Contemporary management and outcomes of penetrating colon injuries: Validation of the 2020 AAST Colon Organ Injury Scale

Ahmad Zeineddin, MD, Gail T. Tominaga, MD, Marie Crandall, MD, MPH, Mariana Almeida, BS, Kevin M. Schuster, MD, MPH, Ghassan Jawad, MD, Baila Maqbool, MD, Abby C. Sheffield, DO, Navpreet K. Dhillon, MD, Brandon S. Radow, MD, Matthew L. Moorman, MD, MBA, Niels D. Martin, MD, Christina L. Jacovides, MD, Debra Lowry, MD, Krista Kaups, MD, MSc, Chelsea R. Horwood, MD, MPH, Nicole L. Werner, MD, MS, Jefferson A. Proaño-Zamudio, MD, Haytham M. A. Kaafarani, MD, MPH, William A. Marshall, MD, Laura N. Haines, MD, Kathryn B. Schaffer, MPH, CCRP, Kristan L. Staudenmayer, MD, MS, *and* **Rosemary A. Kozar, MD, PhD,** *Washington, DC*

INTRODUCTION: The American Association for the Surgery of Trauma Colon Organ Injury Scale (OIS) was updated in 2020 to include a separate OIS for penetrating colon injuries and included imaging criteria. In this multicenter study, we describe the contemporary management and outcomes of penetrating colon injuries and hypothesize that the 2020 OIS system correlates with operative management, complications, and outcomes.

METHODS: This was a retrospective study of patients presenting to 12 Level 1 trauma centers between 2016 and 2020 with penetrating colon injuries and Abbreviated Injury Scale score of <3 in other body regions. We assessed the association of the new OIS with surgical management and clinical outcomes and the association of OIS imaging criteria with operative criteria. Bivariate analysis was done with χ^2, analysis of variance, and Kruskal-Wallis, where appropriate. Multivariable models were constructed in a stepwise selection fashion.

RESULTS: We identified 573 patients with penetrating colon injuries. Patients were young and predominantly male; 79% suffered a gunshot injury, 11% had a grade V destructive injury, 19% required ≥6 U of transfusion, 24% had an Injury Severity Score of >15, and 42% had moderate-to-large contamination. Higher OIS was independently associated with a lower likelihood of primary repair, higher likelihood of resection with anastomosis and/or diversion, need for damage-control laparotomy, and higher incidence of abscess, wound infection, extra-abdominal infections, acute kidney injury, and lung injury. Damage control was independently associated with diversion and intra-abdominal and extra-abdominal infections. Preoperative imaging in 152 (27%) cases had a low correlation with operative findings (κ coefficient, 0.13).

CONCLUSION: This is the largest study to date of penetrating colon injuries and the first multicenter validation of the new OIS specific to these injuries. While imaging criteria alone lacked strong predictive value, operative American Association for the Surgery of Trauma OIS colon grade strongly predicted type of interventions and outcomes, supporting use of this grading scale for research and clinical practice. (*J Trauma Acute Care Surg.* 2023;95: 213–219.

LEVEL OF EVIDENCE: Prognostic and Epidemiological; Level III.

KEY WORDS: Penetrating colon injury; AAST grade; infection; damage-control laparotomy; abscess; resection and anastomosis; colostomy.

Submitted: December 3, 2022, Revised: February 28, 2023, Accepted: March 9, 2023, Published online: April 19, 2023.

From the Department of Surgery (A.Z.), Howard University Hospital, Washington, DC; Department of Surgery (A.Z., N.K.D., R.A.K.), Shock Trauma Center, University of Maryland School of Medicine, Baltimore, Maryland; Department of Surgery (M.A., K.M.S.), Yale University, New Haven, Connecticut; Department of Surgery (G.J., B.M.), University of New Mexico Health Science Center, Albuquerque, New Mexico; Department of Surgery (M.C., A.C.S.), College of Medicine, University of Florida, Jacksonville, Florida; Department of Surgery (B.S.R., M.L.M.), University Hospitals Cleveland Medical Center, Cleveland, Ohio; Department of Surgery (N.D.M., C.L.J.), University of Pennsylvania, Philadelphia, Pennsylvania; Department of Surgery (D.L., K.K.), Community Regional Medical Center, UCSF Fresno, Fresno, California; Department of Surgery (C.R.H., N.L.W.), Denver Health, Denver, Colorado; Department of Surgery (J.A.P.-Z., H.M.A.K.), Massachusetts General Hospital and Harvard Medical School, Boston, Massachusetts; Department of Surgery (W.A.M., L.N.H.), University of California San Diego Health, San Diego; Department of Surgery (G.T.T., K.B.S.), Scripps Memorial Hospital, La Jolla; and Department of Surgery (K.L.S.), Stanford University, Stanford, California.

This study was presented at the 36th annual meeting of the Eastern Association for the Surgery of Trauma, January 17–21, 2023, in Lake Buena Vista, Florida.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal's Web site (www.jtrauma.com).

Address for correspondence: Ahmad Zeineddin, MD, Department of Surgery, Howard University Hospital, 2041 Georgia Ave NW, Washington, DC 20060; email: ahzeineddin@huhosp.org.

DOI: 10.1097/TA.0000000000003969

Over the past few decades, management of penetrating colon injuries has evolved significantly. These injuries were historically managed with mandatory fecal diversion. However, with advancements in trauma systems allowing for earlier presentation to trauma centers, earlier recognition of injuries, and improved resuscitation and antibiotic prophylaxis, growing evidence now supports the safety of primary repair or anastomosis in injuries requiring resection.[1–5] Furthermore, the introduction and wide utilization of damage-control laparotomy (DCL) as a resuscitative tool in the severely injured or unstable patient presenting with abdominal trauma introduced new variables to the management of patients with colon injuries.[6–11]

The American Association for the Surgery of Trauma (AAST) Organ Injury Scale (OIS) for colon injuries was originally developed in 1990 by Moore et al.[12] To reflect the changes in management of colon injuries, the AAST Patient Assessment committee updated the OIS in 2020 and, for the first time, included a distinct OIS for penetrating colon injuries.[13] In addition, given the advancements in imaging technology, the updated OIS also includes separate criteria for imaging as well as operative and pathologic findings and aims to provide a tool to guide treatment. In this multicenter study, we describe the

contemporary management and outcomes of penetrating colon injuries and hypothesize that the 2020 OIS system correlates with operative management, complications, and outcomes.

PATIENTS AND METHODS

This was a retrospective study of patients presenting to 12 Level 1 trauma centers between the years 2016 and 2020. Institutional review board approval was secured at all participating sites with the requisite data-sharing agreements. The study population included all adult patients (age 16 years or older) who presented with penetrating colon injuries. Patients with severe injuries in body regions other than the abdomen, defined as an Abbreviated Injury Scale score of ≥3 in any other body region, and those who expired within 24 hours of admission were excluded from the analysis. The trauma registry at each institution was queried for patients meeting inclusion criteria, and charts were individually reviewed. Data points collected included the following: age, sex, Injury Severity Score (ISS), presenting blood pressure, blood products from admission to the end of index operation, time to operation, severity of colon injury (serosal tear, hematoma, full-thickness injury, transection, devascularization), degree of contamination per operative dictation, concomitant small bowel or stomach injuries, need for DCL, number of abdominal washouts, and number of days of open abdomen. The updated AAST OIS colon injury grade[13] shown in Supplementary Table 1, http://links.lww.com/TA/C983, was assigned to each patient for operative findings based on operative reports, for imaging from review of reports and images when available, and for pathology from pathology reports when available. American Association for the Surgery of Trauma OIS operative grade was available for all patients and was used in analysis of outcomes. Our primary outcomes were the association of OIS grade with clinical outcomes and the association between different component of the OIS. The clinical outcomes of interest were type of surgical management (primary repair, resection and anastomosis, ileostomy/colostomy) and infectious and noninfectious outcomes (anastomotic leak, intra-abdominal abscess, superficial wound infection, acute kidney injury, acute respiratory distress syndrome, venous thromboembolism, length of stay, and mortality). We specifically focused on infectious complications, including pneumonia, urinary tract infection, bacteremia, and *Clostridium difficile* infection. Moreover, we identified patients who had positive cultures (e.g., abscess, wound, blood, respiratory, urine), recorded the identified bacteria and antibiotic resistance patterns, and defined multi-drug resistance as resistance to three or more antibiotic agents.

Categorical variables were reported as percentages, while continuous variables were reported as medians with interquartile range (IQR). Bivariate analysis was performed to describe patient demographics, surgical management, and outcomes across AAST grades using χ^2, analysis of variance, and Kruskal-Wallis, where appropriate. Multivariable models to predict outcomes were constructed in a backward stepwise selection fashion of the following variables: age, mechanism (gunshot vs. stab), ISS, hypotension on arrival, time to operating room, transfusion of 6 or more units, AAST operative grade, concomitant small bowel injury, concomitant stomach injury, degree of contamination, and DCL. The variables were removed from the model if they did not improve the predictive performance of the model assessed by its receiver operating characteristic curves. Hosmer-Lemeshow goodness-of-fit test was used to test our models. All models were clustered by center to adjust for practice variability and treatment bias by the different centers. Complete regression models are displayed in Supplemental Digital Content (Supplementary Tables 2–8, http://links.lww.com/TA/C985). The correlation between the three components of the AAST grade (imaging, operative, and pathology) was assessed using κ coefficient for interrate reliability. All statistical analyses were performed using Stata Statistical software (Release 14.2; StataCorp LLC, College Station, TX). STrengthening the Reporting of OBservational studies in Epidemiology guidelines were followed (Supplemental Digital Content, Supplementary Data 1, http://links.lww.com/TA/C984).

RESULTS

Patient Characteristics

Among 12 centers, we identified 573 patients who met our inclusion criteria. Overall, patients were young with a mean ± SD age of 32 ± 13 years and predominantly male (88%). Gunshot injury was the mechanism in 79% of patients. Median ISS was 10 (IQR, 9–16). On presentation, 18% of patients were hypotensive (blood pressure, <90 mm Hg), and 18.5% required 6 U of blood or more products before the end of their index operation (Table 1).

Surgical Management

By definition, all patients underwent operative intervention. Intraoperatively, 90 patients (15.7%) were found to have OIS grade 1 injuries; 207 patients (36.1%), grade 2; 162 patients (28.3%), grade 3; 53 patients (9.3%), grade 4; and 61 patients (10.7%), with grade 5 injuries. The median time from emergency department arrival to operating room was 49 (30–60) minutes. Primary repair was performed in 33.7% of patients, resection with anastomosis (RA) in 37.2%, and resection with exteriorization of bowel with an ileostomy or colostomy in 29.2%. Type of operative repair by grade is shown in Table 2 and Figure 1. The type of operative intervention differed significantly between OIS grades with a lower likelihood of primary repair and higher likelihood of RA ($p < 0.001$) or diversion ($p < 0.001$) with increasing grade. Damage-control laparotomy was performed on 32.1% of patients with significant increase in its rate with higher OIS grades ($p < 0.001$). Median time of open abdomen was 1 day (IQR, 1–2 days) (Table 1).

Clinical Outcomes

Postoperatively, patients with higher OIS grades had a higher rate of developing intra-abdominal abscess, wound infection, an anastomotic or stump leak, and extra-abdominal complications including bacteremia, pneumonia, urinary tract infection, or *C. difficile* infection. Overall rates by OIS grade are shown in Table 1. Patients with higher OIS grade also had higher incidence of acute kidney injury, acute respiratory distress syndrome, and longer length of stay. Venous thromboembolism was not significantly different between groups. Mortality was 2.1% with no statistically significant difference between OIS grades ($p = 0.14$) (Table 1).

In our multivariable regression adjusting for age, mechanism, ISS, hypotension, total blood products ≥6 U, degree of

TABLE 1. Patient Demographics, Injury Characteristics, Operative Intervention, and Clinical Outcomes Per AAST Operative Grade

	Total (n = 573)	Grade 1 (n = 90)	Grade 2 (n = 207)	Grade 3 (n = 162)	Grade 4 (n = 53)	Grade 5 (n = 61)	*p**
Age, y	32 ± 13	34 ± 14	32 ± 12	30 ± 12	34 ± 14	34 ± 13	0.29
Male	88%	88%	87%	91%	85%	90%	0.74
Gunshot wound	79%	57%	77%	91%	79%	84%	<0.01
ISS	10 (9–16)	6.5 (5–11)	10 (7–14)	10 (10–17)	12 (10–17)	14 (10–19)	<0.01
Hypotension in ED	18%	6%	14%	19%	38%	26%	<0.01
Transfusion ≥6 U	19%	6.7%	14%	21%	38%	28%	<0.01
Primary repair	34%	82%	46%	23%	1.9%	—	<0.01
Resection and anastomosis	37%	16%	28%	46%	49%	57%	<0.01
Ileostomy/colostomy	29%	1.6%	26%	32%	49%	43%	<0.01
DCL	32%	14%	24%	40%	47%	52%	<0.01
Intra-abdominal abscess	26%	2.2%	23%	30%	43%	46%	<0.01
Wound infection	13%	5.6%	11%	11%	25%	21%	<0.01
Anastomotic leak	5.6%	—	2.4%	8.6%	11%	11%	<0.01
Extra-abdominal infectious complications*	28%	5.6%	23%	31%	47%	51%	<0.01
Acute kidney injury	19%	8.9%	15%	22%	32%	28%	<0.01
ARDS	4.8%	1.1%	2%	5.6%	7.8%	15%	<0.01
VTE	2.7%	—	3.4%	3.1%	—	5%	0.22
Length of stay, d	11 (7–19)	7 (4–10)	9 (6–16)	13 (7–21)	20 (9–31)	16 (11–22)	<0.01
Mortality	2.1%	2.2%	1.5%	1.2%	1.9%	6.6%	0.14

*Infectious complications included bacteremia, urinary tract infection, pneumonia, and *C. difficile* infection.
ARDS, acute respiratory distress syndrome; ED, emergency department; VTE, venous thromboembolism.

contamination/spillage, concomitant stomach or small bowel injury, time to operative intervention, and damage control in a stepwise selection model, higher OIS remained associated with lower chance of primary repair and a higher rate of RA or diversion, as well as a higher incidence of intra-abdominal abscess, leak, and extra-abdominal infections (Table 2).

Infectious Complications

More than a third of the patients in our cohort developed an infectious complication during their stay (36.8%). The most common source of infection was an intra-abdominal abscess, followed by wound infection, bacteremia, and pneumonia, all of which were significantly associated with higher grades of injury (Table 1). Infectious complications were also associated with greater degrees of contamination and a longer postoperative antibiotic course (Table 3). Superficial wound infection was associated with age (odds ratio [OR], 1.03; 95% confidence interval [CI], 1.01–1.04) and severe contamination (OR, 1.44; 95% CI, 0.61–3.38) and was not found to be significantly associated with the mechanism or degree of injury, or the use of a skin vac or delayed primary closure (Supplementary Table 6, http://links.lww.com/TA/C985).

Of postoperative cultures collected from 147 patients' blood, wounds, abscess cavities, respiratory tracts, or urine, there were 91 patients with positive growth on culture of abscess aspirate (median day 10), 54 with positive wound cultures (median day 9), 52 with positive blood cultures (median day 7), and 37 with positive respiratory/urine cultures (median day 9). Bacterial growth in 36% of cultures exhibited resistance to at least one antibacterial agent, with 19% of cultures growing multidrug resistance organisms.

Most patients (94%) received preoperative antibiotic prophylaxis. However, the duration of postoperative antibiotic course varied. A longer antibiotic course was associated with

TABLE 2. Adjusted OR and 95% CIs of Operative Intervention and Clinical Outcomes Per AAST Grade

AAST Grade	1	2	3	4	5	AUROC
Primary repair	Ref.	0.64 (0.2–2)	0.26* (0.08–0.78)	0.01* (0.002–0.1)	0.06* (0.01–0.24)	0.85 (0.8–0.89)
Resection and anastomosis	Ref.	2.12 (0.77–5.8)	4.6* (1.88–11)	14.6* (2.58–82)	6.6* (1.64–26.7)	0.74 (0.69–0.8)
Ileostomy/colostomy	Ref.	9.7* (3.7–26)	9.8* (2.3–42)	14* (1.65–119)	19* (2.6–135)	0.83 (0.77–0.88)
Intra-abdominal abscess	Ref	5.5* (2–15)	4.6* (1.2–17)	7.2* (1.7–31)	10* (2.1–48)	0.76 (0.7–0.82)
Wound infection	Ref.	1.84 (0.7–4.85)	1 (0.49–2.02)	2.5 (0.66–9.7)	2.6 (0.89–7.8)	0.73 (0.65–0.81)
Anastomotic leak	—	Ref.	3.3* (1.31–8.13)	4.95* (2.09–11.7)	4.79* (1.78–12.9)	0.79 (0.7–0.88)
Extra-abdominal infections	Ref.	3.69 (0.93–15)	5.3* (1.39–20)	9.7* (1.94–49)	9.4* (2.4–36)	0.77 (0.71–0.83)

*Statistically significant.
Models are adjusted for age, ISS, mechanism (gunshot wound vs. stab), hypotension on arrival, hours from presentation to OR, concomitant small bowel injury, concomitant stomach injury, and DCL. Full regression models are available in Supplemental Digital Content, Supplementary Tables 2–8, http://links.lww.com/TA/C985.
AUROC, area under the receiver operating curve; Ref., reference.

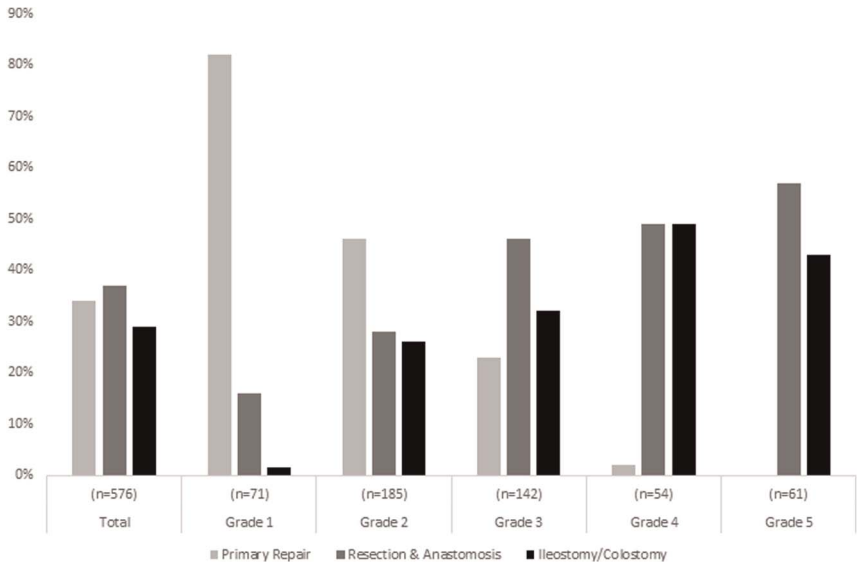

Figure 1. Surgical management of penetrating colon injury by AAST grade.

higher injury grade and higher rate of infectious complications ($p < 0.01$).

On multivariable regression, AAST grade, severe contamination, and days of open abdomen were significantly associated with developing an infectious complication (Table 4).

Resection and Anastomosis Versus Ostomy

Examining outcomes following the different surgical management groups, that is, primary repair, resection and anastomosis, and resection with ileostomy/colostomy, patients who received an ostomy had higher ISS and were more likely to be hypotensive, to receive 6 U of blood or more, and to undergo DCL. Those patients also had a higher rate of overall complications (Table 5).

The overall colonic leak rate in our study was 5.6%, with 1.2% in patients who underwent primary repair, and 8.4% in patients who underwent RA. In patients with a destructive injury (grade 5), the leak rate was 9.4%. The AAST grade and age (OR, 1.04; 95% CI, 1.004–1.07) were independent predictors of anastomotic leak

TABLE 3. Infectious Complications

		All Infectious Complications (n = 211)		
	No Infectious Complications (n = 362)	Intra-abdominal Infection (n = 148)	Extra-abdominal Infection (n = 177)	*p*
Surgical intervention				<0.01
Primary repair	84%	7%	13%	
Resection and anastomosis	56%	29%	37%	
Ileostomy/colostomy	42%	48%	50%	
Damage control	45%	41%	49%	<0.01
Transfusion ≥6 U	45%	40%	49%	<0.01
Degree of contamination				<0.01
None	79%	11%	16%	
Mild	68%	20%	26%	
Moderate	60%	31%	36%	
Severe	42%	48%	54%	
Duration of antibiotic prophylaxis				<0.01
No postoperative antibiotics	67%	18%	31%	
24 h	72%	22%	20%	
48 h	58%	30%	33%	
3–7 d	60%	31%	34%	
>7 d	35%	45%	58%	
Bacterial resistance		(n = 95)	(n = 75)	
No resistance	—	70.5%	57%	
1 Agent	—	9.5%	15%	
2 Agents	—	8.4%	4%	
Multidrug-resistant organisms	—	11.6%	24%	

TABLE 4. Multivariate Regression for Predictors of Developing Any Postoperative Infectious Complication

	OR	SE	*p*	95% CI
Age	1.013	0.008	0.097	0.998–1.03
ISS	1.03	0.036	0.382	0.96–1.1
Mechanism (GSW vs. stab)	1.21	0.48	0.635	0.55–2.63
Hours from injury to operating room	0.98	0.03	0.604	0.92–1.05
Concomitant small bowel injury	0.96	0.39	0.921	0.44–2.12
DCL	1.73	0.63	0.136	0.84–3.55
Days of open abdomen	1.31*	0.13	0.007	1.08–1.59
AAST grade (vs. grade 1)				
2	4.78*	1.92	<0.001	2.17–10.5
3	3.94*	1.78	0.003	1.62–9.59
4	7.54*	3.5	<0.001	3.1–18.6
5	6.26*	4.45	0.01	1.55–25.2
Degree of contamination (vs. none)				
Mild	1.28	0.47	0.503	0.62–2.64
Moderate	1.74	0.54	0.07	0.95–3.19
Severe	4.27*	1.75	<0.001	1.91–9.55
Postoperative antibiotic duration (vs. none)				
24 h	0.45	0.21	0.08	0.18–1.1
48 h	1.16	0.31	0.569	0.69–1.95
3–7 d	0.56	0.24	0.17	0.24–1.28
>7 d	1.38	0.78	0.57	0.46–4.19

*Statistically significant. Area under the receiver operating curve, 0.77 (0.648–0.893). Hosmer-Lemeshow goodness of fit: $\chi^2_8 = 6.77$. Prob > $\chi^2 = 0.562$.
GSW, gunshot wound.

on multivariable regression (Supplementary Table 7, http://links.lww.com/TA/C985).

Independent predictors of diversion included higher AAST grade, receiving 6 U of blood or more (OR, 3.27; 95% CI, 1.58–6.78), and DCL (OR, 4.34; 95% CI, 2.16–8.7) (Supplementary Table 4, http://links.lww.com/TA/C985). There was no significant difference between RA compared with ileostomy/colostomy in the rate of total infectious complications (ostomy: OR, 0.94; 95% CI, 0.46–1.93), or in the rate of intra-abdominal abscess formation (OR, 1.16; 95% CI, 0.69–1.95).

Damage-Control Laparotomy

Patients who underwent DCL had more severe injuries, were much more likely to receive ≥6 U of blood products, had a significantly lower rate of primary repair, and had a significantly higher rate of ostomy formation. All clinical outcomes were significantly worse in DCL patients (Table 5). Damage-control laparotomy patients with infectious complications had a longer time with open abdomen than those without infectious complications (median days 1 [IQR, 1–2] vs. 1 [IQR, 1–1], $p = 0.004$). There was a large variation in the antibiotic course for patients who underwent DCL: 17% had no antibiotics after index operation, 7.5% stopped antibiotics before abdomen closure, 18% stopped antibiotics the day of abdomen closure, 11.6% stopped antibiotics 24 hours after closure, and 46% continued the antibiotic course for more than 24 hours after abdomen closure.

In our regression models, DCL was associated with higher rate of colostomy formation (OR, 4.34; 95% CI, 2.16–8.7), higher rate of intra-abdominal abscess (OR, 2.47; 95% CI, 1.35–4.51), and higher rate of extra-abdominal complications (OR, 2.3; 95% CI, 1.1–3.8).

OIS Grade Validation

As described previously, OIS operative grade was highly predictive of outcomes in patients with penetrating colon injury, with area under the receiver operating curve ranging from 0.68 for wound infection up to 0.90 for acute respiratory distress syndrome. Our secondary aim was to determine the utility of the imaging and pathology criteria of the new OIS grade.

TABLE 5. Patient Demographics, Injury Characteristics, Operative Intervention, and Clinical Outcomes per Surgical Intervention

	Primary Repair (n = 195)	Resection and Anastomosis (n = 212)	Ileostomy/Colostomy (n = 166)	*p*	Single Laparotomy (n = 389)	Damage Control (n = 184)	*p*
Age, y	32 ± 14	31 ± 12	32 ± 12	0.66	31 ± 12	34 ± 14	0.12
Male	88%	90%	90%	0.91	88%	89%	0.91
ISS	9 (5–13)	10 (10–17)	14 (10–21)	<0.01	10 (6–14)	16.5 (10–24.5)	<0.01
Hypotension	10%	19%	30%	<0.01	12%	30%	<0.01
Transfusion ≥6 U	8.7%	16%	33%	<0.01	7%	43%	<0.01
Intra-abdominal abscess	7%	29%	48%	<0.01	19%	41%	<0.01
Wound infection	7.6%	19%	14%	<0.01	11%	17%	0.03
Anastomotic leak	1.2%	8.4%	8.1%	<0.01	4.1%	8.7%	<0.01
Extra-abdominal Infectious complications*	8.7%	33%	48%	<0.01	19%	47%	<0.01
Acute kidney injury	9.9%	20%	28%	<0.01	14%	30%	<0.01
ARDS	3.5%	6.4%	5.4%	0.45	2.8%	8.9%	<0.01
VTE	1.2%	3.2%	4.1%	0.26	1.3%	5.5%	<0.01
Length of stay, d	7 (5–12)	11 (7–18)	17 (11–30)	<0.01	8 (6–15)	18 (11–29.5)	<0.01
Mortality	—	1.6%	3.4%	0.054	0.8%	4.9%	<0.01

*Infectious complications included bacteremia, urinary tract infection, pneumonia, and *C. difficile* infection.
ARDS, acute respiratory distress syndrome; VTE, venous thromboembolism.

Preoperative imaging was performed in 152 (27%) of cases. Imaging grade was found to have a low correlation with operative grade (κ coefficient, 0.13). Imaging grade was found to be higher than the operative grade in 43 patients (28%), lower in 50 patients (33%), and matched the operative grade in 59 patients (39%). In 28% of patients where imaging grade overestimated the injury, this was mainly due to contrast extravasation, which is designated a grade 5 on the imaging criteria with subsequent operative findings of a nondestructive injury. The reason for underestimation of operative grade was not able to be clearly elucidated in this retrospective study and will require further analysis.

Pathology reports were available for 377 patients (66%). Pathology grade was to have a high correlation with operative grade (κ coefficient, 0.61). Pathology grade was higher than operative grade in 69 patients (18%), lower in 40 patients (11%), and matched the operative grade in 266 patients (71%).

DISCUSSION

In this study, we validate the new OIS for penetrating injury, which showed high correlation with clinical outcomes with higher OIS operative grades. The new OIS operative grade was significantly associated with the type of surgical management and infectious outcomes, which remained significant after adjusting for severity of injury, degree of contamination, concomitant injuries, blood loss, transfusion requirement, antibiotic prophylaxis, and delay to operative intervention. However, in the subset of patients who underwent preoperative computed tomography, the imaging grade did not correlate well with the operative findings, was not as strongly associated with clinical outcomes, and may require revision before clinical implementation.

Numerous studies in the past two decades have provided sufficient evidence to change practice management of penetrating colon injuries and recommend primary repair or resection and anastomosis of the injured colon, even in the severely injured patient with a destructive colonic injury. In the most recent Eastern Association for the Surgery of Trauma practice management guidelines (2019) for intraperitoneal colon injuries, colon repair or RA was strongly recommended for stable patients without severe spillage or delay in intervention and conditionally recommended for high-risk patients and patients undergoing DCL.[5] Most recently, a large retrospective study from Mitchao et al.[14] found liberal use of primary anastomosis in patients with destructive injuries to be safe with favorable outcomes, including high-risk patients with high ISS and transfusion requirement.

Our cohort included patients with all grades of injury and describes type of surgical intervention by grades and is the largest to date study that we are aware of in penetrating colon injury patients. Surgical management did differ widely between centers, with a DCL rate ranging from 6% to 57%, and a colostomy rate ranging from 11% to 74%. The leak rate in our study was consistent with that reported in the literature[7,15–17]; however, we noted a high rate of intra-abdominal abscess formation.

Damage-control laparotomy was used in a third of our patients and in more than half of those with destructive injuries. Previous studies show conflicting evidence on the outcomes of colon repairs in the setting of DCL. Weinberg et al.[6] reported colon-related complications in 30% versus 12% and a leak rate of 12% versus 3% compared with single laparotomy. This was contrasted with another study by Tatebe et al.,[11] which reported no difference in leak or abscess rates and concluded the safety of a delayed anastomosis after DCL. In this study, DCL patients had worse injury and fared worse in all outcomes. Damage-control laparotomy was independently predictive of intra-abdominal abscess formation, extra-abdominal infections, and colostomy formation.

There are no current guidelines on antibiotic prophylaxis for open abdomen after traumatic colon injury. A previous study by Goldberg et al.[18] showed wide variation in practice with prolonged postoperative antibiotics being associated with higher infectious complications. We also noted significant variation in antibiotic practice, but the duration of antibiotic prophylaxis was not significantly associated with infectious outcomes. In all patients, however, both DCL and single laparotomy, longer antibiotic course was associated with higher rate of intra-abdominal and extra-abdominal infections. This did not persist though on multivariable regression. The high resistance rate on postoperative cultures is worrisome and calls for careful antibiotic stewardship and limited use to only proven infections. This study was not powered to detect independent predictors for antibiotic resistance, but we noted a trend toward higher resistance with higher grade, higher degree of contamination, and DCL, although this did not reach statistical significance.

The study has inherent limitations given its retrospective design. Despite its large sample size, this study was not powered to find statistical difference in some of our low incidence outcomes like mortality, venous thromboembolism, and antibiotic resistance. Some confounding comorbidities that may have influenced decision making or outcomes may have been missed in these often critically ill patients. There were center level variations in the rates of DCL utilization. Our analysis did not adjust for intra-abdominal injuries outside colon, small bowel, and stomach, which may have contributed to outcomes. Given the number of outcomes evaluated, there is a concern for increased false positive findings with multiple testing. Lastly, injury grade was determined by the authors for determination of imaging, operative, and pathologic criteria. It is possible, particularly for the imaging grades, that authors could have overestimated or underestimated the OIS grade.

CONCLUSION

This is the largest study of penetrating colon injuries and the first multicenter validation of the new OIS specific to these injuries, expanding on a previously reported single-center study.[19] This study adds to the increasing evidence of the safety of an ostomy-sparing approach while highlighting the persistent variation in surgical management of penetrating colon injuries. Infectious complications remain high in this patient population regardless of surgical approach or antibiotic prophylaxis. Liberal use of DCL is not without its complications and may be best used judiciously in the setting of colon injuries. The imaging criteria lacked strong predictive value and was incongruent with operative criteria. A modification of imaging criteria may be necessary before its introduction into practice for preoperative

prognostication and planning. However, the new operative OIS for penetrating injuries correlated well with outcomes.

AUTHORSHIP

A.Z. and R.A.K. contributed in the study design, data analysis, and data interpretation. R.A.K., G.T.T., and M.C. contributed in the critical revision and data collection. M.A., K.M.S., G.J., B.M., A.C.S., N.K.D., B.S.R., M.L.M., N.D.M., C.L.J., D.L., K.K., C.R.H., N.L.W., J.A.P.-Z., H.M.A.K., W.A.M., L.N.H., K.B.S., and K.L.S. contributed in the data collection and manuscript revision.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

1. Stone HH, Fabian TC. Management of perforating colon trauma. Randomization between primary closure and exteriorization. *Ann Surg*. 1979;190(4):430–436.
2. Pasquale M, Fabian TC. Practice management guidelines for trauma from the Eastern Association for the Surgery of Trauma. *J Trauma*. 1998;44(6):941–947.
3. Demetriades D, Murray JA, Chan L, Ordoñez C, Bowley D, Nagy KK, Cornwell EE 3rd, Velmahos GC, Muñoz N, Hatzitheofilou C, et al. Penetrating colon injuries requiring resection: diversion or primary anastomosis? An AAST prospective multicenter study. *J Trauma*. 2001;50(5):765–775.
4. Nelson R, Singer M. Primary repair for penetrating colon injuries. *Cochrane Database Syst Rev*. 2003;(3):CD002247.
5. Cullinane DC, Jawa RS, Como JJ, Moore AE, Morris DS, Cheriyan J, Guillamondegui OD, Goldberg SR, Petrey L, Schaefer GP, et al. Management of penetrating intraperitoneal colon injuries: a meta-analysis and practice management guideline from the Eastern Association for the Surgery of Trauma. *J Trauma Acute Care Surg*. 2019;86(3):505–515.
6. Weinberg JA, Griffin RL, Vandromme MJ, Melton SM, George RL, Reiff DA, Kerby JD, Rue LW 3rd. Management of colon wounds in the setting of damage control laparotomy: a cautionary tale. *J Trauma*. 2009;67(5):929–935.
7. Ordoñez CA, Pino LF, Badiel M, Sánchez AI, Loaiza J, Ballestas L, Puyana JC. Safety of performing a delayed anastomosis during damage control laparotomy in patients with destructive colon injuries. *J Trauma*. 2011;71(6):1512–1517.
8. Georgoff P, Perales P, Laguna B, Holena D, Reilly P, Sims C. Colonic injuries and the damage control abdomen: does management strategy matter? *J Surg Res*. 2013;181(2):293–299.
9. Dubose JJ, Scalea TM, Holcomb JB, Shrestha B, Okoye O, Inaba K, Bee TK, Fabian TC, Whelan J, Ivatury RR. Open abdominal management after damage-control laparotomy for trauma: a prospective observational American Association for the Surgery of Trauma multicenter study. *J Trauma Acute Care Surg*. 2013;74(1):113–120.
10. Anjaria DJ, Ullmann TM, Lavery R, Livingston DH. Management of colonic injuries in the setting of damage-control laparotomy: one shot to get it right. *J Trauma Acute Care Surg*. 2014;76(3):594–600.
11. Tatebe LC, Jennings A, Tatebe K, Handy A, Prajapati P, Smith M, Do T, Ogola GO, Gandhi RR, Duane TM, et al. Traumatic colon injury in damage control laparotomy — a multicenter trial: is it safe to do a delayed anastomosis? *J Trauma Acute Care Surg*. 2017;82(4):742–749.
12. Moore EE, Cogbill TH, Malangoni MA, Jurkovich GJ, Champion HR, Gennarelli TA, McAninch JW. Organ injury scaling, II: Pancreas, duodenum, small bowel, colon, and rectum. *J Trauma*. 1990;30(11):1427–1429.
13. Tominaga GT, Crandall M, Cribari C, Zarzaur BL, Bernstein M, Kozar RA. Organ injury scaling 2020 update: bowel and mesentery. *J Trauma Acute Care Surg*. 2021;91(3):e73–e77.
14. Mitchao DP, Lewis MR, Strickland M, Benjamin ER, Wong MD, Demetriades D. Destructive colon injuries requiring resection: is colostomy ever indicated? *J Trauma Acute Care Surg*. 2022;92(6):1039–1046.
15. Miller PR, Fabian TC, Croce MA, Magnotti LJ, Elizabeth Pritchard F, Minard G, Stewart RM. Improving outcomes following penetrating colon wounds: application of a clinical pathway. *Ann Surg*. 2002;235(6):775–781.
16. Demetriades D, Murray JA, Chan LS, Ordoñez C, Bowley D, Nagy KK, Cornwell EE 3rd, Velmahos GC, Muñoz N, Hatzitheofilou C, et al. Handsewn versus stapled anastomosis in penetrating colon injuries requiring resection: a multicenter study. *J Trauma*. 2002;52(1):117–121.
17. Sharpe JP, Magnotti LJ, Weinberg JA, Parks NA, Maish GO, Shahan CP, Fabian TC, Croce MA. Adherence to a simplified management algorithm reduces morbidity and mortality after penetrating colon injuries: a 15-year experience. *J Am Coll Surg*. 2012;214(4):591–597.
18. Goldberg SR, Henning J, Wolfe LG, Duane TM. Practice patterns for the use of antibiotic agents in damage control laparotomy and its impact on outcomes. *Surg Infect (Larchmt)*. 2017;18(3):282–286.
19. Zeineddin A, Crandall M, Tominaga GT, Kozar RA. Validation of the American Association for the Surgery of Trauma Organ Injury Scale for penetrating colon injuries. *Am Surg*. 2022;88(7):1563–1565.