia demonstrate that they have increased rates of infection postoperatively, potentially as high as eightfold greater.[13–15]

The severity of the patients' injuries demonstrated the most significant independent increase in risk of developing an additional IC in our patient population. Patients who undergo multiple laparotomies, akin to our study population, tend to have significantly higher ISS.[16 17] Higher ISS is predictive of outcome measures, including surgical complications and death, regardless of age or mechanism of injury.[18–21] In fact, multiple studies have shown ISS to be a significant independent predictor of nosocomial infections in trauma patients.[22–24] To our knowledge, however, no investigators have demonstrated high ISS as a strong risk factor for IC in the DCL population.

Limitations

There are limitations to our study. First, this study possesses the limitations inherent to all retrospective studies that employ large, nationwide, registry-style data sets. These data were not collected with an a priori hypothesis in mind, so the conclusions that stem from them must be interpreted with discretion. There are possibly variables missing from the NTDB that could have improved our model, such as the use of antimicrobial medications for prophylaxis against ICs and associated organisms.

Second, it is possible that we are seeing increased abdominal explorations as a result of higher infection rates, rather than the converse. DuBose *et al* found that patients who develop bloodstream infections, intra-abdominal abscesses, or sepsis were less likely to achieve definitive closure.[17] These findings essentially swap the exposure and outcome we have studied here. Chabot and Nirula previously recognized this conundrum, stating that regardless of the causal pathway, leaving the abdomen open increases the risk of IC while at the same time developing an IC decreases the chance of closure.[25] It may not be possible to determine the causal pathway, although future investigations should evaluate the dates of diagnosis for each infection as it relates to re-exploration.

Third, it is possible that re-exploration of the abdomen could be either reopening of recently performed laparotomy incision or it could be reaccessing the abdomen through an incision that was left open. We do not know what level of skin closure was obtained at each of the re-explorations, so we cannot assert which patients are left with an OA, which patients have skin closure without primary closure, and which patients have complete closure with subsequent reincision.

Fourth, the inability to accurately describe the time from arrival to definitive abdominal closure is a limitation. The number of re-explorations and ICs increased as time from arrival to final re-exploration increased; however, the final re-exploration may have been primary closure, a subsequent reincision, or an OA. It is possible there is residual confounding because we were unable to evaluate a confirmed time to definitive closure as a covariate in the final Poisson model. While there are no conclusive data regarding timing of re-exploration in the DCL population, the WSES guidelines state re-exploration should occur within 24–72 hours from initial laparotomy or subsequent exploration, and definitive closure should occur as soon as possible.[9] The median time to first re-exploration was 37 (21–53) hours and the median time to final re-exploration was 47 hours, within the suggested range per the WSES recommendations.

Fifth, patients with IC have longer LOS, both in the hospital and in the ICU. It is possible that these longer LOS could contribute to higher rates of IC and other complications due to a longer period during which the patient is susceptible to nosocomial infection.[26] Each of these limitations in the data collection and analyses must be considered when applying the findings presented to clinical practice.

Finally, our analyses incorporated data from 2010 to 2015. Since 2015, the use of DCL has evolved. Studies published after 2015 have suggested reducing the use of DCL due to its association with adverse outcomes such as SSIs,[2 7] and a 2017 review article described a shift toward the use of damage control resuscitation (DCR) alongside DCL, implementing early and aggressive administration of blood products, in an effort to reduce adverse outcomes among DCL patients.[25] Despite this recognized shift in management of DCL patients, we did not examine the use of DCR in tandem with DCL.

CONCLUSIONS

Patients whose abdomens are left open for re-exploration after DCL are at significant risk for iatrogenic morbidity. In our study, each additional re-exploration was associated with a proportional increase in the risk of another IC. While the necessity and utility of DCL in the severely injured and hemodynamically unstable patient is evident, our results demonstrate an association between the number of re-explorations and an increased risk of ICs, which may suggest that limited re-explorations and early abdominal closure may reduce rates of post-DCL infection. We urge investigators pursuing prospective studies to collect information about timing to IC, use of prophylactic antimicrobial medications, and the organisms isolated on culture to better understand the clinical implications of multiple abdominal re-explorations.

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REFERENCES

1 Wafaisade A, Lefering R, Bouillon B, Sakka SG, Thamm OC, Paffrath T, Neugebauer E, Maegele M, Trauma Registry of the German Society for Trauma Surgery. Epidemiology and risk factors of sepsis after multiple trauma: an analysis of 29,829 patients from the trauma registry of the German Society for trauma surgery. *Crit Care Med* 2011;39:621–8.
2 Harvin JA, Wray CJ, Steward J, Lawless RA, McNutt MK, Love JD, Moore LJ, Wade CE, Cotton BA, Holcomb JB. Control the damage: morbidity and mortality after emergent trauma laparotomy. *Am J Surg* 2016;212:200–9.
3 Hatch QM, Osterhout LM, Podbielski J, Kozar RA, Wade CE, Holcomb JB, Cotton BA. Impact of closure at the first take back: complication burden and potential overutilization of damage control laparotomy. *J Trauma* 2011;71:1503–11.
4 Smith JW, Nash N, Procter L, Benns M, Franklin GA, Miller K, Harbrecht BG, Bernard AC. Not all abdomens are the same: a comparison of damage control surgery for intra-abdominal sepsis versus trauma. *Am Surg* 2016;82:427–32.
5 Gundel O, Gundersen SK, Dahl RM, Jørgensen LN, Rasmussen LS, Wetterslev J, Sæbye D, Meyhoff CS. Timing of surgical site infection and pulmonary complications after laparotomy. *Int J Surg* 2018;52:56–60.
6 Bradley MJ, DuBose JJ, Scalea TM, Holcomb JB, Shrestha B, Okoye O, Inaba K, Bee TK, Fabian TC, Whelan JF. Independent predictors of enteric fistula and abdominal sepsis after damage control laparotomy. *JAMA Surg* 2013;148:947–54.
7 Harvin JA, Wray CJ, Steward J, Lawless RA, McNutt MK, Love JD, Moore LJ, Wade CE, Cotton BA, Holcomb JB. Control the damage: morbidity and mortality after emergent trauma laparotomy. *Am J Surg* 2016;212:34–9.
8 Brenner M, Bochicchio G, Bochicchio K, Ilahi O, Rodriguez E, Henry S, Joshi M, Scalea T. Long-Term impact of damage control laparotomy: a prospective study. *Arch Surg* 2011;146:395–9.
9 Coccolini F, Roberts D, Ansaloni L, Ivatury R, Gamberini E, Kluger Y, Moore EE, Coimbra R, Kirkpatrick AW, Pereira BM, *et al*. The open abdomen in trauma and non-trauma patients: WSES guidelines. *World J Emerg Surg* 2018;13:7.
10 American College of Surgeons National Surgical Quality Improvement Program. ACS NSQIP® Surgical Risk Calculator. 2020. https://riskcalculator.facs.org/RiskCalculator/index.jsp.
11 Bilimoria KY, Liu Y, Paruch JL, Zhou L, Kmiecik TE, Ko CY, Cohen ME. Development and evaluation of the universal ACS NSQIP surgical risk calculator: a decision aid and informed consent tool for patients and surgeons. *J Am Coll Surg* 2013;217:833–42.
12 Li X, Nylander W, Smith T, Han S, Gunnar W. Risk factors and predictive model development of Thirty-Day post-operative surgical site infection in the Veterans administration surgical population. *Surg Infect* 2018;19:278–85.
13 Ernstbrunner L, Hingsammer A, Catanzaro S, Sutter R, Brand B, Wieser K, Fucentese SF. Long-term results of total knee arthroplasty in haemophilic patients: an 18-year follow-up. *Knee Surg Sports Traumatol Arthrosc* 2017;25:3431–8.

14 Goddard NJ, Rodriguez-Merchan EC, Wiedel JD. Total knee replacement in haemophilia. *Haemophilia* 2002;8:382–6.
15 Rodriguez-Merchan EC. Preventing surgical site infection in haemophilia patients undergoing total knee arthroplasty. *Blood Coagul Fibrinolysis* 2012;23:477–81.
16 Swaroop M, Williams M, Greene WR, Sava J, Park K, Wang D. Multiple laparotomies are a predictor of fascial dehiscence in the setting of severe trauma. *Am Surg* 2005;71:402–5.
17 DuBose JJ, Scalea TM, Holcomb JB, Shrestha B, Okoye O, Inaba K, Bee TK, Fabian TC, Whelan J, Ivatury RR, AAST Open Abdomen Study Group. Open abdominal management after damage-control laparotomy for trauma: a prospective observational AAST multicenter study. *J Trauma Acute Care Surg* 2013;74:113–20. discussion 1120-1122.
18 Frane N, Iturriaga C, Bub C, Regala P, Katsigiorgis G, Linn M. Risk factors for complications and in-hospital mortality: an analysis of 19,834 open pelvic ring fractures. *J Clin Orthop Trauma* 2020;11:1110–6.
19 Kirshenbom D, Ben-Zaken Z, Albilya N, Niyibizi E, Bala M, Age O. Older age, comorbid illnesses, and injury severity affect immediate outcome in elderly trauma patients. *J Emerg Trauma Shock* 2017;10:146–50.
20 Bradley M, Okoye O, DuBose J, Inaba K, Demetriades D, Scalea T, O'Connor J, Menaker J, Morales C, Shiflett T, *et al*. Risk factors for post-traumatic pneumonia in patients with retained haemothorax: results of a prospective, observational AAST study. *Injury* 2013;44:1159–64.
21 Arroyo W, Nelson KJ, Belmont PJ, Bader JO, Schoenfeld AJ. Pelvic trauma: what are the predictors of mortality and cardiac, venous thrombo-embolic and infectious complications following injury? *Injury* 2013;44:1745–9.
22 Lustenberger T, Turina M, Seifert B, Mica L, Keel M. The severity of injury and the extent of hemorrhagic shock predict the incidence of infectious complications in trauma patients. *Eur J Trauma Emerg Surg* 2009;35:538–46.
23 Wutzler S, Bläsius FM, Störmann P, Lustenberger T, Frink M, Maegele M, Weuster M, Bayer J, Caspers M, Seekamp A, *et al*. Pneumonia in severely injured patients with thoracic trauma: results of a retrospective observational multi-centre study. *Scand J Trauma Resusc Emerg Med* 2019;27:31.
24 Younan D, Delozier SJ, Adamski J, Loudon A, Violette A, Ustin J, Tinkoff G, Moorman ML, McQuay N, Consortium UR, UHRISES Research Consortium. Factors predictive of ventilator-associated pneumonia in critically ill trauma patients. *World J Surg* 2020;44:1121–5.
25 Chabot E, Nirula R. Open abdomen critical care management principles: resuscitation, fluid balance, nutrition, and ventilator management. *Trauma Surg Acute Care Open* 2017;2:e000063.
26 Acker A, Leonard J, Seamon MJ, Holena DN, Pascual J, Smith BP, Reilly PM, Martin ND. Leaving contaminated trauma laparotomy wounds open reduces wound infections but does not add value. *J Surg Res* 2018;232:450–5.