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REVIEW

Management of non-missile penetrating spinal injury

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Abstract

Review of the literature with case illustration. Non-missile penetrating spinal injury (NPSI) represents a small subset of spinal cord injuries at tertiary trauma centers and is comprised mostly of knife violence. Strict guidelines for the management of penetrating spinal cord injury remain elusive given the variability of mechanisms, rarity of clinical experience, and paucity of prospective studies. A review of the literature was conducted by search of the National Library of Medicine (PubMed) in the English language through June of 2018. Additional articles were culled from the reference lists of the included series. Eleven case series totaling 1007 patients, along with 21 case reports, were identified. In summary, magnetic resonance imaging (MRI) may be beneficial in assessing incomplete or progressive spinal injuries and can be considered with retained foreign bodies in select cases. Forty-eight hours of antibiotic prophylaxis is likely sufficient to prevent infection. Puncture wounds should be debrided, washed, and closed. Retained foreign bodies should be removed in the operating room and often require laminectomy. Early intervention is preferred. Non-missile penetrating spinal injury has a higher likelihood of neurologic recovery as compared to other traumatic spinal injuries.

Keywords Non-missile penetrating spinal injury · Incomplete spinal cord injury · Nail gun injuries · Brown-Séquard syndrome

Introduction

Non-missile penetrating spinal injury (NPSI) represents a small subset of spinal injuries. These unusual and often spectacular injuries offer unique challenges to the clinician. Guidelines for the management of penetrating spinal cord injury remain elusive given the variability of mechanisms, rarity of clinical experience, and paucity of prospective studies. There continue to be uncertainties regarding how to approach a patient with NPSI and discrepancies in patient management. This includes variability in obtaining neuroimaging studies, administration of antibiotics, and blood pressure management, as well as in surgical management and timing of surgical intervention.

We present herein a review of the literature to summarize the optimal perioperative and operative management of NPSI. The application of such technique is described in an illustrative case treated at our institution; an adult trauma patient presenting with Brown-Séquard who suffered two nail gun injuries to the spinal cord at the lower thoracic level. Emergent neurosurgical intervention including exploration, removal of nails under direct visualization, and primary repair of visualized durotomies resulted in a favorable outcome with significant improvement of neurological function on subsequent follow-up.

Methods

A review of the literature was conducted by search of the National Library of Medicine (PubMed) in the English language through June of 2018. Eleven case series totaling 1007 patients, along with 21 case reports, were identified. Additional articles were culled from the reference lists of the included series. Summary of the case series with much of the demographic and patient presentation data can be found in Table 1. Informed consent was obtained from all individual participants and/or surrogates included in this manuscript.

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Table 1 Summary of case series of NPSI published from 1962 to 2018

Series	Study	No. of patients	Location	Complete spinal cord injury	Brown-Sequard syndrome	Attributed to knife assault	Retained	Cervical	Thoracic	Lumbosacral	Average age	Male
Lipschitz and Bloc 1962	1955–1959	130	South Africa	30%			2.30%					
Lipschitz 1967	1962–1967	122	South Africa		"Not uncommon"	Majority	"sometimes"				42% 21–30	83%
Peacock et al. 1977	1963–1976	450	South Africa	21%	55%	84%	Yes	30%	64%	7%		84%
Simpson et al. 1989	1980–1986	18	Texas, USA	22%			Yes	27%	54%	19%		
Thakur et al. 1991	1978–1988	11	India	19%	18%	72%					22	91%
Waters et al. 1995		32	USA	38%	31%						27	61%
Velmahos et al. 1995	1988–1992	143	South Africa									
Heary et al. 1996	1979–1994	20	Pennsylvania, USA	25%	45%	95%						
Moyed, et al. 1999		8	Maryland, USA			88%	33%	78%				78%
Jacobsohn, et al. 2007	2004–2005	22	South Africa	27%	59%		5%	32%	68%		30	86%
Enicker, et al. 2015	2003–2015	51	South Africa	34%	33%	100%	100%	18%	74%	8%	28	88%

Additional informed consent was obtained from the patient whose de-identified intra-operative photographs are used in the figures. This article does not contain any studies with animals performed by any of the authors.

Results

Epidemiology

The incidence of spinal cord injury in the USA is about 17,700 per year, with non-missile penetrating injuries accounting for 0.8% [61, 62]. Based on the literature to date, trauma centers within the country of South African undoubtedly treat the highest volume of NPSI, with a combined 925 patients reported from 1955 through 2015 [6, 11, 26, 27, 38, 51, 57]. NPSI most commonly occurs as the result of violence among young men in their 3rd decade of life [6, 11, 26, 33, 38, 49, 59]. Knives are the most common non-missile penetrating object, and typically occur in the thoracic spine [6, 9, 26, 33, 38, 49, 54]. There is high variability as to whether the object is retained [6, 11, 26, 27, 33, 38, 49].

Patients with NPSI present with surprisingly low rates of complete injury—ranging from 19 to 38% [6, 11, 38, 49, 54, 59]. In larger series with details of neurologic injury patterns, Brown-Séquard syndrome variant is noted in 31–55% of cases [6, 9, 38, 59]. Given the precise nature of a cord hemisection, it is not surprising that piercing injuries make up the majority of reported traumatic Brown-Séquard syndromes which include stab wounds from knives [1, 5, 6, 12, 30], drill bits [45], screw drivers [2, 36, 42], an iron fence post [60], gunshot wounds [21, 23, 31], an arrowshot [50], glass fragments [16], a metal wire [58], shrapnel [20], and even a stab wound from a swordfish [52].

Presentation, pre-hospital, and emergency department management

Restraint is necessary to avoid immediate removal of the foreign body in the field [56]. Imaging with the foreign body in situ allows for more reliable identification of the injury track and affected structures, perhaps most importantly involvement hollow viscus structures in non-dorsal NPSI. Often times, patients are transported in decubitus or prone positions. It can be inferred that the risk of spinal instability after these types of injuries is low given there are no reported cases requiring instrumentation and fusion surgery in the reviewed NPSI series [6, 9, 11, 26, 27, 33, 38, 49, 54, 57, 59]. We recommend transport positioning to avoid foreign body manipulation over maintaining strict spinal precautions or placement of a spinal orthosis. Spinal injuries, including NPSI, should be managed at specialized centers [7, 55].

A detailed exam utilizing the American Spinal Injury Association impairment scale should be performed in the emergency department with high suspicion for less common syndromes such as Brown-Séquard. This objective data may be important in capturing neurologic deterioration which may guide operative decisions.

In regard to steroid administration, similar to blunt injury, animal models of spinal cord transection have shown a neuroprotective effect of methylprednisone [34]. However, retrospective institutional reviews at the Los Angeles County-University of Southern California and Thomas Jefferson University found no improvement in patient neurologic outcomes in low-velocity gunshot wounds (GSW) to the spine [9, 24]. Additionally, Jefferson noted an increase in spinal and systemic infections. There does not appear to be a role for steroid use in NPSI.

Antibiotics and prophylaxis

The trauma literature provides guidelines for tetanus toxoid and immune globulin administration [44]. The effectiveness of the tetanus booster is 10 years. The tetanus toxoid booster should be administered if the last booster was more than 10 years prior. This administration can wait until history can be clarified, as its protective effects are for future and not the acute episode. Tetanus immune globulin is administered in the acute setting if last immunization was greater than 10 years, or if immunization status is unknown.

Previous series have described low rates of infection of 2–4% with NPSI [18, 48]. Literature from the combat field (which includes gunshot wounds and high-velocity trauma) recommends prophylaxis with cefazolin for 5 days or until a CSF fistula is closed [10, 39]. Coverage would be expanded to include metronidazole in cases of gross contamination with organic debris or concomitant abdominal cavity penetration.

The civilian setting has demonstrated a trend toward less aggressive antibiotic use. Low-velocity gunshots even in the setting of traversing hollow viscus organs prior to entering the spinal column have been observed to have low rates of meningitis and osteomyelitis with a 5-day course of parenteral antibiotics without debridement [25, 40]. More recently, retrospective case reviews from the University of Maryland and Rutgers found just two infections to the spine and CNS from 112 transperitoneal GSWs with just 48 h of parenteral antibiotics [37, 41].

A series of 22 patients with stab wounds to the spine from South Africa did not employ routine antibiotic prophylaxis [11]. They report a serious infection rate of 18% (4 of 22), 2 of which had neurologic decline from intraparenchymal abscess and myelitis.

With these considerations, 48 h of prophylactic, broad-spectrum antibiotics is likely sufficient for NPSI.

Blood pressure management

Blood pressure management in spinal cord injury is another clinical quandary. Current guidelines in spinal cord injury management cite class III medical evidence for the recommendation to maintain supraphysiologic MAP goals of 85–90 mmHg for 7 days after injury [7, 46]. However, the authors' literature review excluded penetrating spinal injuries. Continuous cardiac and blood pressure monitoring is recommended which indeed applies to this injury population.

One modest series of complete spinal cord injuries from GSW to the spine found only 1 of 14 patients improved from ASIA A to B after maintenance of supraphysiologic MAP goals [43]. Authors also cited a cardiogenic complication rate of 71%—though their definitions of such complications included tachycardia (HR > 130) and bradycardia (HR < 50).

There is no clinical or experimental data regarding blooding pressure management specific to NPSI. Given the higher prevalence of incomplete spinal injuries as mentioned above, extrapolating the level III evidence from the non-penetrating SCI guidelines would have weak support for the maintenance of MAP goals 85–90 mmHg for 7 days. Potential exceptions would include patients with spinal cord transection, those at risk of neurological decline from expansion of a hematoma within the spinal canal, and those with high risk of cardiac complications.

Imaging studies

Imaging studies are paramount in the trauma survey and in understanding the local and regional injury pattern of NPSI. The appropriate imaging study can identify damage to neurological structures, locate entry, and exit sites and reveal proximity of foreign material to neurovascular or digestive organs. Non-contrast CT scans and plain films are the modalities of choice for localization and identification of bony injuries [35]. CT myelography may aid in identification of compressive hematomas, cord swelling, and transection. CT angiography or conventional angiography should be considered in cases with proximity to the vertebral arteries and aorta.

Analysis of MR safety in ballistics may give new consideration to this typically contraindicated imaging modality [4, 29]. Dedini et al. demonstrated through lab testing that ballistics made of lead with copper or alloy jackets are likely safe in MRI-related movement and heating on 3-T MRI [4]. Alternatively, steel was found to have a high risk of movement. The Barrow group reviewed data from 25 articles with civilian and military lumbar GSWs who underwent MRI scans [29]. Twenty-two patients with bullet fragments of differing composition underwent MRI without neurologic deterioration or discomfort. It appears that metallic fragments of known materials in proximity to the spinal cord should not

absolutely exclude patients from MRI that may benefit from its findings.

MRI of the spine in NPSI without retained foreign bodies can affect surgical decisions in select cases [11, 19]. Jacobsohn et al. in Cape Town, South Africa, found that in cases of neurologic deterioration, MR was helpful in identifying extradural collections and abscesses. In this series, in cases of non-compressive hematomas and tract transections or parenchymal contusions that best explained a neurologic injury, surgery was not pursued. Other case reports have found spinal cord herniation, arachnoid cyst formation, and compressive hematomas on delayed MRI [3, 8, 22]. Conversely, intramedullary air bubbles and retained metal objects can cause susceptibility artifact and obscure critical regions [33].

Collectively, these data refute the need for routine MRI scanning in the setting of neurologically intact patients without retained objects, but may aid decision making in patients with spinal cord injury. Retained foreign objects of known materials are not an absolute contraindication.

Role of surgery

The surgical treatment algorithm is dependent on the retention of the foreign body.

Best available evidence for non-retained foreign objects may come from missile injuries. A meta-analysis on penetrating spinal cord injuries due to shrapnel and two institutional reviews on civilian GSW found no neurologic benefits surgery, with increased length of stay [9, 20, 31]. Another review of military and civilian review of penetrating spinal injury found no benefit of decompressive laminectomy; however, expressed opinion that early surgery should still be considered in cases of incomplete spinal cord injury with evidence of canal compromise [15].

While CSF leak occurs in up to 4% of stab wounds, the majority resolve without surgical intervention [35]. The South African experience describes bedside closure of puncture wounds, including those with CSF leak, under local anesthetic in the trauma bay with success [11].

In situ and retained metallic objects causing spinal cord injury present a different treatment algorithm. Foreign materials that traverse the skin can lead to further neurologic decline from manipulation and act as a nidus for infection [32, 48]. Retained foreign objects have rarely led to delayed complications including myelopathy, arthropathies, and lead poisoning [13, 28, 47]. Removing foreign bodies in the operating room allows for precise identification of the injury track for irrigation and debridement [14, 56]. Extension of the contaminated area can be avoided.

Modern South African Trauma centers undoubtedly have the most experience in treatment algorithms [6, 11, 51]. In regard to timing, authors reported fewer complications among patients who underwent early surgical intervention, and also theorize a lower risk of infection [6, 17]. Placement of a lumbar drain for CSF diversion at the time dural repair is at the discretion of the surgeon. Lumbar drainage is a good option for treatment of delayed CSF leak and after debridement for infection. Laminectomy is typically required to safely remove retained knife blades. The retained object should be held stationary while the adjacent lamina is removed with a high-speed drill and removed en bloc to avoid manipulation of the object tip. The risk of post-extraction hemorrhage with retained knife blades to all body sites was only 5% with simple extraction in one study [51].

In summary, NPSI with retained foreign bodies should be removed in the operating room, with use of laminectomy and careful avoidance of manipulation with extraction. NPSI without retained foreign bodies can be managed with a bedside washout and closure in a neurologically intact patient, even in the setting of CSF leak. A partial neurologic injury without retained foreign body should undergo MRI to determine if a compressive lesion can be relieved surgically.

Neurologic prognosis

Neurologic recovery overall fares well. Lipschitz et al. in 1962 reported that 40% of those with partial spinal cord injuries returned to their previous employment and an additional 57% had significant recovery [27]. Peacock et al. reported 66% of patients walked unassisted or with minimal assistance [38]. Simpson et al. in their Texas spinal cord injury population found that chances for significant neurologic recovery were highest among NPSI (61%), greater than motor-vehicle accidents (44%) and GSWs (32%) [57]. In a series among rehabilitation patients recovering from NPSI in the USA, Waters et al. reported recovery to independent ambulation in 80% of partial injuries, and 1 patient out of 10 with motor complete injuries [59].

Illustrative case

History and physical exam

A 30-year-old male presented to our institution after a coworker discharged two 3-inch. framing nails from a nail gun into the patient's back, through his work overalls (Fig. 1). The patient arrived from the scene to the trauma bay with complete loss of motor strength and numbness of the right lower extremity up to the level of the T9 dermatome. His left lower extremity exhibited normal strength, but loss of pain and temperature sensation up to the T10 dermatome on the left. Additionally, he had loss of rectal tone.

A non-contrasted CT scan of the chest revealed two linear metallic foreign bodies entering dorsally into the thoracic spine at T8 and T10. (Fig. 2).

Fig. 1 Two 3-inch nails in situ. Traversing the patient's work wear (*left*) and after removal of all clothing between the nail heads and skin (*right*)

Operation, pathology, and post-operative course

A trauma survey identified no other injuries, and no major thoracic vasculature was threatened by the nails. Tetanus prophylaxis was administered. The patient underwent emergent operative intervention. A skin incision was made to incorporate the puncture wounds from the nails. Careful subcutaneous dissection exposed the 3-inch nails to the level of the lamina. The nails required significant force applied with surgical plyers for removal. This was followed by immediate decompressive laminectomies of T8 through T10. Intra-operatively, we identified two traumatic durotomies following removal of the nails. The rostral durotomy was easily accessible in the surgical field and closed primarily with 6–0 non-absorbable monofilament suture. The caudal durotomy was oriented more laterally, and was repaired by suturing in a small muscle patch. The anterior durotomies were not explored. A water-tight, multi-layered closure was employed.

Following surgery, the patient was kept in the neurosciences intensive care unit on a norepinephrine drip to maintain mean arterial pressures above 85 mmHg for 5 days following surgery. An immediate post-operative MRI scan of the thoracic spine revealed increased T2 signal in the spinal cord at the level of T8–10 with no epidural, intradural, or intramedullary hematoma (Fig. 3). Intravenous vancomycin, cefepime, and metronidazole were administered for 7 days post-operatively. While in the intensive care unit, the patient continued to have no movement in his right lower extremity but started to exhibit improved sensation to light touch. He was unable to perceive temperature sensation in his left leg but maintained normal

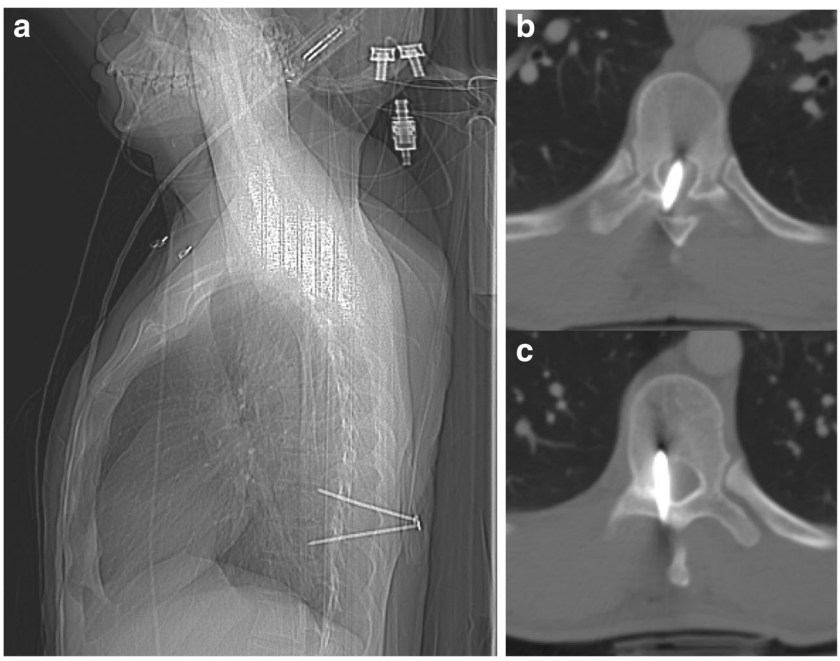

Fig. 2 Scout image showing the trajectory and position of the nails (**a**). Axial CT images showing the tip of the rostral nail (**b**) and the caudal nail (**c**). The rostral nail entered to the right-of-midline at the level of T8–9, traversing the spinal canal, and into the intervertebral disk space. The more caudally nail coursed through the lamina of T10 on the right and through the right side of the spinal canal before wedging into the T10 vertebral body anteriorly

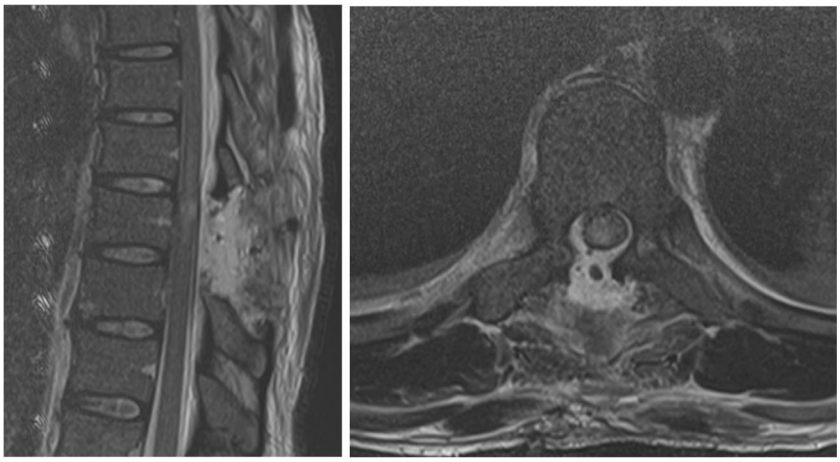

Fig. 3 Post-operative MR T2-weighted images in sagittal (*left*) and axial (*right*) plans revealing the intramedullary cord signal change without associated hematoma

strength in all left lower extremity muscle groups. The patient was discharged to inpatient rehabilitation on post-operative day 5.

At his six-week post-operative clinic visit, the patient showed significant improvement in his neurologic exam. Right leg examination revealed 5 out of 5 strength in his hip flexion and knee extension, and 3 out of 5 strength in ankle dorsiflexion, plantarflexion, and great toe extension. Sensation to light touch improved in the right lower extremity and the patient was able to perceive cold temperature in his left lower extremity. He denied neuropathic or radicular pain but did have lower extremity muscle spasms and exhibited bilateral ankle clonus with marked hypertonia of the right lower extremity. He denied any bladder/bowel dysfunction or incontinence. On gait testing, the patient was able to walk 100 ft with use of a cane and a right ankle-foot orthosis. The incision was well healed, and the patient exhibited no signs or symptoms of infection.

Discussion of illustrative case

Penetrating spinal cord injuries from a nail as in our index case are uncommon; the only reported case in the literature describes an unfortunate pediatric patient who suffered a cord transection with complete spinal cord injury [53]. To our knowledge, this is the first reported case of classic BSS in an adult patient from a penetrating nail gun injury to the spinal cord.

Surgical intervention was necessary given that the heads of both nails protruded from the skin. Expediting surgery afforded the patient the best chance of neurologic recovery from his incomplete spinal cord injury. Additionally, we felt that early intervention reduced his risk of CSF leak and infection. Supraphysiologic blood pressure was maintained for 5 days without clinically significant complication. Antibiotic duration continued longer than the recommendation contained herein, at the behest of our infectious disease consult team given the circumstances of a construction site contamination. With these measures, the patient achieved good functional recovery without complication.

Conclusion

Strict guidelines for the management of penetrating spinal cord injury remain elusive given the variability of mechanisms, rarity of clinical experience, and paucity of prospective studies.

A review of the literature does distill some recommendations in management. These recommendations based mostly on retrospective case series and expert opinion are of moderate strength at best. Magnetic resonance imaging may be beneficial in assessing incomplete or progressive spinal injuries and may even be considered with retained foreign bodies in select cases. Forty-eight hours of antibiotic prophylaxis is likely sufficient to prevent infection. Puncture wounds without retained objects should be debrided, washed, and closed, and often can be done at the bedside. Retained foreign bodies should be removed in the operating room and often require laminectomy. Early intervention is preferred to lower the risk of complications. Finally, NPSI has a higher likelihood of neurologic recovery as compared to other traumatic spinal injuries.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest to report.

Statement of human rights Informed consent was obtained from all individual participants and/or surrogates included in this manuscript. Additional informed consent was obtained from the patient whose de-identified intra-operative photographs are used in the figures.

Statement on the welfare of animals This article does not contain any studies with animals performed by any of the authors.

Consent Informed consent was obtained from the patient for the reporting of this case as well as use of photographs and images.

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