A case series of penetrating spinal trauma: comparisons to blunt trauma, surgical indications, and outcomes

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OBJECTIVE While blunt spinal trauma accounts for the majority of spine trauma, penetrating injuries affect a substantial number of patients. The goal of this study was to examine the epidemiology of penetrating spine injuries compared with blunt injuries and review the operative interventions and outcomes in the penetrating spine injury group.

METHODS The prospectively maintained trauma database was queried for spinal fractures from 2012 to 2018. Charts from patients with penetrating spine trauma were reviewed.

RESULTS A total of 1130 patients were evaluated for traumatic spinal fractures; 154 injuries (13.6%) were secondary to penetrating injuries. Patients with penetrating injuries were significantly younger (29.2 years vs 44.1 years, $p < 0.001$), more likely male (87.7% vs 69.2%, $p < 0.001$), and more commonly African American (80.5% vs 33.3%, $p < 0.05$). When comparing primary insurers, the penetrating group had a significantly higher percentage of patients covered by Medicaid (60.4% vs 32.6%, $p < 0.05$) or prison (3.9% vs 0.1%, $p < 0.05$) or being uninsured (17.5% vs 10.3%, $p < 0.05$). The penetrating group had a higher Injury Severity Score on admission (20.2 vs 15.6, $p < 0.001$) and longer hospital length of stay (20.1 days vs 10.3 days, $p < 0.001$) and were less likely to be discharged home (51.3% vs 65.1%, $p < 0.05$). Of the penetrating injuries, 142 (92.2%) were due to firearms. Sixty-three patients (40.9%) with penetrating injuries had a concomitant spinal cord or cauda equina injury. Of those, 44 (69.8%) had an American Spinal Injury Association Impairment Scale (AIS) grade of A. Ten patients (15.9%) improved at least 1 AIS grade, while 2 patients (3.2%) declined at least 1 AIS grade. Nine patients with penetrating injuries underwent neurosurgical intervention: 5 for spinal instability, 4 for compressive lesions with declining neurological examination results, and 2 for infectious concerns, with some patients having multiple indications. Patients undergoing neurosurgical intervention did not show a significantly greater change in AIS grade than those who did not. No patient experienced a complication directly related to neurosurgical intervention.

CONCLUSIONS Penetrating spinal trauma affects a younger, more publicly funded cohort than blunt spinal trauma. These patients utilize more healthcare resources and are more severely injured. Surgery is undertaken for limiting progression of neurological deficit, stabilization, or infection control.

<https://thejns.org/doi/abs/10.3171/2018.12.FOCUS18577>

KEYWORDS penetrating spinal trauma; gunshot wound spine; blunt spinal trauma

IN the United States, spinal trauma represents both a major public health concern and substantial economic burden.^{8,19,25} Spine trauma and spinal cord injury (SCI) account for a significant source of long-term impairment and disability, affecting younger populations disproportionately.^{1,9,19} While blunt trauma accounts for most trau-

matic spinal injuries, penetrating injuries represent higher rates of morbidity, disability, and financial burden.^{3,21}

Literature on management of spinal trauma reflects the comparative rarity of penetrating spine data, with the studies to date focusing on the immediate management and sequelae of penetrating spine injuries.^{3,11,21} In contrast to the

ABBREVIATIONS AIS = American Spinal Injury Association Impairment Scale; ISS = Injury Severity Score; LOS = length of stay; MAP = mean arterial pressure; SCI = spinal cord injury.

ACCOMPANYING EDITORIAL DOI: 10.3171/2019.1.FOCUS1913.

SUBMITTED October 30, 2018. **ACCEPTED** December 7, 2018.

INCLUDE WHEN CITING DOI: 10.3171/2018.12.FOCUS18577.

vast composite epidemiological data available for blunt spinal injuries that have been used to create guidelines for the classification and management of blunt spine trauma,³⁰ data on penetrating spine trauma are relatively lacking. Consequently, there is significant variability in penetrating spinal trauma management practices with most trauma centers relying on blunt spine trauma guidelines, which may be ill-equipped for the distinct patient population and mechanism of penetrating injury.^{11,13,20}

Our institution is an academic level 1 trauma center and safety-net hospital in the southeastern United States with a relatively high rate of penetrating spine injuries.²⁷ The goal of this study was to examine the epidemiology of penetrating spine injuries compared with blunt injuries. Additionally, we reviewed operative interventions and outcomes in the penetrating spine injury group.

Methods

Institutional review board approval was obtained for this study. The trauma database at our institution is prospectively maintained and was queried for all traumatic spinal fractures from August 2012 to February 2018. The start date of our query was chosen to coincide with implementation of electronic medical records at our institution. Epidemiological data were collected, along with data on injury mechanism, injury intent, toxicology screen results, primary payer, Injury Severity Score (ISS), hospital length of stay (LOS), discharge location, and mortality.

Patients with penetrating spine injury were then selected for chart review. These charts were queried for neurological injuries, American Spinal Injury Association Impairment Scale (AIS) grade, vascular injury, vasopressor use, surgical intervention, and follow-up. Surgical decision-making was at the discretion of the attending neurosurgeon on call.

Statistical analysis was performed using the independent sample t-test for continuous variables and the chi-square test for nominal variables, with individual categories compared using the z-test with Bonferroni method. Statistical analyses were performed using IBM SPSS (version 24, IBM Corp.). A p value of ≤ 0.05 was used to determine statistical significance.

Results

A total of 1130 patients were evaluated for spinal fractures during the period of our study. Of these, 154 (13.6%) spinal traumas were secondary to penetrating injuries.

There are many significant differences between the spine trauma patients with penetrating injuries versus blunt injuries. The patients with penetrating injuries were significantly younger (mean 29.2 years vs 44.1 years, $p < 0.001$) and were more likely to be male (87.7% vs 69.2%, $p < 0.001$). Chi-square analysis showed that the patients were significantly different when categorized by race ($p < 0.001$), with more African Americans in the penetrating group (80.5% vs 33.3%, $p < 0.05$) and a lower percentage of Caucasians (14.3% vs 55.5%, $p < 0.05$). Fewer patients in the penetrating group had a blood alcohol level over the legal limit (10.4% vs 22.5%, $p < 0.001$). The groups differed significantly based on primary payer as well ($p <$

0.001), with the penetrating group having a significantly higher percentage of patients covered by Medicaid (60.4% vs 32.6%, $p < 0.05$) or prison (3.9% vs 0.1%, $p < 0.05$) or being uninsured (17.5% vs 10.3%, $p < 0.05$), while having lower percentages of patients covered by commercial insurance (13.0% vs 22.2%, $p < 0.05$), Medicare (3.2% vs 18.1%, $p < 0.05$), workers' compensation (1.3% vs 5.6%, $p < 0.05$), and liability (0% vs 6.8%, $p < 0.05$). The patients in the penetrating group had a higher ISS on admission (mean 20.2 vs 15.6, $p < 0.001$) and a longer hospital LOS (mean 20.1 days vs 10.3 days, $p < 0.001$). Discharge location differed significantly as well ($p < 0.001$), with more patients from the penetrating group being discharged to inpatient rehabilitation facilities (27.3% vs 13.6%, $p < 0.05$), other acute care facilities (9.1% vs 3.3%, $p < 0.05$), or jail (5.2% vs 0.9%, $p < 0.05$), while they had a lower frequency of being discharged to home (51.3% vs 65.1%, $p < 0.05$) or long-term acute care (0% vs 3.0%, $p < 0.05$). There was no significant difference in the in-hospital mortality rate (3.9% vs 6.7%, $p > 0.05$). See Table 1 for a summary comparison of the 2 groups.

The age range of the penetrating spine injury patients was 15–65 years, and the average was 29.2 years. Regarding race, 124 (80.5%) were African American, 22 (14.3%) were Caucasian, 2 (1.3%) were Asian, and 6 (3.9%) were other or unspecified. Sixty-three patients (40.9%) had a concomitant SCI or cauda equina injury. Of the penetrating injuries, 142 (92.2%) were due to firearms, while the remaining injuries were due to other objects. The injury intent was assault in 143 (92.9%) of cases, self-inflicted in 2 (1.3%), and accidental in 9 (5.8%). The injury levels were distributed evenly throughout the spinal levels. Vasopressors were used to maintain elevated mean arterial pressure (MAP) goals in 23 patients (14.9%). Two of the patients maintaining MAP goals underwent spinal surgery. Thirty-seven patients (24.0%) also sustained a vascular injury. Nine patients (5.8%) underwent neurosurgical intervention. See Table 2 for a summary of the demographics of the penetrating spinal trauma patients.

Sixty-three patients in the penetrating group (40.9%) had a neurological deficit due to spinal cord or cauda equina injury. Of those, 44 (69.8%) were AIS grade A. The average follow-up for the patients with neurological injury was 14.4 months, including 22 patients with no follow-up at all. Ten patients (15.9%) improved at least 1 AIS grade, while 2 patients (3.2%) declined at least 1 AIS grade, including 1 patient who presented as AIS grade E and declined to grade A. Patients treated with vasopressors to keep MAPs elevated did not show a greater difference in final AIS grade than those who were not (0.36 vs 0.24, $p = 0.713$). Additionally, patients undergoing neurosurgical intervention also did not show a significantly greater change in AIS grade when compared with those who did not (0.0 vs 0.30, $p = 0.476$).

Nine patients with penetrating injuries underwent surgery for spinal instability ($n = 5$), compressive lesions with declining neurological examination findings ($n = 4$), and infectious concerns ($n = 2$), with some patients having multiple indications. All patients underwent surgery in a delayed fashion (> 24 hours from admission). No patient experienced a complication directly related to neurosur-

TABLE 1. Comparison between patients with penetrating and blunt spinal injuries

Variable	Penetrating	Blunt	p Value
No. of patients	154	976	
Mean age, yrs	29.2	44.1	<0.001
Mean ISS	20.2	15.6	<0.001
Mean hospital LOS, days	20.1	10.3	<0.001
% male	87.7%	69.2%	<0.001
Race			<0.001
African American	80.5%	33.3%	*
Caucasian	14.3%	55.5%	*
Asian	1.3%	1.2%	
Other	3.9%	9.7%	
EtOH over limit	10.4%	22.5%	<0.001
Payer			<0.001
Liability	0	6.8%	*
VA	0	2.2%	
Commercial	13.0%	22.2%	*
Uninsured	17.5%	10.3%	*
Prison	3.9%	0.1%	*
Medicaid	60.4%	32.6%	*
Medicare	3.2%	18.1%	*
Research	0.6%	0%	
Workers' comp	1.3%	5.6%	*
Discharge location			<0.001
Other acute care	9.1%	3.3%	*
Left AMA	1.9%	1.7%	
Deceased	3.9%	6.7%	
Home	51.3%	65.1%	*
Hospice	0%	0.3%	
Jail	5.2%	0.9%	*
LTAC	0	3.0%	*
Rehab	27.3%	13.6%	*
SNF	1.3%	3.4%	

AMA = against medical advice; comp = compensation; LTAC = long-term acute care; SNF = skilled nursing facility; VA = Veterans Affairs.

The independent sample t-test was used to compare continuous variables. For nominal variables, the Pearson chi-square was used to calculate the given p value.

* Individual categories with statistically significant differences ($p < 0.05$) using the z-test with Bonferroni method.

gical intervention. There were no cases of postoperative CSF leakage. There were no statistically significant differences between patients who underwent surgery and those who did not regarding age, ISS, hospital LOS, change in AIS grade, or total follow-up. See Table 3 for individual descriptions of the 9 surgical patients.

The images in Fig. 1 are from the patient in case 9, who had a C2 transverse process fracture with vertebral artery injury but was neurologically intact. Because of the unilateral fracture and lack of neurological deficit, he was treated nonoperatively with a cervical collar. He presented again 2 months later with worsening neck pain and new-onset bilateral upper-extremity numbness and weakness.

TABLE 2. Characteristics of patients with penetrating spine injuries

Variable	Value
No. of patients	154
Mean age, yrs (range)	29.2 (15–65)
Male sex	135 (87.7)
Race	
African American	124 (80.5)
Caucasian	22 (14.3)
Asian	2 (1.3)
Other	6 (3.9)
Mean ISS (range)	20.2 (4–75)
SCI	63 (40.9)
Injury level	
Cervical	48 (21.2)
Thoracic	43 (27.8)
Lumbar/sacral	44 (29.2)
MAP goals used	18 (11.7)
Vasopressors used	23 (14.9)
Vascular injury	37 (24.0)
Underwent op	9 (5.8)
Injury intent	
Assault	143 (92.9)
Self-inflicted	2 (1.3)
Accidental	9 (5.8)
Mean hospital LOS, days (range)	20.1 (1–278)

Values are presented as the number of patients (%) unless otherwise indicated.

Repeat imaging showed ligamentous injury, spinal cord edema, and worsening alignment. Posterior stabilization was performed without complication, and he eventually regained full strength. He continues to have minor residual numbness.

Discussion

In the United States, penetrating spinal injuries are typically from gunshot wounds. The county in which our study took place has a disproportionately high number of gunshot wounds, with 45.3 per 100,000 deaths by firearm, compared to the national average of 10.18 (<https://www.cdc.gov/injury/wisqars/>). This study represents one of the largest epidemiological comparisons between blunt and penetrating spinal fractures. The differences between groups are notable, with the penetrating injury patients being younger and more severely injured. There are also substantial differences regarding sex, race, and primary payers (Table 1).

Guidelines for acute care and surgical management of spine trauma are generally focused around blunt injuries.³⁰ However, there are publications addressing some of the more pressing questions for penetrating spinal trauma. Fractures due to penetrating injury are typically stable, especially in comparison with blunt injuries.^{4,12,15,17,22,26} Infection rates are high, especially when combined with a

TABLE 3. Description of the 9 surgical cases within our series of penetrating spinal injuries

Case No.	Age (yrs), Sex	Spinal Level	Initial AIS Grade	Indication	Spinal Procedure Performed	Other Procedures	FU (mos)	Final AIS Grade
1	24, M	T12–L1	E	Declining exam due to epidural hematoma	Laminectomy & lumbar drain placement	Exploratory laparotomy; resection of colon, spleen, kidney	5	A
2	40, F	L1–4	A	Persistent CSF leak & meningitis	Laminectomy, dural repair, & lumbar drain placement	None	36	C
3	30, M	L4	E	Spinal instability & delayed neuro decline	Laminectomy & fusion	Exploratory laparotomy, colectomy, retroperitoneal abscess drainage	10	E
4	32, F	C5	A	Spinal instability	Anterior cervical corpectomy & fusion	Neck exploration; PEG & tracheostomy	1	A
5	23, M	C5	A	Spinal instability & intramedullary spinal cord abscess	Posterior cervical laminectomy, myelotomy, washout, & fusion	Neck exploration, esophageal repair, tracheostomy, ORIF mandible	Lost to FU	A
6	37, M	C7	A	Spinal instability	Anterior cervical discectomy & fusion	Exploratory laparotomy, neck exploration, tracheostomy	60	A
7	20, M	L1–2	A	Bullet in lumbar canal	Minimally invasive bullet removal	Exploratory laparotomy, small bowel resection, kidney resection	4	C
8	55, M	L4	D	Declining neuro exam due to compression from bullet	Minimally invasive bullet removal	None	2	D
9	25, M	C2	E	Spinal instability	Posterior cervical fusion	Neck exploration, PEG	7	E

FU = follow-up; neuro = neurological; ORIF = open reduction and internal fixation; PEG = percutaneous endoscopic gastrostomy.

hollow viscus injury,²³ and 7–14 days of prophylactic antibiotic coverage can reduce the rate of infection in this population.⁴ In comparison to blunt SCI, a study by Reddy et al. showed that vasopressor use did not improve neurological outcomes.²⁰ We also did not find any significant improvement in neurological outcome in patients who sustained penetrating injuries and were treated with vasopressors.

The existing literature provides some guidance on surgical indication, reserving surgical intervention for progressive neurological deficit, spinal instability, or infection control.^{2–4,10–13,26–28} Thus, surgical intervention is largely to prevent worsening of the patient's neurological deficit and has not been shown to improve outcomes^{2,13,16,27} except when the bullet is in the spinal canal from T12 to L5.^{4,24} Our data reiterate this, with our patients who underwent surgery not showing any better neurological results, on average, than those with penetrating injury who did not undergo surgery. One patient experienced a substantial decline secondary to an expanding epidural hematoma.

He remained an AIS grade A at 5 months postoperatively and was ultimately lost to follow-up. Two patients with compressive lesions in the upper lumbar spine showed improvement postoperatively.

Spinal instability is a concern with any spinal trauma. Management of blunt spinal trauma is assisted by algorithms such as the thoracolumbar injury classification¹⁴ and SLIC²⁹ or the Denis 3-column system.⁷ However, due to the nature of penetrating injuries, these systems have not been shown to be applicable in penetrating spinal trauma.^{11,18} Five patients in our series (3.2% of all the penetrating injuries) underwent surgery for instability, all in the cervical spine. One patient presented with delayed spinal instability that was recognized on follow-up (Fig. 1).

The neurological outcomes from penetrating spine injury are worse than those of blunt injuries. Patients with penetrating injuries are more likely to have SCI,³ and those with SCI are more likely to be AIS grade A.^{2,5,11,21} A recent SCI database review by Roach et al. showed that blunt SCIs exhibit a significantly higher rate of improve-

FIG. 1. Case 9. **A:** Noncontrast CT scan of the cervical spine, showing a comminuted fracture of the right C2 lateral mass. **B:** CT scan obtained 1 month after the initial presentation, showing left lateral subluxation. **C:** Plain radiograph revealing the subluxation. **D:** Significant posterior ligamentous injury is seen on STIR (short tau inversion recovery) MRI.

ment at 1 year compared with penetrating injuries.²¹ Our data complement this study, showing that the penetrating spine injury patients had worse overall trauma, demonstrated by ISS. Additionally, the patients in our penetrating group had a nearly double the hospital LOS compared with the blunt injury group, as well as a reduced likelihood of being discharged home. There was no difference, however, in mortality rate during the acute inpatient stay. Our data did show that more patients in the blunt trauma group were intoxicated with alcohol, while previous studies have found that alcohol intoxication can lead to increased LOS and complications in spine trauma.⁶

The blunt trauma patients were, on average, less severely injured than the penetrating patients based on ISS. This is because of the large number of patients with “minor” spinal trauma, most without SCI, captured in the trauma database. For example, 401 blunt trauma patients (41.1% of all blunt trauma) had an ISS ≤ 10 while only 38 patients with penetrating injuries (24.6%) had an ISS ≤ 10 . This likely explains why the blunt trauma patients had a shorter hospital stay and were more likely to be discharged home. Comparing patients with SCIs may yield different data, but that is beyond the scope of our current study.

Our study is limited by its retrospective nature. The trauma database at our institution does not collect neurological examination information outside of the Glasgow Coma Scale, so AIS grades were retrieved by chart review. Therefore, we did not have neurological outcome information for the large group of blunt injury patients for comparison. Limitations also include the geographic nature of our cohort, which does not necessarily reflect similar populations in the rest of the United States.

Conclusions

While much less common than blunt spinal trauma, penetrating spinal injuries affect a substantial proportion of patients. The patients affected by penetrating spinal trauma differ from those with blunt spinal trauma regarding age, ISS, hospital LOS, sex, race, payer, and discharge location. These patients are largely publicly funded and consume more resources than their blunt injury counterparts. We recommend against utilizing MAP goals for penetrating SCI, as these did not improve neurological outcomes and pressor use can lead to complications. The severity of injuries, combined with younger age of the patients, contributes to an expected larger overall impact of lifetime healthcare costs in the penetrating spinal injury group.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Morrow, DiGiorgio. Acquisition of data: Morrow, Podet, Spinelli, DiGiorgio. Analysis and interpretation of data: Podet, DiGiorgio. Drafting the article: Morrow, Podet, DiGiorgio. Critically revising the article: Morrow, Podet, Lasseigne, Crutcher, Wilson, Tender, DiGiorgio. Reviewed submitted version of manuscript: Morrow, Podet, Lasseigne, Crutcher, Wilson, DiGiorgio. Statistical analysis: DiGiorgio. Administrative/technical/material support: Wilson, Tender, DiGiorgio. Study supervision: Tender, DiGiorgio.

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