Single-Center Experience With Antibiotic Prophylaxis and Infectious Complications in Civilian Cranial Gunshot Wounds

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BACKGROUND: Despite the widespread adoption of systemic antibiotic prophylaxis in civilian cranial gunshot wounds (cGSWs), there remains a lack of consensus on microbial coverage and duration of therapy.

OBJECTIVE: To analyze a 6-yr experience with prophylactic antibiotics in civilian cGSWs with a focus on infectious complications.

METHODS: Records were reviewed for demographic and injury characteristics that could influence the risk of intracranial infection. Patients over 16 yr of age with cGSWs who survived more than 48 h were included. Antimicrobial prophylaxis was initiated at the discretion of the treating neurosurgeon, with eligible patients divided into 3 groups: no prophylaxis, single agent, and multiagent. Univariate analysis and multivariable logistic regression were performed to determine variables contributing to the development of intracranial infection.

RESULTS: Of 75 eligible patients, prophylactic antibiotics were utilized in 61 (81.3%) with a 5 d median duration. Injury Severity Score (ISS) was significantly higher and Glasgow Coma Scale (GCS) was significantly lower in those who received prophylaxis. Eight intracranial infections were documented (10.7%) over a range of 1 wk to 3 yr from injury. Antibiotic prophylaxis did not contribute to infection, but the presence of cerebrospinal fluid (CSF) leak was associated with intracranial infection risk in multivariable regression (odds ratio [OR] = 11.8, \( P = .013 \)).

CONCLUSION: In a cohort of cGSW patients, those with a more severe injury profile were more likely to receive multiagent antimicrobial prophylaxis. However, we found that multiagent antimicrobial prophylaxis did not confer an advantage, and that the presence of CSF leak may be a more important contributing variable to the development of intracranial infection.

KEY WORDS: Civilian, Craniocerebral gunshot wounds, Antibiotic prophylaxis, Intracranial infections

Civilian cranial gunshot wounds (cGSWs) carry a high mortality rate, but for those who survive, morbidity reduction, including avoiding infection, becomes paramount.\(^1\) Much of the historical literature on intracranial infections following cGSW is derived from the military arena, with no identified civilian series prior to the widespread introduction of systemic antibiotics to clinical practice in 1943.\(^2,3\) Rates of intracranial infection from World War I combat were reported to be as high as 58.8%.\(^6\) Over the ensuing century, the prevalence of antibiotic prophylaxis for cGSW has increased by both military and civilian neurosurgical communities.\(^7,8\) This increasing antibiotic use has correlated with a decline in civilian intracranial infection rates to as low as 1% to 5%.\(^8,15\) Despite a 91% decrease in infection rate over the past century, there is no consensus on the spectrum and duration of antibiotic prophylaxis.\(^2,3,7\)
Guidelines and recommendations have advocated for varied approaches to antibiotic prophylaxis following cranial trauma. Over the past decade, providers and healthcare systems have begun to advocate for antibiotic stewardship given the increased recognition of multidrug resistant organisms and nosocomial infections. Here, we present our 6-yr institutional experience with the utilization of prophylactic antibiotics for civilian cGSWs, and test the hypothesis that multiantibiotic prophylaxis is associated with a lower risk of intracranial infection.

**METHODS**

**Selection of Subjects**

Retrospective data from our University trauma registry over a 6-yr period between November 2012 and October 2018 were queried for cases coded as “gunshot wounds to the head or neck.” This search returned 282 patients. Patients below age 16 or without confirmed cGSWs were excluded (ie, face or neck GSW). After the application of these exclusion criteria, 174 patients remained (Figure). Those who did not survive more than 48 h were excluded given the low likelihood of developing an intracranial infection, yielding 75 eligible patients (Table 1).

The study protocol is consistent with the Strength in Reporting of Observational Studies in Epidemiology (STROBE) guidelines and received approval from our Institutional Review Board (IRB) with a waiver of the requirement to obtain informed consent and authorization for the use of protected health information as the research was determined to present no greater than minimal risk.

**cGSW Management**

All patients were initially evaluated by a multidisciplinary team upon arrival to the hospital. Initial resuscitation was carried out by the trauma surgery team according to the Advanced Trauma Life Support (ATLS) guidelines with appropriate subspecialty consultation. The intensive care units (ICUs) at our institution are open units with critical management decisions deferred to the primary admitting service. The decision for aggressive versus conservative management, ancillary interventions, and prophylactic antibiotic use was at the discretion of the treating physicians as there was no standardized protocol for antibiotic prophylaxis at our institution over the time period studied.

**Patients Characteristics and Outcome Measures**

Electronic health records (EHRs) were reviewed for demographic information, including presenting Glasgow Coma Scale (GCS), Injury Severity Score (ISS), surgical intervention, and hospital length of stay (LOS). The presence of a documented cerebrospinal fluid (CSF) leak and medical comorbidities, including current smoking, positive drug screen, alcohol abuse, obesity, diabetes mellitus, or cancer, were collected. Injury characteristics such as motive, trajectory, and presence of multiple cGSWs were assessed. Tangential trajectory was defined as an oblique impact without bullet entry into the parenchyma. Penetrating trajectory was defined as the retention of the missile within the parenchyma, and perforating trajectory had identifiable cranial entry and exit wounds. Utilization of prophylactic antibiotics, including specific antibiotics administered, and duration of antibiotic therapy were recorded. Intracranial infection was defined as a culture positive wound or bone infection, intracranial abscess, meningitis, or cerebritis. A nosocomial infection was defined as any noncranial infection developing after 48 h of hospital admission to 3 d after discharge. Infections were tracked for the duration of follow-up available in the EHR.

**Statistical Analysis**

The 75 eligible patients were grouped according to whether they received no prophylactic antibiotics (No Abx), one prophylactic antibiotic (Single Abx), or two or more antibiotics (Multi Abx) (Figure). To assess for the bias in antibiotic group, between-group differences were analyzed as percent totals for categorical variables, median ± interquartile range for continuous variables, and group differences assessed with the Kruskal-Wallis test and chi-square test. To determine variables that contribute to the development of intracranial infection, those with and without intracranial infection were compared via univariate analysis and forward stepwise multivariable logistic regression subse-
### TABLE 1. Demographic and Injury Characteristics of Patients Surviving Less Than or More Than 48 Hours

| Characteristic                  | Survived less than 48 h | Survived more than 48 h | P value |
|---------------------------------|-------------------------|-------------------------|---------|
| No. of patients                 | 99                      | 75                      |         |
| Age (median, IQR)               | 28 (23-41)              | 30 (20-45)              | .998    |
| Gender (N, %)                   |                         |                         | .593    |
| Male                            | 86 (86.9)               | 63 (84)                 |         |
| Female                          | 13 (13.1)               | 12 (16)                 |         |
| Ethnicity (N, %)                |                         |                         | .200    |
| Caucasian                       | 55 (55.6)               | 36 (48)                 |         |
| African American                | 37 (37.4)               | 36 (48)                 |         |
| Hispanic                        | 4 (4)                   | 0 (0)                   |         |
| Asian                           | 1 (1)                   | 0 (0)                   |         |
| Other                           | 2 (2)                   | 3 (4)                   |         |
| Initial GCS (median, IQR)       | 3 (3-3)                 | 10 (6-15)               | <.001   |
| ISS (median, IQR)               | 29 (26-46)              | 25 (13-30)              | <.001   |
| Motive (N, %)                   |                         |                         | .266    |
| Assault                         | 63 (63.6)               | 40 (53.3)               |         |
| Self                            | 34 (34.3)               | 32 (42.7)               |         |
| Accident                        | 1 (1)                   | 3 (4)                   |         |
| Unknown                         | 1 (1)                   | 0 (0)                   |         |
| Radiographic findings*          |                         |                         |         |
| Injury number (N, %)            |                         |                         | .452    |
| Single                          | 76 (95)                 | 73 (97.3)               |         |
| Multiple                        | 4 (5)                   | 2 (2.7)                 |         |
| Trajectory (N, %)               |                         |                         | <.001   |
| Tangential                      | 1 (1.3)                 | 24 (32)                 |         |
| Penetrating                     | 30 (38.5)               | 31 (41.3)               |         |
| Perforating                     | 47 (60.3)               | 20 (26.7)               |         |
| Transventricular (N, %)         | 51 (73.9)               | 8 (10.7)                | <.001   |
| CSF leak (N, %)                 | 0 (0)                   | 6 (8)                   | <.004   |
| Antibiotic prophylaxis (N, %)   |                         |                         | <.001   |
| None                            | 62 (62.6)               | 13 (17.3)               |         |
| Single agent                    | 23 (23.2)               | 28 (37.3)               |         |
| Multiple agents                 | 14 (14.1)               | 34 (45.3)               |         |
| Hospital LOS (d) (median, IQR)  | 1 (0-1)                 | 8 (3.3-12.8)            | <.001   |

*Head imaging not available for all patients who survived less than 48 h. Statistical significance of p<0.05 noted with italics.
| Characteristic | No Abx | Single Abx | Multi Abx | P value |
|---------------|--------|------------|-----------|---------|
| No. of patients | 13     | 28         | 34        |         |
| Age (median, IQR) | 29 (21-44) | 30 (18.7-37.3) | 30 (21.5-46) | .560   |
| Gender (N, %) |        |            |           | .585    |
| Male          | 11 (84.6) | 22 (78.6)  | 30 (88.2) |         |
| Female        | 2 (15.4)  | 6 (21.4)   | 4 (11.7)  |         |
| Ethnicity (N, %) |    |             |           | .760    |
| Caucasian     | 6 (46.2)  | 12 (42.9)  | 18 (52.9) |         |
| African American | 7 (53.8) | 14 (50)    | 15 (44.1) |         |
| Hispanic      | 0 (0)     | 0 (0)      | 0 (0)     |         |
| Asian         | 0 (0)     | 0 (0)      | 0 (0)     |         |
| Other         | 0 (0)     | 2 (7.1)    | 1 (2.9)   |         |
| Initial GCS (median, IQR) | 15 (13-15) | 10.5 (6.8-15) | 8 (6-13.8) | .043    |
| ISS (median, IQR) | 14 (1-25) | 17.5 (10-27) | 29 (22.5-30) | .007    |
| Motive (N, %) |        |            |           | .781    |
| Assault       | 8 (61.5)  | 15 (53.6)  | 17 (50)   |         |
| Self          | 4 (30.8)  | 12 (42.9)  | 16 (47.1) |         |
| Accident      | 1 (7.7)   | 1 (3.6)    | 1 (2.9)   |         |
| Unknown       | 0 (0)     | 0 (0)      | 0 (0)     |         |
| Radiographic findings | | | | |
| Injury number (N, %) |        |            |           | .289    |
| Single        | 13 (100)  | 28 (100)   | 32 (94.1) |         |
| Multiple      | (0)       | 0 (0)      | 2 (5.9)   |         |
| Trajectory (N, %) |    |            |           | .026    |
| Tangential    | 6 (50.0)  | 12 (42.9)  | 4 (12.1)  |         |
| Penetrating   | 5 (41.7)  | 8 (28.6)   | 18 (54.5) |         |
| Perforating   | 1 (8.3)   | 8 (28.6)   | 11 (33.3) |         |
| Transventricular (N, %) | 1 (8.3) | 1 (3.6) | 6 (17.6) | .197    |
| CSF leak (N, %) | 0 (0) | 4 (14.3) | 2 (5.9) | .242    |
| Surgical intervention (N, %) | 1 (7.7) | 8 (28.6) | 22 (64.7) | ≤.001   |
| Comorbidities (N, %) |        |            |           |         |
| Current smoker | 7 (53.8) | 10 (35.7) | 10 (29.4) | .295    |
| Positive drug screen | 4 (30.8) | 5 (17.9) | 4 (11.8) | .304    |
| Alcohol-use disorder | 3 (23.1) | 2 (7.1) | 4 (11.8) | .343    |
| Obesity       | 0 (0)     | 2 (7.1)    | 3 (8.8)   | .551    |
| Diabetes      | 1 (7.7)   | 1 (3.6)    | 2 (5.9)   | .845    |
| Cancer        | 0 (0)     | 0 (0)      | 0 (0)     |         |
**RESULTS**

Table 1 compares the characteristics of those excluded from the study and those included. Patients that did not survive more than 48 h were excluded and expectantly had worse injury severity. Of the 75 civilian cGSWs included, 84% were male with a median age of 30 yr old (Interquartile range [IQR] 20-45). The median GCS at hospital presentation and ISS were 10 (IQR 6-15) and 25 (13-30), respectively. The majority of patients had a single cranial injury (97.3%) with a predominantly penetrating (41.3%) trajectory. The median hospital LOS was 8 d (IQR 3.3-12.8). Comorbidities at the time of admission are summarized in Table 2. There were 6 CSF leaks documented with all receiving prophylactic antibiotic therapy for the leak and half requiring short-term CSF diversion via lumbar drain. A total of 31 (41.3%) patients underwent surgical operation, with significantly more receiving multiagent prophylaxis for at least 48 h. The group without antibiotics had a higher presenting GCS, lower ISS, fewer penetrating injuries, and shorter median hospital LOS (Table 2).

Overall use of prophylactic antibiotics was 81.3%. The most common agents administered overall were cephalosporins (69.3%) followed by vancomycin (42.7%). Table 3 provides complete descriptive data on antibiotics administered for prophylaxis.

Eight intracranial infections were documented (10.7%) over a range of 1 wk to 3 yr from injury (Table 4). Intracranial infection was significantly associated with CSF leak ($P = .014$) and surgical intervention ($P = .007$; Table 5). Surprisingly, patients undergoing surgical intervention were more likely to develop an intracranial infection (7 out of 8 infections were in those who underwent surgery; Table 5), which may reflect surgeon bias. Incidence of intracranial infection did not differ significantly between groups based on antibiotic group ($P = .19$) or antibiotic duration ($P = .42$). Multivariable logistic regression using all univariate variables yielded a model in which CSF leak (odds ratio [OR] = 6.29 [0.756-52.304], $P = .089$), diabetes (OR = 15.459 [0.824-290.207], $P = .067$), and surgery (OR = 11.178 [1.019-122.621], $P = .048$) contributed to the model. Antibiotic group and duration were not contributors. As the decision for surgery contains a bias that partially reflects surgeon concern about infection risk, the multivariable logistic regression was repeated without the confounding variable of surgical intervention. This alternate model had contributors of CSF leak (OR = 11.8 33 [1.682-83.258]; $P = .013$) and diabetes (OR = 9.598 [0.905-101.803]; $P = .061$).

Fourteen nosocomial infections were documented in our series, with no significant difference in incidence based on the number of agents used ($P = .8$) or duration of prophylaxis use ($P = .18$). Additionally, the presence of nosocomial infection was not related to later development of intracranial infection ($P = .621$). The most common documented nosocomial infection was pneumonia (9.3%). Other infections included bacteremia (4%), urinary tract infection (1.3%), clostridium difficile infection (1.3%), and a facial wound/eye infection (2.7%). Among all infections, isolated organisms were gram positive (68.2%), gram negative (22.7%), and polymicrobial (9.1%). Intracranial infections were predominately by gram-positive organisms (75%).
### Table 4. Characteristics of Intracranial Infections

| Case ID | Infection    | Age, sex | GCS | Motive, trajectory | CSF leak | Surgical intervention       | Comorbidities                   | Abx group | Abx duration (d) | Time to infection (d) | Organism               |
|---------|--------------|----------|-----|-------------------|----------|-----------------------------|--------------------------------|-----------|------------------|----------------------|------------------------|
| 34      | Osteomyelitis| 52, F    | 10  | Self, Pf          | N        | Bifrontal craniectomy       | Diabetes, obesity              | Multi     | 1                | 1697                 | MRSA                  |
| 69      | SDE, meningitis| 58, M   | 8   | Self, Pn          | Y        | DCH with partial lobectomy  | Alcohol, diabetes              | Multi     | 7                | 56                   | E. coli               |
| 79      | Abscess      | 42, M    | 6   | Self, Pn          | N        | Bedside washout             | smoker                         | None      | 0                | 6                    | Polymicrob            |
| 97      | SDE          | 58, M    | 11  | Self, Pf          | N        | DCH and evac of EDH         | None                           | Multi     | 3                | 149                  | MSSA, P. acnes        |
| 208     | Wound        | 17, M    | 6   | Assault, Pf       | Y        | DCH and evac of SDH         | smoker                         | Single    | 2                | 190                  | MRSE, S. epi          |
| 214     | Meningitis   | 30, M    | 6   | Assault, Pf       | Y        | DCH with partial lobectomy  | None                           | Multi     | 5                | 31                   | E. faecalis           |
| 234     | Wound        | 24, M    | 15  | Assault, Pn       | N        | Craniotomy                  | Smoker                         | Multi     | 2                | 3                    | Coag neg staph        |
| 246     | Osteomyelitis| 20, M    | 15  | Assault, T        | N        | Craniotomy                  | Smoker                         | Multi     | 5                | 3                    | S. aureus             |

Coag neg staph, coagulase-negative staphylococcus; DCH, decompressive hemicraniectomy; E. coli, Escherichia coli; EDH, epidural hematoma; E. faecalis, Enterococcus faecalis; MRSA, methicillin-resistant Staphylococcus aureus; MRSE, methicillin-resistant Staphylococcus epidermidis; MSSA, methicillin-sensitive Staphylococcus aureus; P. acnes, Propionibacterium acnes; Pf, perforating; Pn, penetrating; polymicrob, polymicrobial; S. aureus, Staphylococcus aureus; SDE, subdural empyema; SDH, subdural hematoma; S. epi, Staphylococcus epidermidis; T, tangential.
| Characteristic                  | No. of patients | Intracranial infection | P value |
|--------------------------------|-----------------|------------------------|---------|
| No. of patients                | 67              | 8                      |         |
| Age (median, IQR)              | 30 (20-44)      | 36 (21-56.5)           | .424    |
| Gender (N, %)                  |                 |                        | 1.000   |
| Male                           | 56 (83.6)       | 7 (87.5)               |         |
| Female                         | 11 (16.4)       | 1 (12.5)               |         |
| Ethnicity (N, %)               |                 |                        | .620    |
| Caucasian                      | 33 (49.3)       | 3 (37.5)               |         |
| African American               | 31 (46.3)       | 5 (62.5)               |         |
| Other                          | 3 (4.5)         | 0 (0)                  |         |
| Initial GCS (median, IQR)      | 11 (6-15)       | 9 (6-14)               | .746    |
| ISS (median, IQR)              | 25 (13-30)      | 30 (11-33.8)           | .297    |
| Motive (N, %)                  |                 |                        | .803    |
| Assault                        | 35 (52.2)       | 4 (50.0)               |         |
| Self                           | 29 (43.3)       | 4 (50.0)               |         |
| Accident                       | 3 (4.5)         | 0 (0.0)                |         |
| Radiographic findings          |                 |                        |         |
| Injury number (N, %)           | 2 (3.0)         | 0 (0.0)                | 1.000   |
| Trajectory (N, %)              |                 |                        | .265    |
| Tangential                     | 21 (32.3)       | 1 (12.5)               |         |
| Penetrating                    | 28 (43.1)       | 3 (37.5)               |         |
| Perforating                    | 16 (24.6)       | 4 (50.0)               |         |
| Transventricular (N, %)        | 6 (9.1)         | 2 (25.0)               | .206    |
| CSF leak (N, %)                | 3 (4.5)         | 3 (37.5)               | .014    |
| Surgical intervention (N, %)   | 24 (35.8)       | 7 (87.5)               | .007    |
| Comorbidities (N, %)           |                 |                        |         |
| Current smoker                 | 23 (34.3)       | 4 (50.0)               | .448    |
| Positive drug screen           | 13 (19.4)       | 0 (0)                  | .337    |
| Alcohol-use disorder           | 8 (11.9)        | 1 (12.5)               | 1.000   |
| Obesity                        | 4 (6.0)         | 1 (12.5)               | .440    |
| Diabetes                       | 2 (3.0)         | 2 (25.0)               | .054    |
| Antibiotic group               |                 |                        | .188    |
| None                           | 12 (17.9)       | 1 (12.5)               |         |
| Single Abx                     | 27 (40.3)       | 1 (12.5)               |         |
| Multi Abx                      | 13 (17.3)       | 28 (37.3)              |         |
**DISCUSSION**

Our study found significant provider bias in antibiotic prophylaxis selection; however, the Abx group did not contribute to the risk of intracranial infection. The overall use of prophylaxis was high (81.3%), with cephalosporins and vancomycin most commonly utilized for a median duration of 5 d. Regression analysis identified CSF leak and comorbid diabetes mellitus as risk factors for the development of intracranial infection.

**Patient Characteristics and Risk Factors for Infection**

Our patient population is generally representative of similarly sized civilian cohorts in the literature. Retrospective studies have found the presence of CSF leak, injury involving air sinuses, injuries crossing midline, transventricular injuries, presence of osseous or metallic fragments after surgery, wound dehiscence, and hospital stay > 12 d as independent predictors of infectious complications. Consistent with previous series, under univariate and multivariable analysis, CSF leak was significantly associated with intracranial infection. A total of 10.8% of our cohort had an injury tract traversing the ventricles and 29.9% had injuries crossing midline; yet, neither injury trajectory nor involvement of the ventricles predicted intracranial infection in our model. Surprisingly, we observed an association between those who underwent surgical procedures and subsequent intracranial infection, suggesting that surgery is a risk factor for infection. However, the decision to undergo surgery is highly surgeon-dependent and involves the neurosurgeon assessment of likelihood of survival and risk of infection. Hence, the decision for surgery included a bias associated with our outcome variable of intracranial infection. Jimenez et al found that hospital LOS greater than 12 d was independently associated with intracranial infection, though the authors caution that infection could lead to prolonged hospitalization. The median hospital LOS in our series was 8 d, thus limiting our ability to fully evaluate this risk factor. We did find that hospital LOS showed a trend toward association with intracranial infection \((P = .076)\) in univariate analysis; however, this was not a contributor to the multivariable model. The relationship between wound dehiscence and development of intracranial infection has been documented by previous authors, with a strong (76%) correlation between organisms cultured from the dehisced scalp and brain; we noted an association with scalp dehiscence in 2 of our cases. The presence of comorbid diabetes mellitus has not been routinely identified as a risk factor for infection following penetrating trauma, despite robust evidence in the general population. Interestingly, Marquardt et al reported a case of intracranial abscess 52 yr after a shrapnel injury in a patient who had for 10 yr struggled with poorly controlled diabetes. In our series, a patient with comorbid diabetes mellitus, hemoglobin A1c 6.7%, at the time of injury was diagnosed with cranial osteomyelitis 3 yr following injury with a hemoglobin A1c of 5.4% at that time. Despite our small sample size, the presence of comorbid diabetes was found to be a contributor to the development of intracranial infection in our univariate and multivariable analyses.

**Antibiotic Prophylaxis and Intracranial Infections**

Our overall (10.66%) and group (3.57%-17.64%) intracranial infection rates are higher than rates (1%-5%) reported in other series of civilian cGSWs. This is likely because we excluded those surviving less than 48 h and our follow-up extended to 3 yr. Our capture of delayed infection is likely reflective of the natural history of cGSWs.

In our series, lack of antibiotic prophylaxis was not associated with increased infection, but there was a significant selection bias in our dataset. As demonstrated in Table 2, No Abx patients had a higher initial GCS, a lower ISS, more favorable injury trajectories, and were less likely to undergo surgery. Because injuries that did not survive more than 48 h were excluded from the analysis, this implies a surgeon bias that these surviving individuals had minor injuries, requiring neither surgery nor antibiotics. Although others have shown no benefit of prophylactic antibiotics, and the antibiotic group was not associated with intracranial infection in our regression model, our single case of acute intracranial abscess occurred with no antibiotic prophylaxis and should raise caution in complete abandonment of prophylaxis.

Failure of Multi Abx prophylaxis to show a clear benefit over Single Abx prophylaxis could be due to the relative consistency between groups in cephalosporin use and the similar antibiotic
duration of 5 d. Selection of cephalosporins makes intuitive sense considering common intracranial pathogens following civilian cGSWs, with gram-positive organisms being the most frequently isolated in our series. In previous reports, largely from military experience, gram-positive organisms have been implicated in over two-thirds of intracranial infections with one study from the Lebanese War finding a predominance of gram-negative organisms. Cephalosporins offer excellent penetration achieved with standard intravenous dosing. In the Multi Abx group, vancomycin and/or metronidazole—in combination or alone—was commonly added to a cephalosporin for prophylaxis. Meticillin-resistant Staphylococcus aureus causes a high proportion of nosocomial infections; however, meticillin-resistance was only noted in a single cranial infection 3 yr after injury in our series. Doses of vancomycin required to penetrate the CNS are much higher than standard dosing, potentially limiting effectiveness secondary to side effects. Metronidazole obtains good CNS penetration, and covers anaerobic organisms; yet, in a series of 45 patients and 90 cerebral matter cultures there were zero cases of anaerobic growth. However, cases of intracerebral abscess formation due to anaerobic organisms after ballistic injury have been reported. The microbiol profile and results of our series indicate a low yield of the frequently utilized antibiotic in multigent regimens.

### Nosocomial Infections

Inappropriate antibiotic indications and duration have been linked to the development of multidrug resistant organisms and nosocomial infections. In a study of 545 neurosurgical patients admitted to a neurointensive care unit, a nosocomial infection rate of 20.7% was reported. Reported rates of nosocomial infections in cGSWs are limited, with one series reporting a 20% rate of postoperative pneumonia. In our study, 14 patients (22.7%) developed a nosocomial infection, but there was no association with intracranial infection or antibiotic group.

### Study Limitations

Our study is limited by a heterogenous duration of follow-up, a single institutional experience, and surgeon bias. Patients who presented to another center, developed an asymptomatic infection, or will later develop a delayed infection were missed. As individual providers had the autonomy to determine the type and number of agents used, duration of use, and whether to undergo a surgical procedure at presentation, a selection bias is inherent to our study. We excluded those patients who did not survive more than 48 h, and Table 1 demonstrates that patients excluded from the study had a lower presenting GCS, higher ISS, worse bullet trajectory, and were more likely to not receive any antibiotic prophylaxis, consistent with a surgeon bias that the injury was nonsurvivable. A similar bias is present in those surviving more than 48 h, in that those receiving Multi Abx regimens were those deemed survivable but with more severe injuries (Table 2). Finally, due to the rarity of intracranial infections, our small sample size is a major limitation of this study. Only 8 intracranial infections were identified in our study; hence, our ability to properly identify all variables that contribute to intracranial infection is limited. Although we could not prove our hypothesis that the antibiotic group contributes to the development of intracranial infection, we did show that the presence of CSF leak and comorbid diabetes were contributing variables.

### CONCLUSION

In an urban cohort of civilian cGSW patients surviving more than 48 h, those with a more severe injury profile were more likely to receive a multiantibiotic prophylaxis regimen at our institution. We found that CSF leak and diabetes are stronger contributors to the development of intracranial infection than antibiotic choice or duration. We did not find an advantage of multidrug regimens over single-agent antimicrobial prophylaxis. The majority of infections were by gram-positive organisms; thus, single-antibiotic coverage with a cephalosporin may be sufficient for most civilian cGSWs.

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**COMMENT**

Penetrating brain injury is a catastrophic wounding mechanism that results in high mortality and complex management scenarios in those who survive. While there is a certain amount of nihilism concerning this patient population, it is the high associated mortality that has hindered meaningful study in this area. This paper highlights the difficulty in answering clinical questions in this setting. The retrospective nature of these data, while well presented, limits broad applicability. A prospective study in this area is needed, but would require multiple centers over an extended period of time. While multiple case series and expert opinion on this subject exist, the last meaningful consensus statement concerning the application of antibiotics in this specific population came in 2001 when the original (and only) guidelines for the management of penetrating brain injury were published. 1 The question, “What is the optimum antibiotic treatment regimen and duration?” was asked then, and it remains unanswered today despite the effort undertaken in this manuscript. What remains clear is that infection is common in patients with penetrating brain injury, antibiotic prophylaxis of some type is probably warranted, and additional study and updated guidelines for the management of penetrating brain injury as a whole are needed.

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