Baltimore City has one of the highest crime rates per capita in the US.35 On average, the R Adams Cowley Shock Trauma Center treats 389 gunshot wounds (GSWs) annually. Consistent with data from other reviews of the literature, only a small minority of these injuries involve the cervical spine.37,38 Over the last 12 years, the University of Maryland encountered an average of 10 cervical GSWs annually. Of those who suffer neurological injury, approximately 4 per year survive initial resuscitation. The inherent rarity and immediate morbidity of this traumatic disease process makes collection of patients for large case series difficult. In 2012, the expected lifetime health care cost, not including opportunity

This article contains some figures that are displayed in color online but in black-and-white in the print edition.
losses, for a 25-year-old with tetraplegia was greater than $4.5 million per patient. The enormous cost burden, combined with the opportunity to improve neurological outcome, makes appropriate initial surgical therapy extremely important. In this paper we present the largest series of GSWs of the cervical spine with neurological deficit and outline the associated surgical decision-making process.

Gun violence has increased in prevalence, resulting in more frequent GSWs to the cervical spine as a source of severe disability in the young population. In the 1980s, GSWs represented 13% of all spinal cord injuries after motor vehicle accidents (38%) and falls (16%). Between 1990 and 1994, gunshot injuries surpassed falls (20%) to become the second most common cause of spinal cord injury (25%). Currently, the National Spinal Cord Injury Statistical Center documents violence as the third most common cause of spinal cord injury (25%) and notes that GSWs (14%) are the primary form of violence. As a type of violent crime, it is an expected outcome that the majority of gunshot injuries are found in young males. These injuries are more likely to result in complete neurological deficits than blunt trauma. However, in reviewing prior case series, outcome data are rarely presented in a discrete and quantifiable manner. Nevertheless, it is clear that neurological recovery is rare. Specifically, there has been no report of significant functional improvement, including American Spinal Injury Association (ASIA) Impairment Scale (AIS) conversion, Frankel score conversion, or large increases in the ASIA motor score.

In determining spinal stability in the setting of penetrating traumatic injury, surgical treatment algorithms based on bone injury patterns for blunt injury are not applicable. Both the neurological injuries and spinal column injuries sustained from ballistic sources are unique compared with other common forms of blunt cervical spinal cord injury or even nonballistic penetrating spinal cord injury (such as stab wounds). As the missile penetrates the soft tissue of the neck, a temporary cavity is formed by the bullet’s kinetic energy, resulting in a blast effect to the surrounding tissues. The high-velocity penetrating injury of GSWs creates a unique form of spinal column injury that has not been well characterized. As opposed to blunt trauma, the penetrating vector of force created by a GSW creates an osseous/discoligamentous complex injury that can cause very specific anatomical injury and is quite distinct from standard traumatic forces. Furthermore, a GSW is often necessary to evaluate solely on CT because of the relative contraindication for MRI, which significantly limits the surgeon’s ability to evaluate the discoligamentous complex and canal anatomy. Neurological tissue injuries from penetrating missiles are also different than neurological injury from blunt trauma. The concussive effect can lead to neurological tissue damage even without direct penetration of spinal elements. Despite this high risk for neurological injury, multiple case series have suggested that gunshot injuries to the neck rarely result in gross instability. Two large studies examining GSWs to the neck showed only 22% and 23% of victims sustaining cervical spine fractures, with only 3%–4% of fractures requiring fusion for instability. In prior reports, even high-velocity military-grade ballistics rarely cause cervical instability among those surviving primary resuscitation. In this series we propose that patients with cervical GSWs to the spine who survive initial resuscitation and have an injury severe enough to cause neurological damage have a greater need for stabilization than prior studies have suggested.

Initial Evaluation and Diagnostic Studies

Fluid resuscitation, evaluation for tracheal or vascular injury, imaging, and neurological examination are the most important parts of the initial medical examination. Immediate cervical stabilization in the field for patients with penetrating ballistic neck trauma should be performed at the scene if safe, but multiple studies suggest that immobilization should not hinder other emergency clinical concerns such as intubation or swift transfer to a trauma facility. The immediate imaging study of choice in a solitary ballistic injury to the neck is a CT angiographic study of the neck and head. This image provides rapid information on bone destruction of the cervical spine as well as valuable information concerning the carotid and vertebral arteries and their ability to perfuse the brain. Several studies show that MRI is a possible diagnostic option when clinically relevant, even in the setting of retained ballistic fragments. In the past, there existed an assumption that all metallic foreign objects within the body should be considered unsuitable for MRI. A small number of in vivo and in vitro studies show that there are minimal sequelae resulting from MRI in civilian ballistic trauma. In assessing a patient for MRI viability, both surgeon and radiologist need to consider the proximity of a metallic fragment from vascular structures or functional neurological structures and inform the patient of additional risks. Magnetic resonance imaging remains a controversial tool for diagnostic workup in this population and requires further investigation.

Surgical Management

For the majority of patients with gunshot injuries to the neck, spinal stabilization or decompression has previously been rarely indicated. Nonsurgical treatment includes external cervical stabilization and mean arterial elevation above 80 mm Hg. Based on a wealth of prior data from blunt spinal cord injury, several studies reference early administration of high-dose steroids for spinal GSWs, but no treatment consensus exists. At our institution we do not routinely use high-dose steroid protocols for spine injury and none of the patients in this series received steroids. Prior studies have also shown a lack of utility and increased complications after decompression, retrieval of bullet fragments, or repair of dural tears without cutaneous CSF fistulas for patients with complete injuries or stable neurological examinations. In these studies, rates of surgical intervention for civilian ballistic injuries to the neck range from zero to 1%.
Commonly accepted indications for surgery include persistent CSF fistula, evidence of overt cervical instability, infection, and neurological deterioration (particularly for incomplete injury) with persistent spinal cord impingement. Case reports of arteriovenous fistulas presenting after GSWs have also been published, which require either endovascular or surgical intervention.\(^8,29,31\) A persistent CSF fistula creates an imminent need for intervention. Attempts can be made to close the skin at the bullet entry or exit site with primary suture along with lumbar drain CSF diversion, but if these efforts fail, more invasive measures must be undertaken. If open surgery becomes necessary for CSF fistulas, primary dural closure is frequently not possible, due to the large dural defects caused by ballistic GSWs. The surgeon should be ready to use a dural patch or sealant followed by layered muscle and fascia closures.

Penetrating gunshot injury comes with an inherent risk of infection. Our center has ceased the use of prophylactic antibiotics for GSW injuries because of high rates of nosocomial multidrug-resistant infections. If infection is identified and subsequent antibiotic therapy fails, surgical wound exploration and debridement may be necessary. As with penetrating ballistic intracranial injury, prophylactic removal of bullet fragments from neural elements during debridement is not recommended. Further manipulation of the cervical spine for the removal of a noncompressive foreign body may worsen edema and is unlikely to restore neurological function.

Neurological deterioration in the presence of persistent spinal cord impingement is an obvious and emergency indicator for surgical intervention. In this setting, if emergency surgery can be performed to eliminate spinal cord compression, it should be performed, particularly for epidural hematoma, empyema, bone or foreign body compressive intrusion, or other remediable mass lesion. In many cases a decompressive surgery alone may suffice. If mechanical forces from unstable spinal elements cause persistent compression and neurological deterioration, then cervical realignment and fusion may also be necessary.

The final indication for surgery is overt cervical instability. Based on a literature review, prior published arguments regarding cervical fusion for instability do not discuss radiographic reviews of injury patterns in detail, or have exceedingly small numbers of patients with limited follow-up examinations.\(^8,5,13,14,18,20,25,26\) We agree with prior reports, which state that GSWs to the cervical spine or neck without neurological injury almost never need neurosurgical intervention.\(^18,26\) However, when patients with neurological deficit are subgrouped, the rate of operative intervention jumps from 0%—1% to 15%—30%.\(^18,20,26\) The need for stabilization of cervical instability has not previously been well characterized in either case series or editorial discussion.

**Methods**

**Study Population**

From August 2000 to July 2012, all GSWs to the cervical spine at the University of Maryland Shock Trauma Center were cataloged. Of the 144 GSWs to the cervical spine, 42 patients sustained cervical spinal cord injury requiring neurosurgical evaluation. The University of Maryland institutional review board approved the collection of data on all patients with penetrating injury to the spine between 2000 and 2012. During this 12-year period, the neurosurgical service was consulted for 42 patients regarding cervical spinal cord injury after a GSW to the neck. Of the 42 patients, 2 were excluded for the following reasons. One patient was excluded due to a neurosurgical examination that revealed that the patient had no neurological deficits despite a bullet lodged in the C-2 lamina, and no intervention was performed on this patient. The other patient was excluded because the bullet injury was located at T-2 but the patient had cervical cord injury secondary to a C5–6 acute ruptured disk caused by the fall after becoming acutely paraplegic.

**Data Collection**

All 40 of the patients reviewed sustained civilian-style assault injuries from handguns. Each patient was transported from the scene of the injury directly to medical care. No patient experienced a delay of care from late presentation to the hospital. Electronic and physical medical records as well as radiological imaging was reviewed by the authors (N.B. and J.S.). Epidemiological and clinical information was collected on each patient including age, sex, timing, indication, type of surgery, initial examination after resuscitation, follow-up examination, and imaging data. American Spinal Injury Association scale assessments were obtained on admission as well as during daily neurosurgical examinations and at all follow-up visits with neurosurgery. Although all patients had been instructed to return for follow-up evaluations by the neurosurgical service, 3 patients were lost in the follow-up period. Two patients who were lost were high functioning, with AIS grades of D with central cord syndrome. One patient who did not return to clinic had a severe cerebral neurological injury in addition to tetraplegia and was discharged 6 weeks after admission with only biceps function.

**Results**

**Patient Characteristics**

Over 12 years we identified 40 patients with cervical spine injury from GSWs and neurological deficit. The median age for our series of patients was 25 years (range 16–56 years). Not surprisingly, males (92.3%) dominated the series. Caudal cervical fractures were more common. Figure 1 documents the summation of all patients with osseous injury sustained at each vertebral level. For this figure, any fracture at a vertebral level was added regardless of the presence of vertebral injury at other levels; many patients had multiple fractured levels. Twenty-eight patients (69.2%) presented with complete neurological deficits and 12 patients (30.8%) presented with incomplete neurological deficits. The average length of time at which follow-up neurological evaluations were performed was

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25.5 weeks (median 12.7 weeks). Using the hospital’s system-wide imaging database, a comprehensive radiological review was also performed to obtain further follow-up information. Based on information from this radiological review, mean follow-up was extended to 74.7 weeks (median 26.9 weeks). In this radiological follow-up in which spine imaging was performed, no instance of progressive deformity was identified for patients treated according to our algorithm described in the surgical discussion.

Neurosurgical and Other Interventions

Fourteen (35%) of the 40 patients underwent neurosurgical intervention (7 for internal fusion, 2 for decompression alone, and 5 for halo stabilization). No open surgical exploration in this series was required for CSF fistula repair, late infection, or arteriovenous fistula. Two patients with incomplete injuries required posterior decompression for a decline in neurological examination results after initial evaluation. One of the decompressions was completed at C1–2 and the other at the atlantooccipital joint. In both cases, the bullet was present and causing continued compression of neurological tissue in conjunction with epidural blood. Both of these patients experienced improved neurological examination results after surgery. The first patient improved from an ASIA motor score of 100 (AIS Grade D) to 100 (AIS Grade E); the latter improved from a motor score of 48 (AIS Grade C) to 88 (AIS Grade D).

Twelve patients (30%) required intervention for cervical instability. Five of these patients were managed using halo immobilization. In 2 of the patients with halo immobilization, the surgical team had planned for internal fixation, but these plans were delayed initially because of hemodynamic instability and esophageal injury, and later because of persistent systemic infection with multidrug-resistant bacteria. Three patients with complete injury treated with halos remained AIS Grade A from admission until the time of follow-up, with only 1 or 2 levels of ASIA motor score improvement. The fourth patient improved from a motor score of 20 (Grade A) to 39 (Grade B) at follow-up. The fifth halo was placed for a patient with C3–4 comminuted right-sided facet fractures in the setting of incomplete neurological deficits. A preprocedural MR image was obtained showing no discoligamentous complex injury, but it is the practice of this group to offer aggressive efforts to stabilize unilateral facet injury for incomplete injuries because of concern for glacial subluxation. This patient with halo treatment presented with an ASIA motor score of 98 (Grade D) and recovered to a score of 100 (Grade D) at follow-up. Dynamic radiographs were completed and stability proven before removing the halo in all 5 cases. Seven patients (17.5%) required internal fixation due to cervical instability, with 4 anterior fusions (1 corpectomy without posterior fusion), 2 posterior fusions, and 1 combined approach performed as a staged procedure, including a 2-level corpectomy and subsequent posterior fusion. Of these 7 operative cases, all remained AIS Grade A except 1 who improved after surgery from an ASIA motor score of 8 (Grade A) to a score of 42 (Grade B). The average ASIA motor score improvement for patients receiving operative intervention was 9.2 points.

Of the 9 patients on whom the surgical team wanted to operate (2 with halo immobilization and 7 with internal fixation), 7 had 3-column injuries and 2 had 2-column injuries with pedicle fractures. All 9 cases had a pedicle fracture or complete pedicle destruction. The 2 patients receiving intervention who recovered from AIS Grade A to B had unilateral bone destruction. One patient had a 3-column injury (motor score of 20 [Grade A] improved to 39 [Grade B], halo immobilization) and the other had a 2-column injury with pedicle destruction (motor score of 8 [Grade A] improved to 42 [Grade B], C5–T2 posterior fusion; see CT scans in Fig. 2). Although the bone injury was extensive in both of these CT scans, the spinal canal was partially spared.
Three patients required bedside intervention for a cutaneous CSF fistula. Each patient received bedside suturing of the skin followed by placement of a lumbar drain, which was used for CSF diversion for 5 days. Through this technique, no patient required exploration for dural repair.

**Effects of MRI**

Eighteen patients underwent inpatient MRI of the cervical spine. One other patient underwent MRI after discharge. No patient suffered worsening symptoms or neurological deterioration as a result of the exposure to high-strength magnetic fields. Of note, 3 of these patients had bullet fragments in the spinal canal and tolerated MRI without worsening neurological function.

**Improvement**

For the entire cohort of 37 patients with follow-up examinations, average improvement in the ASIA motor score was 6.8 points, with 19 patients (51%) showing no change from their initial evaluation. Patients with complete neurological injury improved an average of 5.92 points and 3 of these 26 patients improved their AIS Grade from A to B. Patients with incomplete neurological injury improved an average of 10.5 points and 1 of the 9 patients improved from AIS Grade C to D and 3 improved from AIS Grade D to E.

**Discussion**

The patient demographics and patterns of injury in this study correspond closely to those of prior case series. The majority of gunshot injuries to the cervical spine occurred in young males with a median age of 25 years in our population. All were victims of handgun violence with the exception of 1 patient whose wound was self-inflicted. This patient was also the oldest patient in our series. Figure 1 displays the vertebral levels suffering ballistic injury, indicating a predominance of injury in the caudal levels. These data correspond well with findings that injuries to the thoracic and lumbar spine are more common than cervical injuries, presumably from the tendency of GSWs to congregate around the body’s center of mass. The low amount of T-1 involvement is a selection bias as this series covered only patients with evidence of cervical spinal injury, but excluded purely thoracic or lumbar involvement. For GSWs with neurological deficit, complete neurological injuries represent the majority of patients (nearly 70%). There were no patients with purely radicular complaints that were unilateral and localizable to discrete cervical nerves. For the civilian population with GSWs, we identified 5 indications for surgery: CSF fistula, arteriovenous fistula, late infection, neurological deterioration associated with remediable mass lesion, and cervical spinal instability. For cervical spinal instability we have analyzed our data and devised a treatment algorithm (Fig. 3).

In our series, nearly 30% of patients presented with neurological deficit. Patients without neurological deficit did not require intervention or neurosurgical consultation. These data correspond with those in other modern large case series. Those patients with neurological deficit received nonsurgical therapy at admission. At our institution all patients with severe spinal cord injury are admitted to the intensive care unit, where it is our policy to perform elevation of the mean arterial pressure to a goal of 80 mm Hg or higher. As discussed previously, we do not habitually use steroids in the setting of penetrating spinal cord injury, but we recognize that some trauma centers may.

Intervention was required in 17 (42%) of the 40 patients in our series. Three CSF fistulas were closed with bedside skin suture and lumbar drain placement for CSF diversion, 2 patients required decompression alone for re-
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mediable mass lesion with worsening neurological function after initial examination, and 12 patients required cervical fusion without decompression for overt instability. No patient required washout for late infection. No arteriovenous fistulas were identified or treated.

Cervical instability is of marked interest because it has been the least well defined in this population and is the most controversial indication for surgery. Current standards to determine spinal instability were developed in the setting of blunt traumatic injury in which forces are compounded by the natural moment arms of the spine responding to the traumatic external vector forces. Gunshot wounds have a focused internal vector of force in line with the trajectory of the bullet without a significant rotational component. The motivation behind our retrospective review arose from 1 patient with a 3-column injury and complete deficit who refused recommended intervention. This patient returned at 6 weeks to our clinic with gross progressive kyphotic deformity and continued complete tetraplegia (Fig. 4). It is our belief that this patient may have experienced a more dramatic recovery with less neck pain, allowing for more aggressive physical therapy, had he received stabilization. Since this experience, stabilizing interventions were performed for patients with 3-column injuries and 2-column injuries with at least 1 pedicle fracture (Fig. 2). Patients with 2-column injury without pedicle fracture or 1-column injury were managed with a hard cervical collar. Using this paradigm for stabilization, no nonunion or progressive deformity occurred. A careful review of the literature and the findings in this series have led us to develop an algorithm for managing cervical instability in penetrating ballistic injuries (Fig. 3). This algorithm can be used to help surgeons guide decisions regarding fusion for GSWs to the cervical spine.

In our series, there has been no difference in neurological outcome or rate of healing between the use of halo immobilization or internal fixation. Factors that played a role in our decision process between choosing halo immobilization or internal fixation included hematological stability, esophageal injury, or chest wall injury at the time of admission. Late factors that influence surgical decision-making include persistent aggressive infection, possible future use of a diaphragmatic pacer, and dural injury without a cutaneous fistula noted on MRI. No patient in this series led us to believe that there is a surgical urgency for stabilization in the presence of stable neurological examination results.

Inherent weaknesses exist in retrospective chart reviews, which is currently the only form of evaluation for this traumatic disease. However, with any retrospective series there is an inherent risk of selection bias and information bias. We minimized selection bias by collecting patients consecutively within the study. In addition, this study was susceptible to information bias as there was no predefined follow-up period, multiple examiners performed follow-up evaluations, and no commonly accepted disability scale was implemented other than the ASIA motor score and AIS. The authors are keenly aware that follow-up in this population is difficult, and this will be a weakness of any retrospective analysis of this patient population. However, even limited follow-up in this series is in stark contrast to prior studies, as we have documented neurological improvement in 15% of patients.

**Conclusions**

Gunshot injury to the cervical spine is a relatively rare occurrence in trauma and difficult to study. Seventy percent of patients who presented with neurological deficit had complete spinal cord injury in this study. Where prior studies have shown limited to no capacity of neurological improvement, we observed improvement in AIS grade in 15% of our cohort. A treatment algorithm is presented to assess the need for stabilization. Following this treatment algorithm, either halo orthosis or internal
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References


Fig. 4. Sagittal CT scans in a 27-year-old man who was managed using only a cervical collar for treatment of his cervical GSW. He presented at his 6-week follow-up examination with worsening neck pain and new cervical kyphotic deformity. This new deformity is marked when comparing the initial scan (upper) with his 6-week follow-up scan (lower).

fixation was performed on 30% of patients with cervical GSWs with neurological deficits. The authors have now used this paradigm for 40 consecutive patients and have not experienced incidents of nonunion.

Disclosure

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 to the study and manuscript preparation include the following. Conception and design: Beaty, Slavin, Diaz. Acquisition of data: Beaty, Slavin, Diaz, Zelesnick. Analysis and
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