A comparison of management and outcomes following blunt versus penetrating pancreatic trauma: A secondary analysis from the Western Trauma Association Multicenter Trials Group on Pancreatic Injuries

Walter L. Biffl, MD, Chad G. Ball, MD, Ernest E. Moore, MD, Michaela West, MD, Rachel M. Russo, MD, Zsolt Balogh, MD, Lucy Kornblith, MD, Rachael Callcut, MD, Kathryn B. Schaffer, MPH, Matthew Castelo, BS, *and* **the WTA Multicenter Trials Group on Pancreatic Injuries***, La Jolla, California*

BACKGROUND: The impact of injury mechanism on outcomes of pancreatic trauma has not been well studied, and current guidelines do not differentiate recommendations for blunt and penetrating injuries. The purpose of this study was to analyze interventions and outcomes as they relate to mechanism. We hypothesized that penetrating pancreatic trauma results in greater morbidity than blunt trauma because of more frequent operative exploration without imaging and thus more aggressive surgical management.

METHODS: Secondary analysis of a multicenter retrospective review of pancreatic injuries in patients 15 years and older from 2010 to 2018 was performed. Deaths within 24 hours of admission were excluded from analysis of the primary outcome, pancreas-related complications (PRCs). Data were analyzed by injury mechanism using various statistical tests where appropriate.

RESULTS: Thirty-three centers reported on 1,240 patients (44% penetrating). Penetrating trauma patients were twice as likely to undergo resection (45% vs. 23%) and suffer PRCs (39% vs. 20%). However, differences varied widely based on injury grade and management. There were fewer resections and more nonoperative management in blunt grades I to III injury. Pancreas-related complications occurred in 40% of high-grade injuries with no difference between mechanisms and in 40% of patients after resection, regardless of mechanism or injury grade. High-grade pancreatic injury (odds ratio [OR], 2.39; 95% confidence interval [CI], 1.55–3.67), penetrating injury (OR, 1.99; 95% CI, 1.31–3.05), and management in a low-volume center (i.e., five or fewer cases/year) (OR, 1.65; 95% CI, 1.16–2.35) were independent predictors of PRCs.

CONCLUSION: Management of grades I to III, but not grades IV/V, pancreatic injuries varies based on mechanism. Penetrating injury is an independent risk factor for PRCs, but main pancreatic duct injury and resection are associated with high rates of PRCs regardless of the injury mechanism. Resection appears to offer better outcomes for grade IV/V injuries, and grade I and II injuries should be managed nonoperatively. (*J Trauma Acute Care Surg.* 2022;93: 620–626. Copyright © 2022 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Therapeutic/Care Management; Level III.

KEY WORDS: Pancreas; trauma; pancreatectomy; pancreatography; morbidity.

Management of patients with pancreatic trauma remains a challenging clinical problem. Diagnosis of pancreatic injury and, particularly, main pancreatic duct (MPD) laceration is hindered by the retroperitoneal position of the gland and limitations of laboratory and imaging tests.[1–5] The management of pancreatic injuries can be complex, and the choice of the optimal intervention for any given patient requires consideration of numerous factors.[4,6] Significant morbidity can occur with injuries of any grade[7,8] and is exacerbated by associated injuries.[5,8–10] The fact that pancreatic injuries are uncommon compounds these challenges, as practicing trauma surgeons often lack experience with them and there is a dearth of high-quality data guiding management.[3,11,12]

The impact of injury mechanism on management and outcomes of pancreatic trauma has not been well studied. The existing body of literature on pancreatic trauma generally falls into one of two categories: papers that combine blunt and penetrating trauma patients but do not compare the two cohorts[2,7,13–17] and those that report on either blunt or penetrating injuries but lack a mechanistic comparator group.[9,18–23] Consequently, current guidelines do not differentiate management recommendations based on mechanism of injury because there are no data to support such recommendations.[3,11,12] We recently performed a multicenter trial evaluating the contemporary management of pancreatic trauma, primarily focused on injury grades.[5,8] The purpose of the current study was to specifically analyze interventions and outcomes as they relate to injury mechanism. We hypothesized that penetrating pancreatic trauma will result in greater morbidity than blunt injuries because of more frequent operative exploration without imaging and thus more aggressive surgical management.

Submitted: January 15, 2022, Revised: March 26, 2022, Accepted: April 4, 2022, Published online: April 21, 2022.

From the Scripps Memorial Hospital La Jolla, La Jolla, California.

This study was presented at the 51st Annual Meeting of the Western Trauma Association, February 23, 2022, in Big Sky, Montana.

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 correspondence to: Walter L. Biffl, MD, Scripps Memorial Hospital La Jolla, 9888 Genesee Ave, MC LJ601, La Jolla, CA 92037; email: biffl.walter@scrippshealth.org.

DOI: 10.1097/TA.0000000000003651

PATIENTS AND METHODS

This study represents a secondary analysis of a retrospective multicenter study of traumatic pancreatic injuries conducted under the auspices of the Western Trauma Association Multicenter Trials Committee.[5,8] Inclusion criteria were age 15 years or older, American Association for the Surgery of Trauma Organ Injury Scale (AAST-OIS)[24] grades I to V pancreatic injury, and direct admission to participating American College of Surgeons–verified (or locally designated, in foreign countries) levels I and II trauma centers between January 2010 and September 2018. Patients who were transferred from other hospitals after laparotomy or specific pancreatic intervention were excluded; those who died within 24 hours were included for demographic reporting but were excluded from outcomes analyses.

Data Collection

This study was conducted following approval from the appropriate institutional review board at each collaborating center with a waiver of informed consent, and STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) checklist was used to ensure proper reporting of methods, results, and discussion (Supplemental Digital Content, Supplementary Data 1, http://links.lww.com/TA/C503).[25] Each site provided deidentified data for patients with pancreatic injuries included in the institution's trauma registry. The case report form included demographic information and detailed data regarding injuries, diagnostic testing, interventions, and outcomes. The timing and specific findings of imaging studies, operative and endoscopic interventions, and decision-making were recorded. The primary outcome of interest was pancreas-related complications (PRCs; pancreatic leak, peripancreatic abscess, pancreatic fistula or delayed pancreatic pseudocyst); pancreas-related mortality was a secondary outcome of interest. Outcomes were recorded for the index hospitalization and up to 30 days after discharge.

The pancreatic injury grade was recorded for both computed tomography (CT) and intraoperative inspection. Given the importance of MPD integrity to outcomes, additional effort was made to ascertain the integrity of the duct. Specifically, case report forms were evaluated for other information (e.g., magnetic resonance cholangiopancreatography [MRCP] or endoscopic retrograde cholangiopancreatography [ERCP] results) to confirm the correct grade. If there was still uncertainty, the site principal investigator was queried and assigned a final grade. Indications for ERCP and stenting were recorded as either empiric/prophylactic therapy (for a newly diagnosed injury) or treatment of a PRC.

Statistical Analysis

Study groups were defined dichotomously by injury mechanism (blunt vs. penetrating). Patient demographics and characteristics are reported using descriptive statistics, including mean, median, interquartile range, and proportions. Continuous variables were compared using *t* test; for not normally distributed data, Wilcoxon rank-sum test were performed. The χ^2 test, Fisher's exact test, two-proportion *z* test, or one proportion *z* test were used to compare categorical variables. Predictors of PRCs were analyzed using multivariate logistic regression. Variables of significance based on univariate analysis ($p < 0.05$) and those of presumed clinical significance were selected for inclusion in multivariate analysis. A train data set of 747 patients was used, and test data set consisted of 321 patients. Multiple models were assessed, and the final model had the best fit in terms of area under the curve. Youden's index was calculated to identify optimal value to distinguish between high- and low-volume sites. Missing data did not exceed 10%, so no adjustment to address missingness was made. Statistical significance was defined as p value of <0.05. All statistical tests were performed using R software (version 3.6.3; The R Foundation, Vienna, Austria).

RESULTS

Patients

Thirty-three trauma centers (31 level I, 2 level II) from the United States, Canada, Australia, and Israel provided complete data on 1,240 patients. The overall population consisted of 699 blunt (56%) and 541 penetrating trauma patients (44%) (Supplemental Digital Content, Supplementary Data 2, http://links.lww.com/TA/C504). Demographics differed based on mechanism. Blunt trauma patients accounted for 63% of low-grade pancreatic injuries (LGPIs; i.e., AAST-OIS grades I and II) and 47% of high-grade injuries (HGPIs; AAST-OIS grades III–V). The percentage of penetrating injuries increased with increasing grade: grade I, 32%; grade II, 43%; grade III, 49%; grade IV, 57%; and grade V, 66% ($p = 0.01$). There were 88 patients (7%) 65 years or older, of whom 12 died early. These older patients comprised 3% of the penetrating and 10% of the blunt injury cohort.

Detailed information about the subjects contributed from each of the centers is shown in Figure 1. The average annual number of patients ranged from less than 1 to 14. Youden's analysis identified the optimal cut point for designation as "high"- versus "low"-volume centers to be five; that is, centers in which five or fewer cases were managed annually are considered low-volume centers. Based on this criterion, 13 centers (39%) were high volume and contributed 832 patients (67%). The 20 low-volume centers (61%) contributed 408 patients (33%). The blunt/penetrating ratio was similar between high- (57:43) and low-volume (55:45) centers.

Additional abdominal injuries, that is, stomach, duodenum, small intestine, colon, liver, spleen, and kidney, were present in 1,047 (84%) of the overall cohort. One hundred thirty-two patients (11%) died within 24 hours: most were intraoperative deaths, and 85 (64%) were attributed to massive blood loss. The remainder was due to traumatic brain injury, cardiopulmonary failure, or other causes. None of the early deaths were attributed to the pancreatic injury.

Diagnosis

The diagnosis of pancreatic injury was made intraoperatively in 573 patients (46%). The large majority (79%) of penetrating trauma patients were taken directly to the operating room without cross-sectional imaging, compared with 21% of blunt trauma patients (Fig. 2). There was 50% agreement between CT and operating room injury grades; it was concordant in 88% of grade I, 72% of grade II, 36% of grade III, 21% of grade IV, and 38% of grade V. Of the discordant CT and operating room grades, 92% were graded higher in the operating room. The CT was considered diagnostic of MPD integrity in only 26% of cases.

Overall, 137 patients (12%) underwent MRCP; it was used significantly more (16% vs. 8%, $p < 0.01$) in blunt trauma

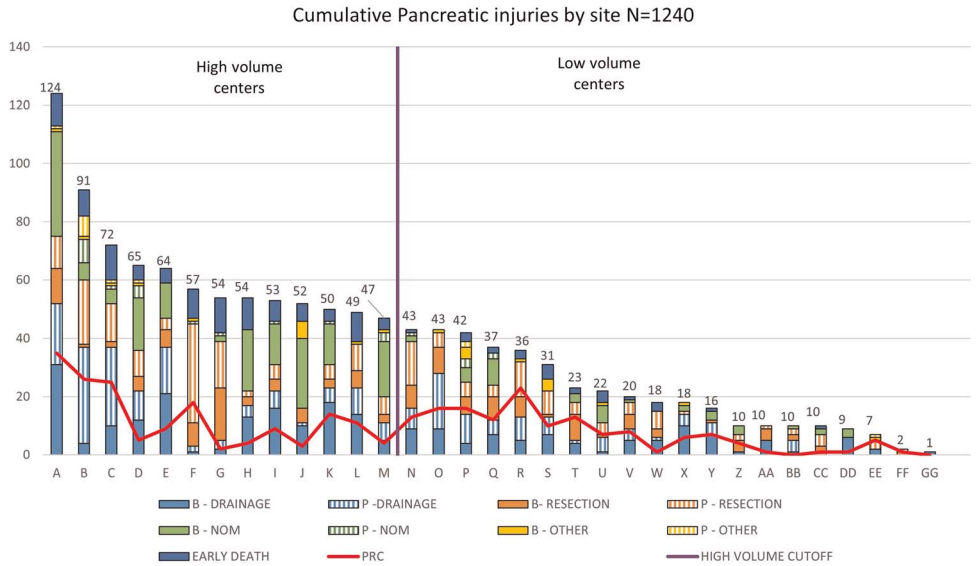

Figure 1. Number of subjects from participating trauma centers. The figure shows the total number contributed during the study period. Centers caring for more than five pancreatic injuries per year were considered "high-volume" centers. The legend and color-coding shown indicates details about the nature, interventions, or outcomes of subjects from each center. B, blunt; NOM, nonoperative management P, penetrating; PRC, pancreas-related complications.

patients. One hundred eleven patients (10%) underwent ERCP, and 77 of them had pancreatic duct stent placement. In 36% of these cases, the stents were used to prevent pancreatic duct leak; in the other 64%, it was meant to manage a PRC. Six patients had stent as part of nonoperative management (NOM): five to prevent leak and one to treat PRC. The use of ERCP did not differ based on mechanism (9% blunt vs. 12% penetrating, $p = 0.10$).

Definitive Management and Outcomes

The early deaths are included in Supplemental Digital Content (Supplementary Data 1, http://links.lww.com/TA/C503), to accurately depict the population and immediate management and allow comparison with previously published series. However, only the 24-hour survivors (n = 1,108) were included in the analyses of diagnostic evaluation, definitive treatment, and related outcomes (i.e., PRCs). There were 98 late deaths in this study, of which only 2 (2%) were felt to be related to the pancreatic injury and PRCs. Among the 24-hour survivors, 92% of penetrating and 78% of blunt trauma patients had other abdominal injuries.

Overall

A diagrammatic representation of the flow of patients through diagnosis and management is shown in Figure 2. Overall, the management of pancreatic injuries varied based on injury mechanism (Table 1). Among penetrating trauma patients, 95% underwent surgical treatment, which was primarily split between resection and operative drainage. Only 3% had other pancreatic procedures (e.g., mobilization, debridement or suturing, but without formal resection or drain placement). In contrast, 33% of blunt trauma patients underwent NOM, and drainage (39%) was performed more often than resection (23%). The rate of PRCs was

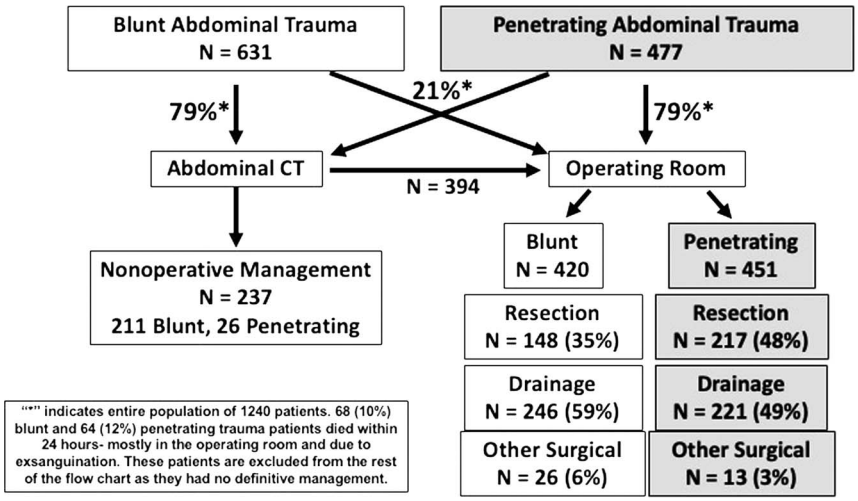

Figure 2. Flow chart of patients through diagnosis and definitive management.

TABLE 1. Definitive Management and Outcomes (PRCs) of Blunt versus Penetrating Pancreatic Injuries among All 24-hour Survivors (n = 1,108*)

All Grades	Blunt	Penetrating	Total	*p*
24-h Survivors	631 (57%)	477 (43%)	1,108	—
Overall PRC	127 (20%)	184 (39%)	311 (28%)	<0.01
Resection	148 (23%)	217 (45%)	365 (33%)	<0.01
Resection—PRC	63 (43%)	83 (38%)	146 (40%)	0.41
Drainage	246 (39%)	221 (46%)	467 (42%)	0.01
Drainage—PRC	49 (20%)	94 (43%)	143 (31%)	<0.01
NOM	211 (33%)	26 (5%)	237 (21%)	<0.01
NOM—PRC	9 (4%)	4 (15%)	13 (5%)	0.058

*Thirty-nine patients (3.5%) were managed with other surgical procedures (e.g., mobilization, suturing, debridement), without resection or drain placement.
p Value = blunt versus penetrating.
Two proportion *z* tests were performed.

nearly twice as high in penetrating versus blunt trauma patients overall. The rate of PRCs was 40% after resection and was not different between blunt and penetrating injuries. On the other hand, the rate of PRCs was significantly higher after drainage of penetrating versus blunt injuries and, after NOM, was 4% in blunt and 15% in penetrating injury ($p = 0.058$).

Among patients who had additional abdominal injuries, PRCs occurred in 281 (30%) overall (penetrating, 40%; blunt, 21%; $p < 0.01$). For every organ, the PRC rate was significantly higher in the penetrating versus blunt cohort, with the exception of stomach injuries (46% vs. 29%, $p = 0.11$). Of note, in both penetrating and blunt injuries, concomitant colon (47% and 27%, respectively) and stomach injuries (46%, 29%) were associated with the highest rates of PRCs, and duodenal injuries (31%, 10%) with the lowest rates. The rate of PRCs was higher in low-volume centers for both blunt (29% vs. 15%, $p < 0.01$) and penetrating injuries (49% vs. 33%, $p < 0.01$).

There were no differences in PRCs after resection in which the end was stapled versus sutured. Drains were left after 331 of 365 distal pancreatic resections (91%), and PRCs were higher with (42%) versus without drain placement (21%) ($p = 0.01$). The difference did not reach statistical significance for blunt (44% vs. 20%, $p = 0.24$) or penetrating subgroups (40% vs. 21%, $p = 0.06$).

Based on Injury Grade

In Figure 3, the PRC rate is compared for blunt versus penetrating injuries based on injury severity. The rate does not vary significantly for penetrating injury across the grades; however, it does differ for blunt injuries between LGPIs and HGPIs. A comparison of management and outcomes based on grade is shown in Table 2. Grade IV and V injuries are rare, together accounting for only 9% of the 24-hour survivors. There was no difference in their management or outcomes between blunt and penetrating injuries. The only significant difference noted was that PRCs after surgical drainage (61%) were higher than after resection (32%; $p < 0.01$). The management of grade III injuries varied between blunt and penetrating mechanisms, with significantly more resection and less drainage in the penetrating group. The rate of PRCs was not different after blunt versus penetrating injuries. In the LGPI cohort, both management and outcomes varied significantly based on mechanism.

The management strategies for HGPIs did not differ between high- and low-volume centers for either blunt or penetrating cohorts. The only significant difference in outcomes was seen in those who had operative drainage of HGPIs, with PRCs occurring in 71% of those managed in low-volume centers versus 42% in high-volume centers ($p = 0.045$). In the LGPI cohort, there were multiple differences in management and outcomes between low- and high-volume centers. In low-volume versus high-volume centers managing blunt injuries, resection (10% vs. 4%, $p = 0.02$) and drainage (54% vs. 43%, $p = 0.04$) were more

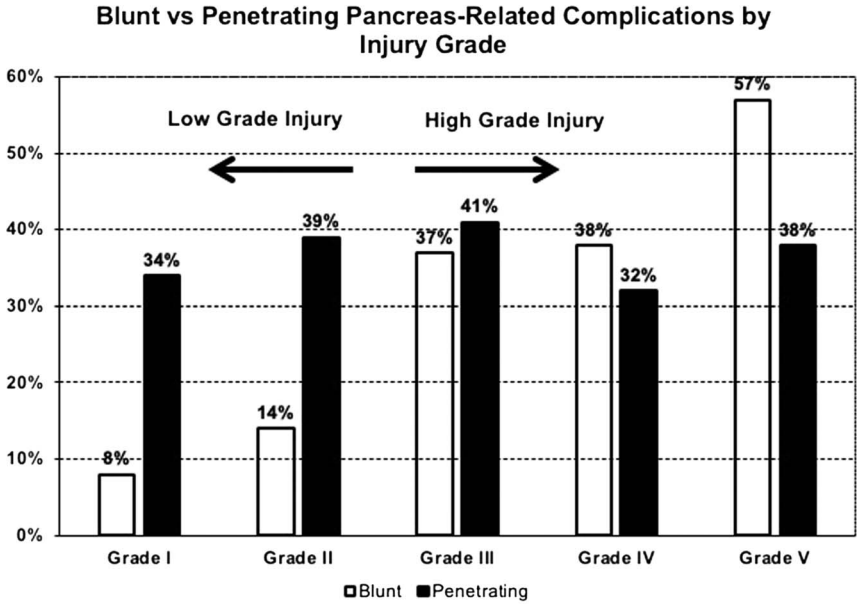

Figure 3. Breakdown of proportion of PRCs by pancreatic injury grade, for blunt and penetrating mechanisms of injury.

TABLE 2. Definitive Management and Outcomes (PRCs) of Blunt versus Penetrating Pancreatic Injuries among All 24-hour Survivors (n = 1,108*), by Injury Grades

	Grade IV/V				Grade III				Grade I/II			
	Total	Blunt	Penetrating	*p*	Total	Blunt	Penetrating	*p*	Total	Blunt	Penetrating	*p*
24-h Survivors	105 (9%)	43 (41%)	62 (59%)	—	321 (29%)	164 (51%)	157 (49%)	—	682 (62%)	424 (62%)	258 (38%)	—
Overall PRC	44 (42%)	19 (44%)	25 (40%)	0.69	126 (39%)	62 (38%)	64 (41%)	0.59	141 (21%)	46 (11%)	95 (37%)	<0.01
Resection	47 (45%)	16 (37%)	31 (50%)	0.19	247 (77%)	110 (67%)	137 (87%)	<0.01	71 (10%)	22 (5%)	49 (19%)	<0.01
Resection—PRC	15 (32%)	7 (44%)	8 (26%)	0.21	101 (41%)	45 (41%)	56 (41%)	1.0	30 (42%)	11 (50%)	19 (39%)	0.38
Drainage	46 (44%)	18 (42%)	28 (45%)	0.74	51 (16%)	34 (21%)	17 (11%)	0.02	370 (54%)	194 (46%)	176 (68%)	<0.01
Drainage—PRC	28 (61%)	11 (61%)	17 (61%)	0.98	18 (35%)	10 (29%)	8 (47%)	0.21	97 (26%)	28 (14%)	69 (39%)	<0.01
NOM	11 (10%)	8 (19%)	3 (5%)	0.62	17 (5%)	15 (9%)	2 (1%)	<0.01	209 (31%)	188 (44%)	21 (8%)	<0.01
NOM—PRC	1 (9%)	1 (13%)	0	1	3 (18%)	3 (20%)	0	1	9 (4%)	5 (3%)	4 (19%)	<0.01

*Thirty-nine patients (3.5%) were managed with other surgical procedures (e.g., mobilization, suturing, debridement), without resection or drain placement.
p Value = blunt versus penetrating.
Two proportion *z* tests were performed.

common, and NOM (28% vs. 50%, $p < 0.01$) was less common. The rate of PRCs was higher overall for low- versus high-volume centers after blunt LGPI (16% vs. 9%, $p = 0.04$). In the case of penetrating LGPIs, there were no significant differences in management strategies, but the overall rate of PRCs was higher in low-volume centers (52% vs. 30%, $p < 0.01$). This was due in large part to a difference in PRCs after operative drainage, the most common intervention, which occurred more often in low-volume centers (53% vs. 33%, $p = 0.01$).

Multivariate analysis identified penetrating injury, HGPI, and management in a low-volume center to be independently associated with PRCs (Table 3).

DISCUSSION

There seems to be a prevailing notion that blunt and penetrating pancreatic injuries are different entities; however, there is a paucity of data in the current literature to substantiate this belief. In this secondary analysis of a large multicenter study,[5,8] we have confirmed that penetrating mechanism is an independent risk factor for PRCs following pancreatic trauma: the rate of PRCs was twice as high in the setting of penetrating versus blunt pancreatic injury. However, this gross comparison is potentially confounded by many factors including the grade of injury, management strategy, and possibly surgeon/institutional factors.

In the presence of MPD injury (i.e., HGPI), there is no difference in PRCs between penetrating and blunt mechanisms, whether MPD injuries are to the left (grade III) or right (grade IV/V) of the superior mesenteric vein (SMV). However, our data indicate that the management of HGPIs and the PRCs related to management strategy differ based on mechanism, a finding that has not been previously reported. In this study, grade IV/V injuries were managed primarily by resection or drainage, in 45% and 44%, respectively. The significantly higher rate of PRCs after drainage (61%) versus resection (32%) raises serious concerns about the nonresectional strategy, particularly after penetrating trauma, where the differences were more pronounced (61% vs. 26%). Although the Memphis group has promulgated an algorithm[16,26] calling for drainage of pancreatic head injuries, it must be recognized that their algorithm does not include assessment of the integrity of the MPD, and thus, many of their injuries were likely LGPIs. The recent multicenter study of the American Association for the Surgery of Trauma[2] reported that drainage of grade IV/V injuries, when compared with resection, carried an increased risk of pancreatic fistula/pseudocyst (odds ratio, 8.3; 95% CI, 2.2–32.9). There were only 24 patients with grade IV/V injuries in their series, and the authors rightly hesitated to make definitive statements regarding outcomes. The recent long-term follow-up study by Ball et al.[27] reported that the immediate, intermediate, and long-term outcomes of patients with grade IV injuries favored resection as the preferred strategy, to reduce the number of interventions and improve quality of life. All of these data, when

TABLE 3. Multivariate Model of Predictors of PRC (n = 1,068)

Predictor	PRC, OR (95% CI)	*p*
High grade	2.39 (1.55–3.67)	<0.01
Resection	1.18 (0.76–1.82)	0.47
Low volume	1.65 (1.16–2.35)	<0.01
Other intra-abdominal injury	1.35 (0.78–2.42)	0.30
ISS	0.99 (0.98–1.01)	0.64
Direct to operating room	1.25 (0.82–1.91)	0.30
Penetrating injury	1.99 (1.31–3.05)	<0.01

Predictor Interpretations for Multivariate Model.
Train data set, n = 747; test data set, n = 321.
• High grade: For high-grade injuries, the odds of pancreatic complication is 2.39 (1.55–3.67) times as large as the odds for low-grade injuries.
• Resection: For a resection, the odds of pancreatic complication is 1.18 (0.76–1.82) times as large as the odds for nonresections.
• Low volume: When a patient is treated at a low-volume site (≤5 cases/year), the odds of pancreatic complication is 1.65 (1.16–2.35) times as large as the odds for a patient treated at a high-volume site.
• Other intra-abdominal injury: When a patient has another intra-abdominal injury, the odds of a pancreatic complication is 1.35 (0.78–2.42) times as large as the odds for those with no other intra-abdominal injuries.
• ISS: From 0 when the ISS of a patient increases by 1, the odds of a pancreatic complication decreases by 1% (−2% to +1%).
• Directly to operating room: When a patient goes directly to operating room, the odds of a pancreatic complication is 1.25 (0.82–1.91) times as large as the odds of those who had imaging first.
• Penetrating injury: For a penetrating injury, the odds of a pancreatic complication is 1.99 (1.31–3.05) times as large as the odds of blunt injuries.
Multivariate Pancreatic Complication Model Fit Stats.
• AUC (95% CI): 0.6709 (0.6105–0.7313).
ISS, Injury Severity Score.
OR, odds ratio.

taken together, support a current recommendation for primary resectional management of grade IV/V injuries. It must be noted that any complex procedure should be delayed until the patient is physiologically well and able to tolerate it and ideally involve a surgeon adequately experienced in the procedure.[28] Damage-control principles, including drainage of the pancreas, are recommended at the first laparotomy in the unstable patient or while waiting for the "cavalry" to arrive.[28] These data also emphasize the need for prospective study of resectional versus nonresectional management of grade IV/V injuries. As we found no significant differences in outcomes between blunt and penetrating injuries, studies should include all injury types, with planned subgroup analysis.

Another notable finding in this study is that, although distal pancreatectomy has long been considered the optimal management of grade III injuries and is recommended in current guidelines,[3,11,12] resection was performed in only 67% of blunt grade III injuries. That being said, there is no evidence that blunt grade III injuries were "undertreated" by this strategy, as the PRCs were not different between resection and drainage alone, for either mechanism. Resection versus drainage of grade III injuries should be subjected to prospective study with rigorous documentation of MPD integrity.

The major differences in outcomes between blunt and penetrating injuries were seen in the LGPI cohort. Pancreatic resection for LGPIs is associated with a high rate of PRCs that is equivalent to that of HGPIs and independent of injury mechanism. However, whereas the PRCs in blunt trauma patients were much lower with drainage (14%) and NOM (3%) compared with resection (50%), the occurrence of PRCs after penetrating LGPI was not lower when treated with drainage alone (39%). Even the NOM subgroup of penetrating trauma patients, consisted of only 21 patients, had a significantly higher rate of PRCs (19%) compared with the blunt injured patients. There are several hypotheses for this. One is that the penetrating trauma patients, who are mainly taken to the operating room without imaging, are "overtreated" in some manner. As noted, however, the penetrating LGPI patients do equally poorly when treated with drainage or resection. Another possibility is that the presence of a drain resulted in a bias toward the diagnosis of PRCs, whether or not it actually met the definition for pancreatic fistula. This highlights the need for strict definitions of PRCs and their impact on outcomes in future studies. A third possibility is that violation of the pancreatic capsule, even in the absence of MPD injury, results in pancreatic enzyme leak and further morbidity. This seems most plausible, as penetrating trauma by definition violates the capsule. Consequently, a revision to the American Association for the Surgery of Trauma grading scale has recently been proposed.[29] The new scale attempts to alleviate confusion and subjectivity over the terms "major" and "minor" contusion and laceration and separates injuries into those with and without capsular disruption. This proposed scale should be subjected to further validation study.

Management in a low-volume center was an independent risk factor for PRCs. While there was a significant difference in the patient populations, with more LGPIs in the high-volume centers, there were management differences that raise concerns. Specifically, NOM of LGPIs was pursued less frequently in low-volume centers. Given the significant differences in outcomes between resection, drainage, and NOM, an effort to avoid surgical management or unnecessary manipulation of the pancreas may improve outcomes. Furthermore, it may help to consult a more experienced surgeon if there is time to plan definitive treatment.

One final consideration relates to identifying the presence or absence of MPD laceration. In this study, intraoperative grading was assigned based on visual inspection. The intraoperative criteria for ductal injury described by Heitsch et al.[30] include the presence of complete pancreatic transection, direct visualization of duct injury, laceration through more than half the diameter of the pancreas, central pancreatic perforation, or severe maceration of the pancreas. These criteria seem reliable in identifying a population at lower risk, who do relatively well with nonresectional management.[16,26] However, they are nonspecific and subjective. No patients in this study underwent intraoperative pancreatography. The utility of this has been questioned,[4,31] and we do not endorse its routine use. On the other hand, intraoperative ultrasonography is a tool with which surgeons have become increasingly comfortable, and a direct assessment of the MPD may prove beneficial in directing optimal treatment.[32] This is worthy of trauma surgeon education and further assessment of accuracy. In the patient able to undergo imaging before surgery, one should consider the use of pancreatography. Although noninvasive studies are generally preferred, the shortcomings of MRCP have been described.[33,34] Therefore, ERCP should be considered in equivocal cases before committing to a major operation. Pancreaticographic classification of ductal injuries appears to be a useful tool in selecting patients for NOM and in planning interventions.[35–37]

Limitations

This study was retrospective in design and suffers from all the limitations of such studies. Specific to this study, injury grading may have been inaccurate because CT scanning, intraoperative assessment, and MRCP all have shortcomings, and trauma registry data may not be correct. Moreover, we did not collect data on the physiologic status or resuscitation details of the patients and cannot directly assess the role of shock or transfusions in the occurrence of PRCs. Definitive management may have been influenced by factors other than the injury grade, and our ability to determine clinical decision making was limited. The recording of PRCs was based on retrospective review rather than prospective documentation with strict definitions; consequently, a pancreatic leak or fistula may have been diagnosed based on an arbitrary decision to measure pancreatic enzymes in drain fluid. Furthermore, we did not have data on the consequences of each specific PRC (e.g., interventions, contribution to length of stay). Such data would be important to collect in future prospective studies. Data may not be representative of management across the country, as the majority was collected from academic centers with Western Trauma Association members. However, a broad range of centers is represented, so these data and the conclusions should be generalizable. The study period ended in October 2018, so more recent data are not included, and it is possible that ongoing evolution in care is occurring.

CONCLUSION

Blunt and penetrating pancreatic injuries are managed differently, mainly in that most penetrating injuries are identified intraoperatively and NOM is rare. In the presence of MPD injury, outcome does not appear to be related to the injury

mechanism. Grade IV and V injuries should be managed with resection if the patient can be stabilized and a qualified surgeon is available. Nonresectional management of grade III injuries may be noninferior and should be studied prospectively with stratification by injury mechanism. Blunt grade I and II injuries should be managed nonoperatively. Penetrating injuries should be drained, and intraoperative ultrasonography should be studied as a means of determining ductal integrity. Preoperative pancreatography should be performed when considering complex resections.

AUTHORSHIP

All authors contributed to the study design, data collection, data interpretation, and critical revision of the manuscript.

ACKNOWLEDGMENTS

We thank Tala Dandan and Dunya Bayat for data management.
WTA Multicenter Trials Group on Pancreatic Injuries:
Arthur D. Grimes, Jason Lees, S. Rob Todd, Jose Pascual, Jessica L. Weaver, Matthew Yanoff, Salina Wydo, Amanda Teichman, Alicia R. Privette, Stuart Leon, Bryan Morse, Deepika Koganti, Michelle K. McNutt, Thaddeus J. Puzio, Linda Dultz, Kali Kulenschmidt, Ashley Meagher, Anthony Douglas II, Samantha M. Koenig, Katie Bower, Pascal (Osi) Udekwu, Sara Roy, Saskya Byerly, Rishi Rattan, Kevin N. Harrell, Robert A. Maxwell, Allen Chen, James W. Davis, Thomas Clements, Chance Spalding, Kimberly Sperwer, Carmen Flores, Paul Chestovich, Miklosh Bala, Asaf Kedar, Ryan Landis, Bhattacharya Bishwajit, Isabella Struve, Gregory J. Jurkovich, Clay Burlew, Amy V. Gore, Kim Peck, Alexandra S Rooney, Hasan Alam, Galinos Barmparas, Daniel Margulies, Daniel Cullinane, Laura M. Cullinane, Barb Curran, Jeffry Nahmias, Erika Limney-Lasso, Teagan L. Way, Thomas Schroeppel, Zachery Stillman, Ben Zarzaur, and Tatiana C.P. Cardenas.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

1. Phelan HA, Velmahos GC, Jurkovich GJ, Friese RS, Minei JP, Menaker JA, et al. An evaluation of multidetector computed tomography in detecting pancreatic injury: results of a multicenter AAST study. *J Trauma*. 2009;66(3):641–646.
2. Byrge N, Heilbrun M, Winkler N, Sommers D, Evans H, Cattin LM, et al. An AAST-MITC analysis of pancreatic trauma: staple or sew? Resect or drain? *J Trauma Acute Care Surg*. 2018;85(3):435–443.
3. Coccolini F, Kobayashi L, Kluger Y, Moore EE, Ansaloni L, Biffl W, et al. Duodeno-pancreatic and extrahepatic biliary tree trauma: WSES-AAST guidelines. *World J Emerg Surg*. 2019;14(56):1–23.
4. Jurkovich GJ. Pancreatic trauma. *J Trauma Acute Care Surg*. 2020;88(1):19–24.
5. Biffl WL, Zhao FZ, Morse B, McNutt M, Lees J, Byerly S, et al. A multicenter trial of current trends on the diagnosis and management of high-grade pancreatic injuries. *J Trauma Acute Care Surg*. 2021;90(5):776–786.
6. Yilmaz TH, Hauer TJ, Smith MD, Degiannis E, Doll D. Operative techniques in pancreatic trauma—a heuristic approach. *Injury*. 2013;44(1):153–155.
7. Kao LS, Bulger EM, Parks DL, Byrd GF, Jurkovich GJ. Predictors of morbidity after traumatic pancreatic injury. *J Trauma*. 2003;55(5):898–905.
8. Biffl WL, Ball CG, Moore EE, Lees J, Todd SR, Wydo S, et al. Don't mess with the pancreas! A multicenter analysis of the management of low-grade pancreatic injuries. *J Trauma Acute Care Surg*. 2021;91(5):820–828.
9. Vasquez JC, Coimbra R, Hoyt DB, Fortlage. Management of penetrating pancreatic trauma: an 11-year experience of a level-1 trauma center. *Injury*. 2001;32(10):753–759.
10. Joos E, de Jong N, Ball CG, Quigley S, Trottier V, Masse M, et al. Time to operating room matters in modern management of pancreatic injuries: a national review on the management of adult pancreatic injury at Canadian level 1 trauma centers. *J Trauma Acute Care Surg*. 2021;90(3):434–440.
11. Biffl WL, Moore EE, Croce M, Davis JW, Coimbra R, Karmy-Jones R, et al. Western Trauma Association critical decisions in trauma: management of pancreatic injuries. *J Trauma Acute Care Surg*. 2013;75(6):941–946.
12. Ho VP, Patel NJ, Bokhari F, Madbak FG, Hambley JE, Yon JR, et al. Management of adult pancreatic injuries: a practice management guideline from the Eastern Association for the Surgery of Trauma. *J Trauma Acute Care Surg*. 2017;82(1):185–199.
13. Graham JM, Mattox KL, Jordan GL Jr. Traumatic in juries of the pancreas. *Am J Surg*. 1978;136(6):744–748.
14. Stone HH, Fabian TC, Satiani B, Turkleson ML. Experiences in the management of pancreatic trauma. *J Trauma*. 1981;21(4):257–262.
15. Jones RC. Management of pancreatic trauma. *Am J Surg*. 1985;150(6):698–704.
16. Patton JH, Lyden SP, Croce MA, Pritchard FE, Minard G, Kudsk KA, et al. Pancreatic trauma: a simplified management guideline. *J Trauma*. 1997;43(2):234–241.
17. Cogbill TH, Moore EE, Morris JA, Hoyt DB, Jurkovich GJ, Mucha P, et al. Distal pancreatectomy for trauma: a multicenter experience. *J Trauma*. 1991;31(12):1600–1606.
18. Ivatury RR, Nallathambi M, Rao P, Stahl WM. Penetrating pancreatic injuries: analysis of 103 consective cases. *Am Surg*. 1990;56(2):90–95.
19. Lin BC, Chen RJ, Fang JF, Hsu YP, Kao YC, Kao JL. Management of blunt major pancreatic injury. *J Trauma Acute Care Surg*. 2004;56(4):774–778.
20. Bradley EL 3rd, Young PR Jr., Chang MC, Allen JE, Baker CC, Meredith W, et al. Diagnosis and initial management of blunt pancreatic trauma: guidelines from a multiinstitutional review. *Ann Surg*. 1998;227(6):861–868.
21. Velmahos GC, Tabbara M, Gross R, Willette P, Hirsch E, Burke P, et al. Blunt pancreatoduodenal injury: a multicenter study of the Research Consortium of New England Centers for Trauma (ReCONECT). *Arch Surg*. 2009;144(5):413–419.
22. Siboni S, Kwon E, Benjamin E, Inaba K, Demetriades D. Isolated blunt pancreatic trauma: a benign injury? *J Trauma Acute Care Surg*. 2016;81(5):855–859.
23. Mohseni S, Holzmacher J, Sjolin G, Ahl R, Sarani B. Outcomes after resection versus non-resection management of penetrating grade III and IV pancreatic injury: a trauma quality improvement (TQIP) databank analysis. *Injury*. 2018;49(1):27–32.
24. Moore EE, Cogbill TH, Malangoni MA, Jurkovich GJ, Champion HR, Gennarelli TA, et al. Organ injury scaling, II: Pancreas, duodenum, small bowel, colon, and rectum. *J Trauma*. 1990;30(11):1427–1429.
25. Von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The stregthening the reporting of observational studies in epidemiology (STROBE) statement. *Epidemiology*. 2007;18(6):800–804.
26. Sharpe JP, Magnotti LJ, Weinberg JA, Zarzaur BL, Stickley SM, Scott SE, et al. Impact of a defined management algorithm on outcome after traumatic pancreatic injury. *J Trauma Acute Care Surg*. 2012;72(1):100–105.
27. Ball CG, Biffl WL, Vogt K, Hameed SM, Parry NG, Kirkpatrick AW. Does drainage or resection predict subsequent interventions and long-term quality of life in patients with grade IV pancreatic injuries: a population-based analysis. *J Trauma Acute Care Surg*. 2021;91(4):708–715.
28. Krige J, Nicol A, Navsaria P. Managing grade 5 pancreatic injuries—think smart, act smart and call in the pancreatic cavalry early. *J Trauma Acute Care Surg*. 2017;82(6):1187–1188.
29. Ball CG, Biffl WL, Moore EE. Time to update the American Association for the Surgery of Trauma pancreas injury grading lexicon? *J Trauma Acute Care Surg*. 2022;92(3):e38–e40.
30. Heitsch RC, Knutson CO, Fulton RL, Jones CE. Delineation of critical factors in the treatment of pancreatic trauma. *Surgery*. 1976;80(4):523–529.
31. Schellenberg M, Inaba K, Bardes JM, Cheng V, Matsushima K, Lam L, et al. Detection of traumatic pancreatic duct disruption in the modern era. *Am J Surg*. 2018;216(2):299–303.
32. Hofmann LJ, Learn PA, Cannon JW. Intraoperative ultrasound to assess for pancreatic duct injuries. *J Trauma Acute Care Surg*. 2015;78(4):888–891.
33. Aydelotte JD, Ali J, Huynh PT, Coopwood TB, Uecker JM, Brown CVR. Use of magnetic resonance cholangiopancreatography in clinical practice: not as good as we once thought. *J Am Coll Surg*. 2015;221(1):215–219.
34. Rosenfeld EH, Vogel A, Russell RT, Maizlin I, Klinkner DB, Polites S, et al. Comparison of diagnostic imaging modalities for the evaluation of pancreatic duct injury in children: a multi-institutional analysis from the Pancreatic Trauma Study Group. *Pediatr Surg Int*. 2018;34(9):961–966.
35. Bhasin DK, Rana SS, Rawal P. Endoscopic retrograde pancreatography in pancreatic trauma: Need to break the mental barrier. *J Gastroenterol Hepatol*. 2009;24(5):720–728.
36. Takishima T, Hirata M, Kataoka Y, Asari Y, Sato K, Ohwada T, et al. Pancreatographic classification of pancreatic ductal injuries caused by blunt injury to the pancreas. *J Trauma*. 2000;48(4):745–752.
37. Lin BC, Wong YC, Chen RJ, Liu NJ, Wu CH, Hwang TL, et al. Major pancreatic duct continuity is the crucial determinant in the management of blunt pancreatic injury: a pancreatographic classification. *Surg Endosc*. 2017;31(10):4201–4210.