Gunshot wounds to the spine

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Abstract

BACKGROUND CONTEXT: The incidence of violent crimes has risen over the past decade. With it, gunshot injuries have become increasingly more common in the civilian population. Among the most devastating injuries are gunshot wounds to the spine.

PURPOSE: The purpose of this article is to provide a thorough review of the pathomechanics, diagnosis and treatment of gunshot wounds to the spine.

STUDY DESIGN/SETTING: Literature review article.

CONCLUSIONS: Treatment of gunshot spine fractures differs from other mechanisms. Fractures are usually inherently stable and rarely require stabilization. In neurologically intact patients, there are few indications for surgery. Evidence of acute lead intoxication, an intracanal copper bullet or new onset neurologic deficit can justify operative decompression and/or bullet removal. Overzealous laminectomy can destabilize the spine and lead to late postoperative deformity. For complete and incomplete neural deficits at the cervical and thoracic levels, operative decompression is of little benefit and can lead to higher complication rates than nonsurgically managed patients. With gunshots to the T12 to L5 levels, better motor recovery has been reported after intracanal bullet removal versus nonoperative treatment. The use of steroids for gunshot paralysis has not improved the neurologic outcome and has resulted in a greater frequency of nonspinal complications. Although numerous recommendations exist, 7 to 14 days of broad-spectrum antibiosis has lead to the lowest rates of infection after transcolonic gunshots to the spine. © 2004 Elsevier Inc. All rights reserved.

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Introduction

With the rise of violence throughout the world, the incidence of gunshot injuries continues to increase. Among the most troublesome are gunshot wounds to the spine, which account for 13% to 17% of all spinal cord injuries each year [1–3]. Although most common in the thoracic region, they are perhaps most devastating in the cervical spine, where the potential for severe functional impairment is greatest [4,5]. With a predilection for weekend occurrence, spinal gunshots are most frequently sustained by young, male minorities between the ages of 15 and 34 years [1,6,7]. Spinal cord damage after gunshot wound is more likely to result in complete injury compared with blunt trauma. Like spinal cord injury in general, incomplete injuries have much better prognoses [1].

Pertinent ballistics

According to the formula KE=$\frac{1}{2} mv^2$ (where KE=kinetic energy, m=mass and v=velocity), the energy of the bullet is influenced by both the mass and speed. As the equation dictates, increases in velocity have exponential effects on the energy of the injury. Thus, by convention, muzzle velocities of less than 1,000 to 2,000 feet/second are categorized as low energy, whereas speeds greater than 2,000 to 3,000 feet/second are considered high energy. Low-velocity, low-energy firearms include pistols and handguns. High-velocity, high-energy weapons include military assault...
rifles, such as the AK-47 and M-16. In contrast, shotguns are low-velocity weapons that incur high-energy wounds because of the combined mass of the numerous fired pellets. In addition, shotgun wounds are further complicated by the presence of large pieces of “wadding” that are a gross contaminant and require prompt surgical debridement [8].

In general, civilian gunshot wounds are considered low energy. However, an increasing frequency of high-energy injuries is being reported in the nonmilitary population [9]. Greater availability of military-type firearms, especially among the criminal element, is a contributing factor. In 1995, assaults with high-energy weapons accounted for 16% of homicides in New York City [10]. Close-range shotguns lose less energy during transit and therefore transfer more energy to the victim. Differentiation between high- and low-energy injuries is crucial, because treatments are distinct.

**Bullet material and design**

The bullet energy is not the sole determinant of the extent of injury. Fragmentation of the missile can increase the zone of tissue destruction. Hollow-point bullets explode on impact, leading to multiple fragments that deviate from initial linear path. The phenomenon of yaw refers to the tumbling of a bullet along its longitudinal axis. Longer bullets have a tendency for greater yaw, which can further increase the zone of destruction. In its mid-path, one can imagine the bullet turned 90 degrees to its long axis so that it is in effect being pulled through the tissues sideways.

Bullets can be nonjacketed, partially jacketed or fully jacketed. The “jacket” refers to a thin metallic layer covering the surface of the bullet. Fully jacketed bullets exhibit little deformation with firing and are designed for accuracy to hit long-range targets. They are highly precise and incur clean exit and entrance wounds. Partially or nonjacketed missiles expand on tissue impact and, like hollow-point bullets, exponentially extend the circumference of tissue damage. Such designs are intended for close-range targets.

Various materials have been used to produce bullets. Most bullets are composed of a lead core, which may be combined with a number of different metals to achieve a desired hardness. Similarly, the jacketing material can be copper, brass or nickel. These substances can have both systemic and local toxicities on tissues. More common in synovial joints, lead poisoning has been reported with bullets lodged in the intervertebral disc [11]. Although cerebrospinal fluid would intuitively be an effective solvent, systemic lead elution with intramedullary bullets is uncommon. In cases of retained lead bullets, lead levels can be measured periodically. Notwithstanding other clinical factors, significant increases in lead levels and characteristic hematopoietic changes on bone marrow biopsy can be an indication for bullet removal. In actual clinical practice, bullets very rarely need to be removed from the spine to treat or prevent lead toxicity.

In vivo experiments in monkeys have demonstrated the local necrotic effect of copper on brain tissue [12]. Similar studies have been performed on the spinal cord. Tindel et al. [13] demonstrated spinal cord necrosis around copper fragments implanted within the dura of rabbit spinal cords. Whereas lead fragments caused less axonal necrosis than copper, aluminum resulted in minimal pathologic changes. Importantly, extradural fragments, regardless of the metal type, did not cause appreciable pathologic changes within the neural tissue. The authors extrapolated that these effects would be similar to those in the human spinal cord. Although these findings might support removal of intradural copper bullet fragments [14], the clinical challenge is determining the material of the bullet, which in many instances is not known, as well as avoiding further neurologic injury during explantation. The clinical benefits of bullet removal to avoid the neurotoxic effects of copper remain unclear.

**Evaluation**

**Acute examination**

The initial evaluation of the gunshot victim must address all life-threatening injuries. Maintenance of airway, breathing and circulation (ABCs) is paramount. The region of injury should be considered. Gunshot wounds to the neck are frequently complicated by airway injuries that can necessitate emergent intubation [15]. Action should not be delayed for radiographic “clearance” of the cervical spine, because gunshot fractures are usually inherently stable [5,16–18]. Carotid and vertebral artery perforations should be suspected with pulsatile neck bleeding. Immediate vascular consultation to restore cerebral blood flow is important, as temporary stents placed emergently can enable definitive repair at a later time. Pharyngeal and esophageal wounds must also be detected and evaluated, because they are often associated with infections. In particular, large hypopharyngeal lacerations are associated with a higher rate of contamination because of the pooling of secretions in this area. Endoscopic techniques can be used effectively and expeditiously for surveillance in the acute setting. Open surgical exploration is mandatory to repair any documented tears.

The thoracic spine is the most commonly affected with shotguns [4]. The lungs, heart and great vessels are at risk with such injuries. Careful chest auscultation can detect asymmetric breath sounds indicating hemothorax or pneumothorax. Cardiac monitoring, including distal pulses, can suggest heart perforation, aortic disruption or tamponade. Until stabilization of ventilation and hemodynamics, the evaluation of any spinal injury remains secondary. Similarly, the examination of the abdomen is focused on suspected vascular or viscus injuries. In particular, colonic perforations that occur before the missile passing through the spine must be recognized, because they are associated with a high rate of spinal infection if not treated with an appropriate antibiotic regimen [19–22]. In paraplegic or quadriplegic patients, the
abdominal examination may be less reliable because of loss of visceral sensation. This may lower the threshold for obtaining advanced diagnostics, such as peritoneal lavage or abdominal computerized tomography, to rule out injuries.

Although numerous organs exist in the pelvic area, sacral gunshot wounds are most often complicated by hemorrhage [23]. After posterior gunshot wounds, sterile packing of the posterior bullet hole using methyl cellulose and bone wax has been reported effective in facilitating tamponade [23]. Likewise, emergent angiographic embolization can diminish or halt severe bleeding, with the risk of possible devascularization of the neural structures [23].

**Evaluation of the spinal injury**

After patient stabilization by the trauma team, focus is turned toward the spinal injury. Witnesses, emergency medical technicians and law enforcement officers can offer useful information about the direction of the injury, the type of weapon or bullet and the proximity of the shot. Often the alert and awake patient can account for the number of shots fired. The cervical spine should be immobilized with a hard cervical collar until initial radiographs are complete.

The patient must be stripped of all clothing while log rolling the patient to protect the spine from further harm. Entrance and exit wounds should be examined thoroughly. Often, only an entrance hole can be found if the bullet is lodged in tissue. The entrance hole may be differentiated from the exit wound. As a bullet pierces the skin from the outside, the margins of the wound are cleaner and more defined. Upon exit, the bullet can take a more random path (fragmentation) and has more of a “blown out” appearance. In the abdomen, it is critical to determine if the bullet traveled from front to back. Although deep probing is not recommended, superficial inspection for imbedded pieces of clothing or foreign materials is useful. After sterile wound care and dressing, radiopaque markers (eg, electrocardiogram leads) are placed over all wounds. This facilitates roentgenographic deduction of the gunshot path.

The physical examination should proceed as for other types of spinal trauma. Each spinous process must be palpated for tenderness and crepitus. An in-depth neurologic examination, including motor, sensory, reflexes and anal sphincter tone is mandatory and must be documented precisely. In the intubated or unconscious patient, neurologic testing is limited. However, if paralytic agents have not been administered, deep tendon and bulbocavernous reflexes may still be elicited.

**Imaging**

Two orthogonal plain radiographic views of the spine can help detect gunshot fractures and locate bullet fragments. Using radiopaque bullet hole markers, the bullet path can be deduced. Damage must be suspected to structures along this path. Fragments can be located in soft tissue, intervertebral disc, bone or the spinal canal. Such parameters as vertebral body height, interpedicular distance and segmental kyphosis can be measured. In the awake, neurologically intact patient in whom spinal stability is in question, dynamic active flexion-extension views may be obtained. This is best delayed until 2 weeks after injury when pain and spasm have sufficiently subsided.

The necessity of radiographically clearing the cervical spine after gunshot wounds to the head and face has been questioned in a number of recent articles. In a series of 53 consecutive patients sustaining gunshots to the cranium, none had cervical spine fractures [24]. Similarly, Kennedy et al. [17] found wounds limited to the calvaria had no concomitant cervical spine trauma in 105 cases. However, with gunshot wounds extending outside the calvaria, 10% sustained a cervical spine fracture. Kihntir et al. [16] studied the association of cervical injuries with gunshots to the face. Dividing the face into three zones, spinal fractures were noted in 10% and 20% of mid-face (maxillary) and orbital injuries, respectively, whereas surprisingly none were noted after gunshots to the lower face (mandibular region). From these data, it would appear that gunshots to the maxilla and orbits carry the highest risk for concomitant cervical spine injury and that radiographic imaging should be pursued more aggressively after such incidents. Clearing the cervical spine after calvarial injuries is probably not necessary.

After plain films have determined the level of the bullet and/or fracture, computed tomography (CT) should be sought. Currently, this is the advanced modality of choice for spinal gunshot trauma. CT images allow better localization of the bullet within the vertebral segment and can more clearly demonstrate foreign bodies in the spinal canal. Thin slices (1 to 3 mm) are used to evaluate the integrity of the bony elements. Of note, images are often obscured by artifact when metallic bullet fragments are present (Fig. 1). This can limit the amount of detail appreciable.

![Computed tomography images are highly useful in evaluating the location of bullet and bone fragments. However, their utility can sometimes limited by metallic artifact.](image-url)
The use of magnetic resonance imaging (MRI) to evaluate gunshot wounds to the spine is controversial. Bullet migration from the pull of the strong magnet can possibly lead to further neurological or soft tissue damage. However, numerous reports of the use of MRI after gunshot wounds to the spine have not supported this concern [25]. The advantages of MRI over CT include markedly less artifact, better soft-tissue imaging and coronal, sagittal and axial visualization of the neural elements [26,27]. Although these advantages are attractive, the use of MRI should be on an individual and patient-specific basis. For example, bullets lodged in a vertebral body may have fewer propensities to migrate than intracanal fragments. However, these contentions remain unproven in a controlled scientific study. In the authors’ experience, the most common complaint from patients undergoing MRI scans is a complaint of a heat sensation in the area of the bullet (particularly jacketed types), which can lead to discomfort and early abortion of the study.

Treatment

Initial treatment of the gunshot victim is an integral part of the trauma evaluation. As discussed above, maintenance of ABCs is the primary goal. Management can be facilitated with the use of a structured algorithm [4]. Bishop et al. [4] examined the results of a comprehensive treatment scheme for both blunt and penetrating chest and abdominal trauma. Although the authors noted substantially higher mortality for cases of blunt trauma in which treatment deviated from the algorithm, this relationship was not demonstrated in gunshot victims. Among the most common causes of death after gunshot wounds were exsanguination and hypoxemia from massive hemorhorax.

Antibiosis

Tetanus prophylaxis must be considered in all instances of spinal gunshot wounds. If there is any question regarding the most recent immunization, tetanus prophylaxis should be administered in the emergency room at the time of initial evaluation.

Although some advocate initial bullet wound cultures, there is little support of this practice in the literature. Extrapolating the findings from the available literature for open long bone fractures, the utility of wound culture is minimal [28]. Broad-spectrum antibiotics should be initiated as soon as possible. Recommendations for the duration of antibiosis vary. For gunshot wounds not complicated by vescic perforations, it is generally recommended to maintain 48 to 72 hours of prophylaxis. The length of antibiotic treatment is dictated in part by the amount of soft tissue damage and should be considered in regards to clinical evidence of infection both in spinal and extraspinal regions.

Vescic perforations carry a higher risk of infection [19,21,22,29]. Rates are highest with colonic wounds that occur before the bullet entering the spine. It is thought that the stomach and small bowel are sterile, although case reports of spinal infection have been documented. In an early series of 20 low-velocity transabdominal gunshot wounds to the spine, Romanick et al. [22] realized an 88% rate of spinal infection after colonic perforation versus no infections if the bullet penetrated the stomach or small intestine. Although the authors concluded that surgical debridement may be beneficial for transcolonic spinal injuries, it is noted that antibiotics were continued for only 48 to 96 hours. Spinal infections included meningitis in two cases, abscess in three cases and vertebral osteomyelitis in two cases. Culture-specific antibiotics and thorough drainage and debridement were effective in controlling infection. Diverting colostomy was a useful adjunct in two cases of spinal abscess and one case of osteomyelitis. Shotgun wounds were excluded from the study.

After colonic perforation, the lowest infection rates have been documented with antibiotics continued for 7 to 14 days after injury [19,21]. Roffi et al. [21] retrospectively studied the outcome of 42 patients who sustained spinal gunshot wounds with a perforated vescic. In all cases, the missile passed through the vescic before the spine. Patients received at least 6 days of broad-spectrum antibiosis. Various combinations of drugs were used, including cefoxitin, gentamicin, clindamycin and penicillin. The use of a diverting colostomy was not reported. Three spinal infections occurred, two paraspinal abscesses in transcolonic injuries and one case of meningitis after gastric perforation. Initial prophylaxis was continued for only 6 days in one case of transcolonic injury. The authors advised continuation of prophylaxis for at least 7 days if the bowel or stomach were violated. Supportingly, Kumar et al. [19] recently reported no spinal infections in 13 patients treated with at least 7 days of broad-spectrum antibiotics after spinal gunshot wound that first perforated the colon. Dehiscence of a primarily repaired colon was associated with a high rate of intraabdominal abscess and peritonitis but did not increase the rate of spinal infection. From these data, it is the authors’ practice to maintain antibiotic prophylaxis for a minimum of 10 days for transabdominal gunshot wounds with a perforated vescic.

In transabdominal gunshots that perforate a vescic before spinal injury, surgical debridement does not appear to be of benefit (Fig. 2). A minimum of 7 days of broad-spectrum antibiotics is recommended. Although intestinal diverting procedures (ostomies) might help reduce the incidence of intraabdominal infection, it has little influence on the development of spinal infection. Barring other indications, such as neurologic deterioration or lead toxicity, bullet extraction is not advocated to decrease this risk.

The role of antibiotic prophylaxis after esophageal and upper airway perforation is less clear. Pooled secretions in the hypopharynx are thought to increase the propensity for infection with gunshots involving this structure. The decision to explore such wounds is usually based on the size of the lesion, because small rents can effectively be treated nonoperatively. To the authors’ knowledge, there are no controlled studies of the effects of antibiotic prophylaxis...
duration after upper airway injuries associated with gunshot wounds to the spine. Notwithstanding evidence of frank infection or meningitis, it is prudent to extend prophylaxis for at least 48 to 72 hours. Delayed exploration for developing neck infections is recommended, although the role of cervical gunshot wound debridement remains to be defined.

Specific injuries

**Gunshot wound: cerebrospinal fluid leak**

In the initial treatment of gunshot wound patients, the bullet entry site should be treated with debridement of any devitalized skin and superficial soft tissues. Cerebrospinal fluid can be differentiated from other forms of clear drainage by the presence of beta-2 transferrin if the diagnosis is in question [30]. If a cerebrospinal fluid leak appears to be present, then a lumbar subarachnoid drain should be placed. In cases where a persistent cerebrospinal fluid leak or fistulae is present through the bullet entry or exit sites at the level of the skin, consideration of open surgery must be entertained [21,22]. Because of the risk of meningitis resulting from a persistent cerebrospinal fluid leak, the treatment would involve a laminectomy with repair of the dural violation either primarily or with use of a dural graft [31,32]. In these relatively rare instances, placement of a temporary lumbar subarachnoid drain after the laminectomy may be beneficial to supplement the dural repair.

**Gunshot injury: no neurologic deficit**

In addition to the principles of antibiosis described above, the treatment of gunshots to the spine with a neurologically intact patient is similar to that from blunt trauma. Especially in the neurologically intact patient, spinal stability must be assessed. Although Denis’ three-column theory is useful for blunt traumatic injuries, it is of limited utility for gunshot wounds to the spine. In Denis’ original work, the proposed mechanisms of injury implied an abrupt acceleration/deceleration of the body/spine in space [33]. With gunshots, the body/spine can be considered stationary and the bullet is the directional force. This concept can be likened to the magician who pulls a tablecloth from a table set with glasses and plates. The bullet acts as the tablecloth. If pulled very quickly, the glasses and plates (ie, spinal elements) stay in place. In contrast to blunt trauma, two- or even three-column involvement is therefore less likely to result in instability.

In the best-case scenario, a through-and-through bullet wound will damage only those structures that lie directly in its effective path. Low-energy gunshots have a narrower circumference of damage than high-energy wounds. These factors influence the amount of spinal instability after gunshot wounds to the spine.

In the awake, cooperative, neurologically intact patient, dynamic lateral cervical radiographs can be obtained. Careful flexion and extension of the spine can demonstrate pathologic mobility of adjacent spinal segments. Again, this is best delayed after 2 weeks of collar immobilization to allow pain and spasm to subside. If stability must be determined immediately, an MRI may be obtained (if not considered a risk to neurologic status) to assess ligamentous integrity, although the clinical significance of signal changes within the soft tissues after gunshot wounds has not been well
characterized. If, after appropriate measures, cervical stability remains in question, surgical stabilization may be considered to prevent untoward neurologic injury, particularly if an intracanal bullet or bone fragment is in close proximity to the spinal cord or nerve roots.

In contrast to blunt traumatic injuries, which have more defined radiographic criteria for instability, any degree of abnormal angulation or translation may represent instability after gunshot wounds to the cervical spine. In cases of instability, the affected segments can be stabilized with a variety of instrumentation and fusion constructs. In the patient with neurologic deficit, spinal stability is deduced from imaging findings. Severe comminution of both anterior and posterior elements with evidence of segmental deformity is indicative of instability.

The majority of cases of instability after gunshot wounds have been associated with overly aggressive decompression [34]. Fortunately, there are few indications for decompression in a neurologically intact patient. New onset or progressive neurological deficit associated with an intramedullary bullet, bone fragment or expanding epidural hematoma is an indication for urgent decompression. Importantly, neurologic progression is most accurately detected by means of serial examinations performed by a single experienced observer and documented in the chart so that follow-up examinations can be compared with baseline. Less frequently cited indications are for the treatment of lead intoxication from the bullet or contact of a copper jacketed missile with the neural elements [11,31,35]. Routine removal of the bullet is not warranted for transcolonic injury and is associated with a high rate of complications.

**Gunshot injury: neurologic deficit**

Spinal cord injuries are devastating to the patient, family and society. In a study by Roye et al. [2] in 1988, the average initial admission hospital costs for survivors of cervical level injury can be greater than $50,000. High-level complete injuries frequently leave patients ventilator dependent, requiring highly specialized units for prolonged care. Gunshot wounds more frequently result in complete injuries compared with blunt trauma, which may be paraplegic or quadriplegic depending on the level. Approximately 59% of penetrating cervical spine injuries result in complete spinal cord injury, compared with 49% for blunt trauma [36]. In contrast to the predominance of cervical level injuries after blunt trauma, the majority of spinal cord injuries after gunshot wounds occur at the thoracic level [36]. Incomplete injuries can present in a variety of manners, including Brown-Sequard, central cord, anterior cord or in rare cases cruciate hemiplegic syndromes [37].

**Decompression/bullet removal**

The first rule of medicine is *primum non nocere*, or “do no harm.” This must be kept in mind in management of neurologic deficit after gunshot wounds to the spine (Fig. 3). It is our tendency as surgeons to be compelled to remove bullets and decompress the spinal canal. However, the clinical benefit of these actions is inconsistent and is not without complications.

In both complete and incomplete spinal cord injuries, the role of decompression has been studied. Stauffer et al. [34] reviewed 185 cases of gunshot paralysis, half of which were treated with laminectomy and half with observation only. The authors documented no appreciable return of neurologic function after both surgery and nonoperative management for complete lesions. With incomplete injuries, 71% of decompressed spines and 77% of nonsurgically treated spines demonstrated neural improvement. Incomplete lesions to the lumbar spine and thoracolumbar junction had better neurologic recovery than more cranial levels regardless if surgery was performed. Although antibiotic regimen was not documented, four wound infections and six spinal fistulae were reported in the operative group as well as six cases of late spinal instability. There were no cases of infection, cerebrospinal fluid fistula or spinal instability in the nonsurgically treated patients. Both groups had a high incidence of causalgia (19% and 15% for operative and nonoperative groups, respectively). In support of a nonoperative approach, Robertson and Simpson [38] reported no neurologic improvements with lumbar laminectomy versus nonsurgical treatment in 30 patients with gunshot wounds to the cauda equina region. A high rate of postoperative complications was reported. In no case did the authors report an intracanal bullet.

In a more recent prospective study of lesions associated with intracanal bullets, Waters and Adkins [39] demonstrated statistically significant motor improvement after surgical decompression from the T12 to L4 levels compared with nonoperatively treated spines (Fig. 4). At more cranial sites in the thoracic and cervical regions, surgical removal and decompression had no significant effect on neurologic outcome. No case of infection was reported in either group.

Surgical decompression is indicated for progressive neurologic deficits associated with compressive intracanal blood, bullet or bone fragments. In these situations, the surgeon is lead to conclude that neural damage is actively advancing secondary to spinal cord compression and immediate operation is indicated. Intracanal bullets in the lumbar spine should also be removed to improve the rate of motor recovery in cauda equina level injuries. The role of decompression and bullet removal in the cervical and thoracic levels remains unclear, with the complications of surgery a foreboding detractor. Because of the possible potential benefits of decompression, the authors sometimes elect to remove cervical-level intracanal fragments, especially in incomplete spinal cord injuries. In the current authors’ opinion, the possibility of even one or two levels of recovery justifies the risk of cerebrospinal leak, fistula or infection in the cervical region. This, however, would be difficult to justify in the thoracic spine, where little functional return is sacrificed.
Fig. 3. Management of neurologic deficit after gunshot wounds to the spine.

**Steroids**

The use of corticosteroids in spinal-cord-injured patients after gunshot wounds has recently been examined [40,41]. Levy et al. [41] retrospectively studied 252 cases of both complete and incomplete gunshot spinal cord injuries. Administration of methylprednisolone according to National Acute Spinal Cord Injury Study (NASCIS-II) protocol did not significantly affect neurological prognosis. Similarly, Heary et al. [40] demonstrated that administration of either methylprednisolone or dexamethasone regimens did not significantly improve the neurologic recovery of patients with either complete or incomplete injuries compared with those receiving no steroids. Interestingly, the incidence of pancreatitis was statistically greatest in patients who received methylprednisolone, while gastrointestinal complications were highest in those who received dexamethasone. Although these data were not randomized prospective analyses, they offer compelling evidence that emergent corticosteroid infusion has no role in the treatment of spinal cord injury after gunshot wound. In a recent editorial of the literature, Fehlings [42] reinforced recommendations that steroids should not be administered after penetrating spinal cord injuries.

**Surgical timing**

Timing of decompressive surgery may be an important consideration. Although there is some support for early decompression to improve neurologic outcome after blunt trauma, it has not been similarly supported for gunshot wounds. In a retrospective review of 88 patients, Cybulski et al. [43] found equivalent rates of neurologic recovery in patients undergoing decompressive laminectomy for conus or cauda equina level lesions within 72 hours (47.5% improved) versus those operated more than 72 hours after injury (48.1% improved). Similar studies of thoracic or cervical injuries have not been performed.

Although early surgery does not appear to improve neurologic recovery rates, surgical timing does appear to affect the incidence of other complications. Higher rates of infection and arachnoiditis have been documented when surgery was performed more than 2 weeks from injury [43]. In contrast, it has been suggested that cerebrospinal-cutaneous fistulae may be more common after early or immediate laminectomy [14,34].

For these reasons, some surgeons recommend delaying bullet removal, if warranted, until 5 to 10 days after injury [14]. However, it should be highlighted that others think
that if bullet removal is indicated that it should be performed immediately. Further clinical studies are needed to compare the relative risks and benefits of early versus late bullet removal after gunshot wounds to the spine. Regardless of the level of injury, most agree that a documented progression of neurologic deficit is an indication for urgent bullet removal.

Gunshots to the cervical spine

There is a paucity of information regarding cervical gunshot wounds. Kupcha et al. [5] reviewed the records of 28 patients. Laminectomy was performed in four patients and anterior corpectomy in one patient, with no neurological improvement compared with nondecompressed cases. Neck exploration was undertaken for vascular damage in four cases, expanding hematoma in two cases and airway difficulty in three cases. Long-term complications were primarily thromboembolism, pulmonary congestion and urinary tract infection. Posttraumatic syrinx developed in two patients. Fistulae occurred in two operatively and two nonoperatively treated patients. Despite a lack of description of the antibiotic regimen, only one case of spinal infection (meningitis) was reported. Extended antibiotic prophylaxis is prudent after pharyngeal, hypopharyngeal or airway violations. Neck wound exploration should be based on the severity of extraspinal pathology. The cervical spine should be protected as best as possible during intubation and surgical exploration, while not inhibiting life-saving procedures. This may be effected by gentle in-line traction, either manually or using cranial tongs. However, if endoscopic or direct surgical neck exploration can be safely delayed without endangering the patient’s life, it is preferable to determine cervical stability first.

Decompression or bullet removal at the cervical cord level is probably not useful in improving static neural deficit (Fig. 5), whereas it may be beneficial in cases of neurologic progression. Because of the possible potential neurologic benefit, intracanal bullet removal may be pursued in cases of incomplete neural injury, provided the bullet appears to be relatively accessible and can be removed without extensive dural dissection. When indicated, transoral decompression of upper cervical (C1–C2) lesions has resulted in low rates of postoperative infection, whereas laminectomy is useful for more caudal levels [44]. Ultimately, the optimal approach is dependent on the location of the fragment.

Gunshots with herniated discs

Herniated disc after a gunshot wound to the spine is a rare cause for neurologic compromise [45]. By lodging in the intervertebral space, it is postulated that the pressure in the nucleus pulposus is increased. With a defect in the posterior or posterolateral annulus, the disc material can be expelled into the canal or foramen to compress the cord or root. Treatment recommendations are similar to those for other acute disc herniations. Significant, acute neurologic deficit can be ameliorated with disc excision. Herniations associated with a cauda equina syndrome are a surgical emergency. Bullet removal is neither necessary nor indicated unless it can be easily removed without further jeopardizing surrounding neural or bony structures.
Fig. 5. Lateral cervical radiograph of a patient who sustained a gunshot wound to the neck with the bullet entering from the posterolateral side. The patient had a complete neurologic deficit at the C4 level. There were no associated pharyngeal, tracheal or vascular injuries. Computed tomographic images demonstrated an intracanal bullet. The patient was treated nonsurgically.

High-energy gunshot wounds

The authors strongly emphasize that the above recommendations are relevant to low-energy gunshot wounds. High-energy rifle and shotgun wounds are associated with significantly more soft tissue devitalization and a larger zone of injury. From experience with US combat troops in Panama, Parsons et al. [46] advocated aggressive surgical debridement after such injuries. Likewise, Splavski and others [47] reported low complication rates (14%) in spinal injuries treated with wide debridement and decompressive laminectomy during the Croatian War in the early 1990s. Although not controlled comparative studies, the authors highlighted that decompression did not likely affect neurologic recovery but that surgery was indicated to remove devitalized tissues to decrease the likelihood of secondary infection and sepsis. With increasing prevalence of gang and terrorist acts worldwide, use of high-energy weapons has necessitated adaptation of similar surgical tactics for some civilian injuries.

Late sequelae and complications

Lead intoxication is a rare complication of spinal gunshot wounds [11,35,48]. Elution from bullets bathed in cerebrospinal fluid is rare. Synovial fluid is a more effective solvent [49]. Bullets in close proximity to facet joints or the intervertebral disc may more likely lead to intoxication. The diagnosis is often missed and requires a high level of suspicion. Peripheral blood lead levels can detect increases, and bone marrow biopsy can confirm hematopoietic alterations. Treatment with chelating agents, such as dimercaprol and calcium disodium edetate, is initiated immediately followed by carefully planned bullet removal.

Besides neurologic deficit, pain is probably the most common long-term complication of gunshot wounds with spinal cord injury. In particular, conus medullaris– and cauda equina–level lesions are associated with a high rate of pain [50]. The incidence of pain is not reduced with bullet removal [39]. Pain is mediated by spontaneous discharges from deafferented dorsal horn neurons and can be conservatively managed with oral neuroleptic medication, such as amitriptyline (Elavil, Merck & Co., Inc., Whitehouse Station, NJ) or gabapentin (Neurontin, Pfizer, New York, NY). In unresponsive cases, a vascularized omental pedicle graft can be surgically transplanted to the affected cord level. Increasing the neurovasculature of the region as well as altering the neurotransmitter milieu relieves pain. As a last resort, the dorsal root entry zone procedure surgically removes the nociceptive dorsal rootlets. Spaic et al. [50] have documented excellent results with this maneuver in six patients with pain recalcitrant to omental transplant after thoracolumbar gunshot wounds.

Neuropathic (Charcot) arthropathy may rarely occur in spinal-cord-injured patients after gunshot wounds. It is typified by pain associated with progressive spinal deformity at or below the level of injury. Treatment is directed toward correction and stabilization of the spine through anterior, posterior or combined surgical approaches [51–53].

Other long-term sequelae can occur. Bullet migration can cause neural deficit months to years after the initial injury. Kuijlen et al. [54] documented neurogenic claudication 11 years after a gunshot wound to the abdomen. The bullet migrated from the paraspinal muscles at the L3 level into the spinal canal where it effectively disintegrated into multiple fragments causing a diffuse inflammatory reaction. The patient responded favorably to decompressive laminectomy and bullet removal. Conway et al. [55] reported a case of cauda equina syndrome after a bullet previously lodged in the intervertebral disc migrated into the spinal canal 9 years after injury. Numerous other reports of bullet migration have been documented within the spinal canal, within the dura, and in a caudal to cranial direction [56–58]. Bullet migration is not always associated with neurologic deficit.

Summary

Gunshot wounds to the spine continue to be a significant clinical problem. Although prevention is the best solution, effective treatment relies on understanding the principles of wound ballistics, tissue injury and the role of diagnostic
modalities. Wounds from bullets passing through the colon before the spine require at least 7 days of broad-spectrum antibiotics. Bullet removal caudal to the T11 vertebra can improve motor recovery. Regardless of the level of injury, corticosteroid infusion has little effect on neurologic improvement. Nerve pain is a common long-term sequela and can be responsive to conservative and surgical treatment. Lead intoxication and bullet migration are infrequent causes of late morbidity and require a high index of suspicion for accurate diagnosis.

References


In 1864, in London, Bernard Edward Brodhurst, who has become known more for his contributions to early advancements in knee arthrootomy and treatment of congenital dislocation of the hip, wrote a monograph on scoliosis [1]. He proposed the idea that curvature progresses inexorably until finally an ankylosis between the vertebrae occurs and the curve progression stops. The idea led Hibbs 50 years later to the concept of surgically induced ankylosis by fusion to prevent curve progression.

Reference